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PERFORMANCE IMPROVEMENT OF A SOLAR COLLECTOR IN A SEED DRYER USING FINS

A PROJECT REPORT

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PROJECT WORK

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This is to certify that the project entitled

PERFORMANCE IMPROVEMENT OF A SOLAR COLLECTOR IN A SEED DRYER USING FINS

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ABSTRACT

The general method for drying chilies is the open sun drying. The aim of my project is to reduce the drying time and contamination of the drying product and to increase the performance of the solar collector. A maintenance free and properly enclosed dryer is therefore designed with a solar collector, drying chamber and chimney. An indirect forced convection solar drier integrated with different sensible heat storage material has been developed and tested its performance for drying chilly under the metrological conditions of Coimbatore, India. The system consists of a flat plate solar air heater with heat storage unit, a drying chamber and an exhaust fan. The development and testing of a new type of efficient solar collector for the dryer, particularly meant for drying vegetables and fruit, is described. Drying experiments have been performed at an air flow rate of 0.21 kg/s. The performance test has been carried out with different heat storage unit like fins with different material like aluminium and galvanized iron .The test is also carried to find the performance improved in the collector before and after implementing fins in the collector. The initial moisture content present in the chilies based on the wet basis is 72.8%. The reduced moisture content of the chilly after drying is 26.4% in collector having fins.

Keywords: Solar drier, Chilly drying, Heat storage materials.

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LIST OF ABBREVIATIONS

RH	Relative Humidity
GI	Galvanized Iron
MS	Mild Steel
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
EMC	Equilibrium Moisture Content
HUF	Heat Utilization Factor
COP	Coefficient Of Performancc
DBT	Dry Bulb Temperature
MM	Mineral Matter

CHAPTER 1

INTRODUCTION

In India, sun drying is the most commonly used method to dry the agricultural materials like grains, fruits and vegetables. In sun drying, the crop is spread in a thin layer on the ground and exposed directly to solar radiation and other ambient conditions. The rate of drying depends on various parameters such as solar radiation, ambient temperature, wind velocity, relative humidity, and initial moisture content, type of crops, crop absorptivity and mass of product per unit exposed area.

This form of drying has many drawbacks such as degradation by windblown, debris, rain, and insect infestation, human and animal interference that will result in contamination of the product. Drying rate will reduce due to intermittent sunshine, interruption and wetting by rain.

1.1 CONCEPT OF THE PROJECT

Solar driers using natural convection or forced circulation have been investigated to overcome these problems. For commercial applications, the ability of the drier to process continuously throughout the day is very important to dry the products to its safe storage level and to maintain the quality. Normally thermal storage systems are employed to store thermal energy, which includes sensible heat storage, chemical energy storage and latent heat storage. The solar drier is an energy efficient option in the drying processes. Many experimental studies reported the various methods used for drying of agricultural materials using solar drier for copra drying, for onion drying, and for pineapple drying. Use of forced convection solar driers seems to be an advantage compared to traditional methods and improves the quality of the product considerably.

Use of forced convection solar driers seems to be an advantage and improves the quality of the product considerably. Normally thermal storage systems are employed to store the heat, which includes sensible and latent heat storage. Common sensible heat storage materials used to store the sensible heat are water, gravel bed, sand, clay, concrete, etc.

1.2 OBJECTIVES OF THE PROJECT

- To design a solar dryer and operate it in both natural convection and forced convection mode
- To improve the performance of the solar collector using heat storage materials
- The thermal performance of solar-assisted dryer is studied for supplying heat to dry chillies.
- To compare the moisture removal rate of dryer with fins and without fins at a specified mass flow.
- To design and test the dryer using local materials and a more efficient collector.

1.3 APPLICATIONS OF THE PROJECT

Solar dryers are used in agriculture for food and crop drying, for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required.

Solar dryer is a very useful device for

- Agriculture crop drying
- Food processing industries for dehydration of fruits, potatoes, onions and other vegetables,
- Dairy industries for production of milk powder, casein etc.
- Seasoning of wood and timber.
- Textile industries for drying of textile materials.

1.4 LIMITATIONS OF THE PROJECT

Though this project has several advantages it does have shortcomings. They are of little use during cloudy weather, winter and rainy seasons. During fair weather they can work too well, becoming so hot inside at midday as to damage the drying crop. Only with close supervision this can be prevented. As temperatures rise (determined with a thermometer), the exhaust fan speed should be increased to allow greater airflow through the dryer and to keep the temperatures down. Rice, for example, will crack at temperatures above 57 [degrees] Centigrade; seed grains can be dried at temperatures no higher than 45 to 47 [degrees] Centigrade. Since the dryer is a indirect forced circulation type, it requires a fan to force the air over the collector. It is more complex and expensive compared to direct type solar dryers. Moreover the fin materials we used are aluminium which costs high. So when the collector area is increased the usage of fins also increased which increases the cost ultimately.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Private millers have specially constructed drying floors for paddy sun drying. The floors are usually made of concrete with a fairly smooth and hardwearing surface. The paddy is spread in a thin layer on the floors and raked at intervals, 7-8 times during the day, to facilitate even drying. At night the paddy is heaped into rows and covered with a plastic sheet to prevent rewetting. On rainy days, private millers make use of mechanical dryers to dry their paddy. The project is proposed based on the information of the following journals and papers. The journals and papers that are collected are categorized into natural convection and forced convection as given below.

2.2 STUDIES ON NATURAL CONVECTIVE SOLAR AIR DRYER

K.S. JAIRAJ et al (2009) described his attempts to review various solar dryers developed exclusively for grape drying on a normal scale. Many popular varieties of solar dryers, certain typical models as well as traditional methods practiced for drying grapes are presented in this paper. Technical and economical results have proved that solar drying of grapes is quite feasible. Commercialization of solar drying of grapes has not gained momentum as expected, may be due to high initial investment and low capacity of the dryers. Even, the farmer's acceptance of solar dryers developed is not encouraging. Exhaustive research and development work has to be carried out in order to make solar drying of grapes economical and user friendly. There has been a remarkable achievement in solar drying of grapes due to sustained research and development associated with the adoption of advanced technologies. A review of various solar drying models for grapes is thus necessitated.

A. FUDHOLI et al (2009) Drying of agricultural and marine products are one of the most attractive and cost-effective application of solar energy. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance. Basically, there are four types of solar dryers; (1) direct solar dryers, (2) indirect solar dryers, (3) mixed-mode dryers and (4) hybrid solar dryers. This paper is a economic aspects. The technical directions in the development of solar-assisted drying systems for agricultural produce are compact collector design, high efficiency, integrated storage, and long-life drying system. Air-based solar collectors are not the only available systems.

Water-based collectors can also be used whereby water to air heat exchanger can be used. The hot air for drying of agricultural produce can be forced to flow in the water to air heat exchanger. The hot water tank acts as heat storage of the solar drying system.

A. SALEH et al (2009) described the aims to propose a solar dryer with a uniform temperature profile that meets the requirements of the exponential model over a wide range of cases, thus, providing a simple and accurate design tool. The dryer is characterized by collecting the maximum possible solar energy by having a longer drying period, and allows the fixed dryer to approach with its performance the tracked one with all technical and economical advantages of the tracking system.

The performance was tested under different operational conditions and the drying characteristics were experimentally investigated by conducting the experiments on two local herbs, Jew's mallow and mint leaves. The dryer was able to reduce moisture of the tested products to the recommended level (6%) in about a 12 h period. The reliability of the exponential model was evaluated by comparing the experimental with the predicted curves. A reasonable agreement was found for the different tests carried out for the entire drying period.

M. PRADHAPRAJ et al (2010) described that the solar air heater, flat plat collectors are the best heat transferring devices. But the effectiveness of these collectors is very low because of lack of technology. Solar assisted heated air is successfully used for drying applications and space heating under controlled conditions. From the solar flat plate air heater the hot air is transferred to a conventional dryer or to the combined heater and drying chamber directly. Hence, solar assisted air heaters are cheaper and reliable. The important factors affecting these systems are the solar radiation, mechanical loading, temperature and leakage. The air heater efficiency depends on the design of the system as well as the construction materials and the assembly. The solar air heating systems has acceptable life span of 15 to 20 years.

TOMAS MATUSKA et al (2009) developed a mathematical model and design thermal flat-plate collectors has been built and experimentally validated for different solar thermal flat-plate collector concepts. The design tool is applicable especially for design and virtual prototyping of new solar flat-plate collectors resulting in efficiency curve determination, for parametric analyses to obtain information on different parameters influencing the collector performance and especially for investigation of thermal performance of advanced solar collectors (building integrated, evacuated collectors, etc.). Examples of parametric analyses made for selected construction elements together with modelling possibilities of the design tool KOLEKTOR 2.2 are presented in this paper.

2.3 STUDY ON FORCED CONVECTIVE SOLAR AIR DRYER

GIKURU MWITHIGA et al (2005) described a small solar dryer with limited sun tracking capabilities was designed and tested. The dryer had a mild steel absorber plate and a polyvinyl chloride transparent cover and could be adjusted to track the sun in increments of 15 degrees. The performance was tested by adjusting the angle the dryer made with the horizontal either once, three, five or nine times a day when either loaded with coffee beans or under no load conditions. The temperature distribution in the plenum and also the drying rate of parchment coffee were determined. The temperature inside the plenum chamber could reach a maximum of 70.4 °C and the dryer could lower the moisture content of coffee beans from 54.8% to below 13% in 2 days as opposed to the 5–7 days required in sun drying. Tracking the sun though allow a faster rate of drying did not offer a significant advantage in terms of length of drying duration.

V. SHANMUGAM et al (2006) describes an indirect forced convection with desiccant integrated solar dryer. The main parts are: a flat plate solar air collector, a drying chamber, desiccant bed and a centrifugal blower. The system is operated in two modes, sunshine hours and off sunshine hours. During sun shine hours the hot air from the flat plate collector is forced to the drying chamber for drying the product and simultaneously the desiccant bed receives solar radiation directly and through the reflected mirror.

ABDULLAH AKBULUT et al (2010) describe the energy and energy analyses of the thin layer drying process of mulberry via forced solar dryer. Using the first law of thermodynamics, energy analysis was carried out to estimate the ratios of energy utilization and the amounts of energy gain from the solar air collector. However, energy analysis was accomplished to determine energy losses during the drying process by applying the second law of thermodynamics. The drying experiments were conducted at different five drying mass flow rate varied between 0.014 kg/s and 0.036 kg/s. The effects of inlet air velocity and drying time on both energy and energy were studied. The main values of energy utilization ratio were found to be as 55.2%, 32.19%, 29.2%, 21.5% and 20.5% for the five different drying mass flow rate ranged between 0.014 kg/s and 0.036 kg/s. The main values of energy loss were found to be as 10.82 W, 6.41 W, 4.92 W, 4.06 W and 2.65 W with the drying mass flow rate varied between 0.014 kg/s and 0.036 kg/s. It was concluded that both energy utilization ratio and energy loss decreased with increasing drying mass flow rate while the energetic efficiency increased.

2.4 STUDIES ON FINS AND ITS ANALYSIS

MOHAMMAD MASHUD et al., (2007) an experimental study was performed to provide information about the effect of pressure reduction on heat loss from cylindrical fins of three different geometries. A literature review shows that much of work on radiating fins has been carried out analytically and numerically. In this research, a solid cylindrical fin and two other cylindrical fins with circular grooves and threads on their outside surface are investigated experimentally. A test facility with a pressure reduction chamber and instrumentation is fabricated. The heat input to the fin is varied such that the base temperature is maintained constant under steady state. Based on a study of effect of pressure reduction, using available resources, the chamber is designed for a vacuum of 680 mm Hg. The experimental result shows that for cylindrical fin with circular grooves (depth 3.5mm) heat loss is a maximum.

WAQAR AHMED KHAN, et al., (2008), Analytical models are developed for determining heat transfer from in-line and staggered pin-fin heat sinks used in electronic packaging applications. The heat transfer coefficient for the heat sink and the average temperature of the fluid inside the heat sink are obtained from an energy balance over a control volume. In addition, friction coefficient models for both arrangements are developed from published data. The effects of thermal conductivity on the thermal performance are also examined. All models can be applied over a wide range of heat sink parameters and are suitable for use in the design of pin-fin heat sinks. The present models are in good agreement for high Reynolds numbers with existing experimental/numerical data.

BURAK YAZICIOGLU et al., (2009), a new expression has been developed for prediction of the optimal fin spacing for vertical rectangular fins protruding from a vertical rectangular base. This expression was determined using the results of experimental investigation available in the literature over a wide range of test variables. Data collated from literature covered the range of fin spacing from 2.85 mm to 85.5 mm. The range of base-to-ambient temperature difference was quite extensive, from 14 °C to 162 °C. The fin length range was from 100 mm to 500 mm, the fin height from 5 mm to 90 mm, the fin thickness from 1 mm to 19 mm, the width of rectangular base plate from 180 mm to 250 mm. Its dimensionless parameters were formulated by the intersection of asymptotes method proposed in (Yildiz, and Yüncü, 2004). These dimensionless parameters correlate the experimental data of seven investigators. The expression resulting from this correlation predicted the experimental data within an average overall error of less than 24 %.

2.5 INFERENCE

The technical directions in the development of solar-assisted drying systems for agricultural product are compact collector design, high efficiency, integrated storage, and long-life drying system. Air-based solar collectors are not the only available systems. Water-based collectors can also be used whereby water to air heat exchanger can be used. In the off sunshine hours, desiccant bed can be used for circulating the air inside the drying chamber by a reversible fan. Solar assisted air heaters are cheaper and reliable. The important factors affecting these systems are the solar radiation, mechanical loading, temperature and leakage. The solar air heating systems has acceptable life span of 15 to 20 years. The addition of side mirror, integration of heat storage materials in it enclosures increases the amount of solar radiation absorption at the collector plate so that the collector increases the yield and operate in a higher temperature range.

CHAPTER 3

SOLAR DRYER

3.1 BASIC DESIGN OF A SOLAR CHILLY DRYER

A solar collector may be of different designs and the dryer can be constructed of various designs. The selection of the solar collector depends on various factors such as

(i) cost

(ii) type of application (whether for industrial of agricultural)

(iii) Portable or stationary. The portable solar collectors are transported, to places wherever they are needed. Similarly the selection of the dryers depends on type of grain, time of drying etc.

A solar chilly dryer normally consists of the following components.

1. Solar flat plate collector.
2. Drying chamber.
3. Chimney
4. Exhaust fan
5. Fins

The solar flat plate collector consists of glass plate for absorbing heat from the sun light. The drying chamber is used for loading and drying of crops by utilizing the heated air from the flat plate collector. A chimney is a structure for venting hot flue gases or smoke from a boiler, stove, furnace or fireplace to the outside atmosphere. These are indicated in the fig 3.2 and 3.3. The exhaust fan is used to draw the hot air from the drying chamber to atmosphere.in our project the power requires to drive the fan is given externally.

The fins are used as heat storage materials in the solar collector. A fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature difference between the object and the environment, increasing the convection heat transfer coefficient, or increasing

3.2 PROPOSED SYSTEM

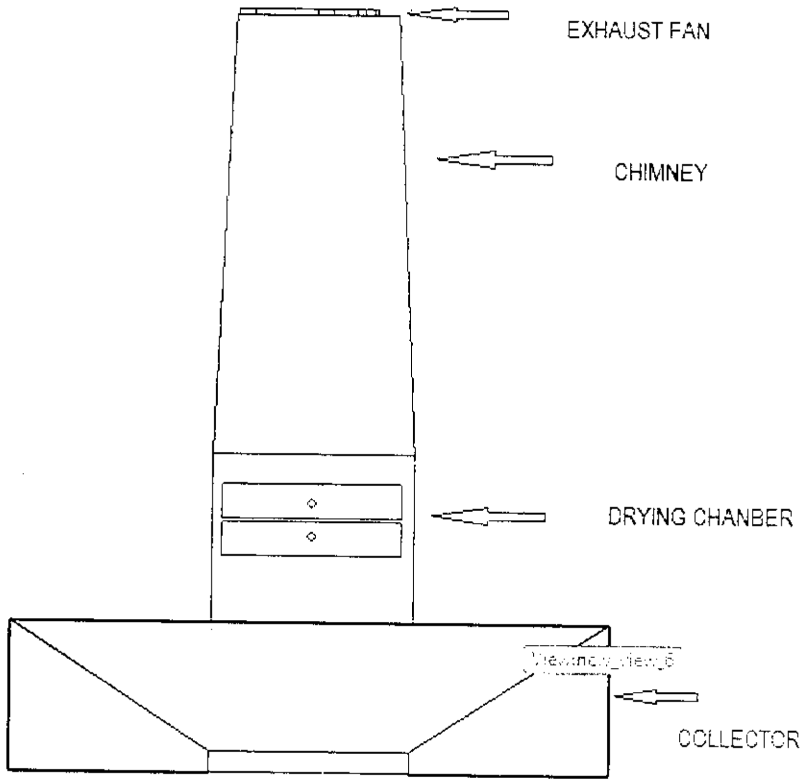

Fig 3.1 Front view of the dryer

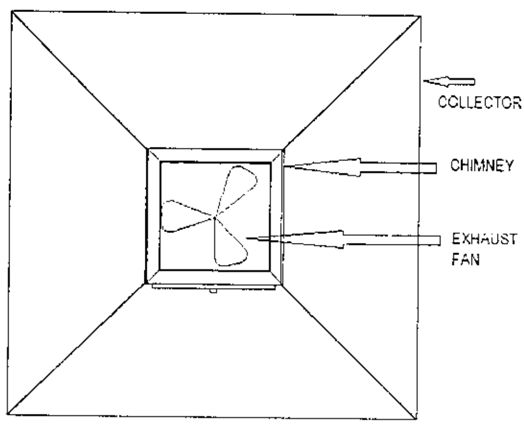

Fig 3.2 Top view of the dryer

3.3 SYSTEM DESCRIPTION

Table 3.1 Solar dryer components and specification

COMPONENTS	SPECIFICATIONS
Collector	Material: galvanized steel Thickness : 0.12cm Total surface area:3200 sq.cm Glass: Thickness = 5 mm
Drying chamber	Material: Galvanized steel Thichness:0.12cm Height:30 cm
Drying Tray	No. of trays:2 Tray area:400sq.cm(each tray) Capacity:1 Kg
Exhaust fan	230-240 V, 2.2 A, 50-60 Hz.
Chimney	Material: Galvanized steel Thichness:0.12cm

3.4 METHODS

3.4.1 Forced Convection

Forced convection is a mechanism, or type of heat transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.). It should be considered as one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently and this mechanism is found very commonly in everyday life, including central heating, air conditioning, steam turbines and in many other machines. Forced convection is often encountered by engineers designing or analyzing heat exchangers, pipe flow, and flow over a plate at a different temperature using air blower

3.4.2 NATURAL CONVECTION

Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding, cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current; this process transfers heat energy from the bottom of the convection cell to top. The driving force for natural convection is buoyancy, a result of differences in fluid density.

CHAPTER 4

THEORY OF SOLAR DRYING

4.1 INTRODUCTION

The first requirement is the transfer of heat to the moist material, (a) by conduction from heated in contact with the material, (b) conduction and convection from the sun. Absorption of heat by the material supplies the energy necessary for vaporization of water from it.

The drying of a product simply by circulating relatively dry air around it, is known as the adiabatic drying. The heat required for vaporizing the moisture is supplied by the air to the solid material, thereby reducing the air temperature while increasing its relative humidity. Air leaving in the drier is almost saturated, nearly at the wet bulb temperature of the incoming air. Because of low heat capacity of the air in comparison with high latent heat of vaporization of water, large volume of air with reasonably low relative humidity must be used in this type of drying process.

Hence drying involves both heat and mass transfer operation simultaneously. In convective drying the heat required for evaporating moisture from the drying product is supplied by air. The drying process is divided into thin layer drying and deep bed drying .thin layer drying refer to the drying process in which all the grains are fully exposed to the drying air under constant drying condition i.e. at constant air temperature and humidity. Generally up to 20 cm thickness of grain bed is taken as a thin bed.

4.2 TYPES OF MOISTURE

Bound Moisture: This refers to moisture contained by a substance which exerts equilibrium vapour pressure equal to that of the pure liquid at the same temperature.

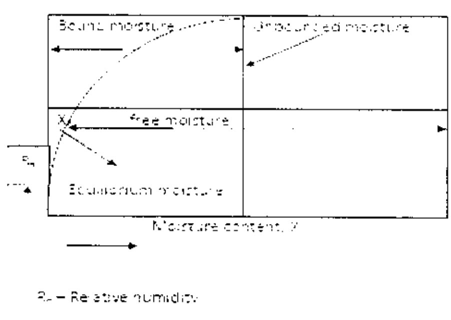

Fig 4.1 Bound and Free moisture

Free Moisture: Free moisture is the moisture contained by a substance in excess of equilibrium moisture X-XE only moisture can be evaporated.

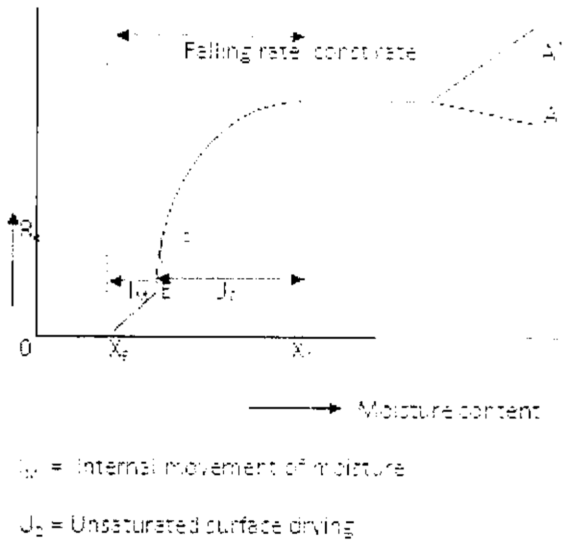

Fig 4.2 Constant rate and Falling rate period

The above relations are shown in the Fig.4.1 for a solid of moisture content X exposed to air of relative humidity RH.A typical drying curve shown in below figure 4.2. The figure clearly shows that there are two major periods of drying, namely the constant rate period and the falling rate period. The plots of moisture content versus drying time or drying rate versus drying time or drying rate versus moisture content are known as drying curves (Fig. 4.3 & 4.4).

4.2.1 Constant rate period:

Some crops including cereal grains at high moisture content are dried under a constant rate period at the initial period of drying .Falling-rate period follows subsequently .wheat is dried under constant rate period .when its moisture content exceeds 72%. In the constant rate period the rate of evaporation under any given set of air conditions is independent of the solid and its essentially the same as the rate of evaporation from a free liquid surface under the same conditions.

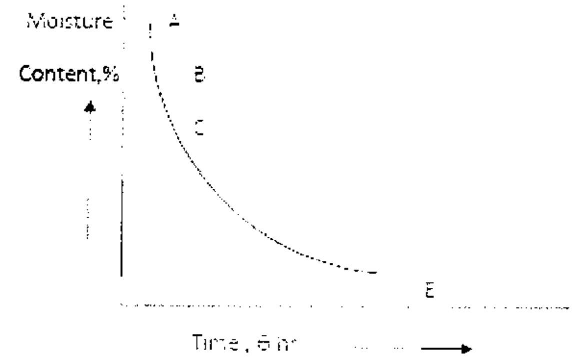

Fig 4.3 Moisture content Vs Time

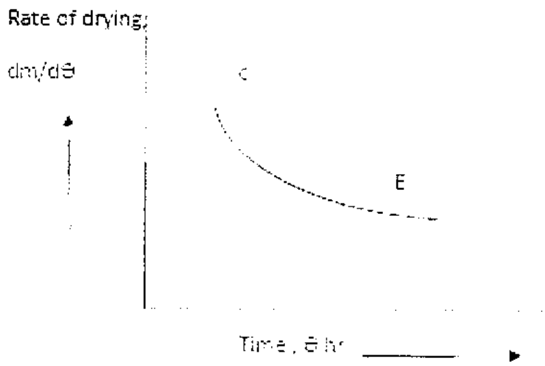

Fig 4.4 Rate of Drying Vs Time

4.2.2 Falling rate period:

Cereals grains are usually dried entirely under falling rate period .The falling rate period enters after the constant dry rate –period and corresponds to the drying cycle where all surface is no longer wetted and the wetted surface continually decreases, until at the end of this period of surface is dry. The cause of falling of in the rate of drying is due to the inability of the moisture to be conveyed from the centre of the body to the surface at a rate comparable with the moisture evaporation from its surface to the surroundings. The falling rate period is characterized by increasing temperatures both at the surface and within the solid .Further more; changes in air velocity have a much smaller effect than during the constant rate period. The falling rate period of drying is controlled largely by the product and these depend upon the movement of the moisture within the materials from the centre to the surface by liquid diffusion and the removal of moisture from the surface of the surface of the product.

The falling rate period of drying often can be divided into two stages: (i) unsaturated surface drying (ii) drying where the rate of water diffusion within the product is slow and is the controlling factor. Practically all cereal grains are dried under falling rate period if the moisture contents are not very high.

The liquid movement may be due to:

- Moisture concentration differences
- Surface forces,
- Moisture diffusion in the pores,
- Differences in vapour pressures,
- Differences in temperatures and
- Difference in total pressures.

4.3 MASS AND HEAT BALANCE IN GRAIN DRYING CONCEPTUAL DIAGRAM

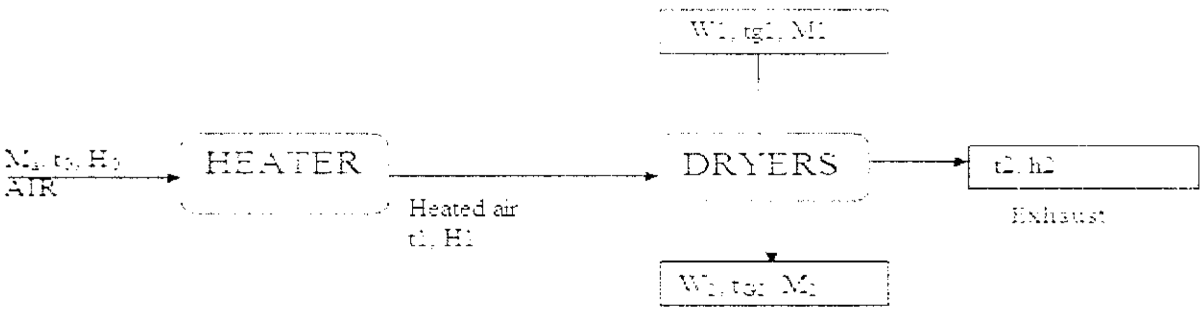

Fig 4.5 Mass and heat balance conceptual diagram

With reference to the above figure, for mass balance,

Let,

$\mathbf{W = W_1 - W_2}$

W = weight of moisture removed

$\mathbf{W_1}$ = weight of grain flow at inlet kg/hr

$\mathbf{W_2}$ = weight of grain flow at outlet kg/hr

Heat utilization factor (HUF):

This is the ratio of temperature decrease to cooling of the air during drying and the temperature increase due to heating of air.

$$HUF = \frac{t_1 - t_2}{t_1 - t_0} \tag{4.1}$$

Coefficient of performance (COP)

$$COP = \frac{t_2 - t_0}{t_1 - t_0} \tag{4.2}$$

Where,

t_2 = DBT of exhaust air

t_1 = DBT of drying air

t_0 = DBT of ambient air

COP + HUF = 1

4.4 METHODS OF GRAIN DRYING

According to the mode of heat transfer, drying methods can be divided into

- Conduction drying
- Convection drying
- Radiation drying

In convection drying, the drying media (hot air) comes in contact with the wet grains is used to supply heat and carry away the vaporized moisture and the heat is transferred to the wet grains mainly by convection.

Convection drying is most popular in grain drying. It can be carried out either continuously or batch wise, continuous tray dryers, continuous sheeting dryers, pneumatic conveying dryers, rotary dryers come under continuous system convection drying con be further classified as

- Drying under fluidized state
- Drying under spouted bed condition

- Drying under ordinary state
- Natural/unheated air drying
- Air drying with supplemental heat
- Heated air drying

Radiation drying is based on the absorption of radiation energy of the sun and its transformation into heat energy by the grain. Sun drying is an example of radiation drying.

CHAPTER 5

EXPERIMENTAL SETUP AND PROCEDURE

5.1 INTRODUCTION

Most agricultural crops which are intended to be stored before use have to be dried first .otherwise insects and fungi, which thrive in moist conditions, render them unusable. Examples include wheat, rice, coffee, copra (coconut flesh) and timber .We shall consider grain drying, but the other cases are similar. All crop drying, involves transfer of water from the crop to the air around it, so we must first determine how much water the air can accept as water vapour.

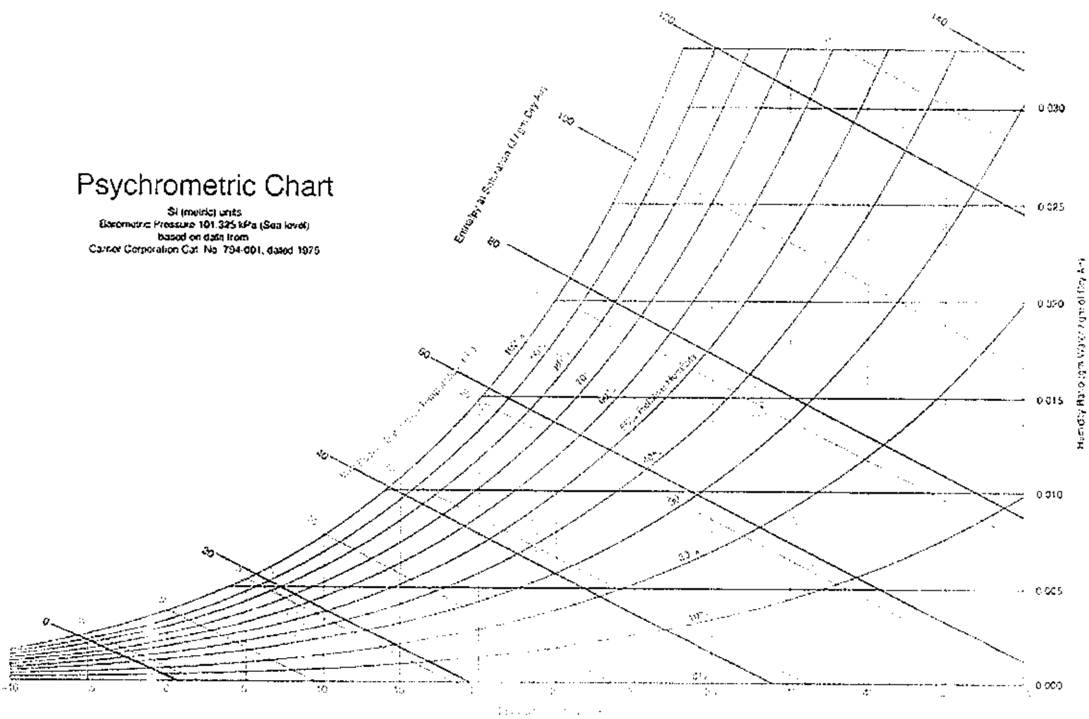

Fig. 5.1 Psychrometric Chart

5.2 PSYCHROMETRIC CHART

The absolute humidity (H_{ow}) (or vapour concentration) is the mass of water vapour in 1 m3 of air. At a particular temperature T, if try to increase the absolute humidity or vapour concentration, beyond saturation (e.g. by blowing in steam), liquid water condenses. The saturation humidity (Hs) depends strongly on temperature. A plot of saturation humidity (or some related measure of humidity) against T is called psychometric chart. The ratio of absolute humidity and saturation humidity (H_o/Hs) is called the relative humidity RH, and ranges from 0% (completely dry air) to 100% (saturated air). Many other measures of humidity are also used.

The drying is a complex phenomenon. It depends on large number of parameters. The most important eight moist air thermodynamic properties are: (i) vapour pressure (ii) relative humidity (iii) humidity ratio (iv) dry bulb temperature (v) dew point temperature (vi) Wet bulb temperature (vii) enthalpy, and (viii) specific volume. Empirical relations are available which could be used to calculate each of the above mentioned parameters. It is tedious job. The special charts known as psychometric chart are available. These charts show the thermodynamic properties of moist air. One of such chart is shown in figure 5.1. If one of the parameter changes, its effect on the other parameters can be seen from psychometric chart. The most important parameter for the drying process is the saturation pressure which depends on the temperature. The drying process can be explained with the help of the psychometric charts as follows:

Suppose the air is not saturated (say dry bulb temp. is 30°C and wet bulb temperature is 20°C). It is allowed to pass over the material. Further, no external heat is supplied to the system. The sensible heat of air and material is exchanged for latent heat of vaporization of water. The starting point on the chart would be point A at 30°C equal to the dry bulb temperature. The path travelled on psychometric chart will be 20°Cwet bulb shown by line AB. The line will stop at B, because the temperature corresponding to point B is equal to the wet bulb temperature. Looking to the chart during this process the humidity ratio has changed from 0.0115 to 0.0140 i.e. about 0.0036 kg of vapour per kg of dry air is absorbed during this process. Now when solar energy is used the air is heated to 45°C with a relative humidity of

17 % and is passed over the drying material. During the drying process, this air is cooled adiabatically along the 24°C wet bulb line.

The final humidity ratio corresponding to point D is 0.0198 whereas initial humidity ratio is 0.0114. Thus the moisture evaporated with the heated air will be 0.0075 kg of vapour per kg of dry air which is almost double the water evaporated compared to when air was not heated.

5.3 PROCEDURE

The main experimental set up consists of 3 major parts

- Thermal collector
- Drying chamber
- Chimney

A fan is used as an exhaust for drawing the hot air from the chimney.

- The entire setup is placed under the sun for a considerable time period.
- The fan is connected to the power supply and the speed of the fan is set up as required. The ambient dry and wet bulb temperatures should be noted for determining the relative humidity, humidity ratio and enthalpy.
- The known weight of green chilli is loaded inside the drying chamber.
- The air gets heated up in the collector. The heated air is then passed in to the drying chamber and escapes out through the chimney.
- At regular time intervals the plate temperature, inlet and outlet air temperature drying chamber temperature, reduction in moisture are noted and tabulated.
- The reduction in weight of agricultural product is the amount of moisture removed.
- All temperature measurements are measured using thermocouple placed at respective points.
- The design of the solar drier and its efficiency is analyzed theoretically using formulas and psychometric chart.

5.4 DETERMINATION OF REDUCED MOISTURE CONTENT AFTER DRYING

The quantity of moisture present in a material can be represented on wet basis and expressed as percentage. About 10 g samples were taken and kept in a convective electrical oven, which was maintained at 105 ± 1°C until constant weight has reached. The initial and final mass, Mt, and final mass, Md, of the samples were recorded with the help of electronic balance. The moisture content, M_{wb}, on wet basis was calculated by using the following equation. The procedure was repeated for every one hour interval till the end of drying.

The formula for finding the moisture under wet basis is as follows.

$$Mwb = \frac{Mt - Md}{Mt} * 100 \qquad (5.1)$$

5.5 RELATIVE HUMIDITY

Relative humidity is the ratio of actual mass of water vapour in a given volume of moist air.

$$\Phi = P_v / P_s \qquad (5.2)$$

$$Pv = Pw - \frac{(Pb - Pw) \times (td - tw)}{1544 - 1.44\,tw} \qquad (5.3)$$

Φ = Relative humidity (%).

P_s = Partial pressure of air corresponding to dry bulb temperature (in bars)

P_v = Partial pressure of water vapour (bar).

P_b = Barometric pressure (1.013 bar).

P_w = Saturated pressure corresponding to wet bulb temperature (in bars)

t_d = dry bulb temperature (^{0}c).

t_w = wet bulb temperature (^{0}c).

5.6 HUMIDITY RATIO

Humidity ratio is the mass of water vapour present in 1 kg of dry air. It is generally expressed in kg/kg of air. It is also called specific humidity.

$$w = 0.622 \frac{Pv}{Pb - Pv} \qquad (5.4)$$

Where,

w = Humidity ratio (kg/kg of air).

P_v = Partial pressure of water vapour (bar).

P_b = Barometric pressure (1.013 bar).

5.7 ENTHALPY

Enthalpy is the quantity of heat necessary to raise the temperature of a substance from one point to a higher temperature. The quantity of heat includes both latent and sensible.

A quantity with units of energy symbolized H and defined by H = E + PV, where E is internal energy, P is pressure, and V is volume.

$$h = 1.022\ t_d + w\ \{h_g + 2.3\ t_{dp}\} \tag{5.5}$$

Where,

h = Enthalpy (KJ/kg).

t_d = Dry bulb temperature (^{0}c).

w = Humidity ratio (kg/kg of air).

h_g = Enthalpy at dew point temperature (from steam tables) (kJ/kg)

t_{dp} = Dew point temperature corresponding to P_v (^{0}c).

5.8 DRYING EFFICIENCIES

The efficiency of solar drying can be studied under two contexts: Collection efficiency (he) and the system efficiency (his) .Collection efficiency (he) measures how effectively the incident energy on the solar collector is transferred to the air flowing through the collector and is given as the ratio of the useful energy output (over a specified time period), to the total radiation energy, IT, available during the same period:

The thermal performance of the solar collector is determined by obtaining values of Instantaneous efficiency using the measured values of incident radiation, ambient temperature, and inlet air temperature. This requires continuous measurement of incident solar radiation on the solar collector as well as the rate of energy addition to the air as it passes through the collector, all under steady state or quasi-steady state conditions.

$$\eta = Q_u/A_c I_t \tag{5.6}$$

Where Ac is the collector surface area,

Q_u is utilised heat flow rate,

I_t is intensity of incident radiation.

System Drying Efficiency:

The system drying efficiency (i_s) or system efficiency is the ratio of the energy required to evaporate the moisture of the commodity to the heat supplied to the drier. Therefore,

$$\eta_s = WL/A_c\, I_t \qquad (5.7)$$

Where,

W is the mass of moisture evaporated

L is the latent heat of evaporation of water at the dryer temperature

A_c is the solar collector area.

Drier efficiency:

The dryer efficiency is given by

$$\eta_d = \eta_s / \eta_c \qquad (5.8)$$

Where the collector efficiency is given by

$$\eta_c = m\, c_p(T_{cout} - T_{cin}) / A_c\, I_t \qquad (5.9)$$

m - Mass flow rate in kg/s

c_p - specific heat of air in kJ/kg K

T_{cout} - collector outlet temperature in ^{o} C

T_{cin} - collector outlet temperature in ^{o} C

A_c – collector area in m^2

I_t - solar intensity in W/m^2

BULATIONS

Table 5.1 Natural convection without fins

Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
	DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
10	30.8	25.5	31.9	26	31.2	26.5	41.4	30.2	24.5	37.7	7
11	34.5	27.5	36.5	28.2	35.5	28.5	57.3	35.1	27	38.4	9
12	35.3	27.5	37.3	28	36	29	57.5	36.7	27.2	40.5	13
1	35.4	28	37.2	29.1	36.2	29.5	58.7	36.9	28	41.1	14
2	32.8	27	36.3	27.5	33.4	28	56.1	33.8	26.5	40.2	12
3	31.8	25.5	33.4	26.3	32.5	27	52.7	31.9	25.4	38.8	10
4	31.6	26	33.3	28	32.2	28	39.9	31.6	25	33.4	6

Table 5.2 Forced convection without fins

y)	Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
		DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
	10	28	27.2	31.4	28.3	31.7	28.5	45.9	27.6	27	33	10
	11	29	27.5	33	28	33.5	28	55.5	28	25.5	38	12
	12	33.4	28.3	37	29	37.2	29.5	56.2	28.2	24.9	37.7	14
	1	36.3	28.5	43.3	29.5	44.7	30.2	63	37.5	27	42.1	19
	2	34.2	28.2	39.2	29	40.4	29.7	56.4	34	24.5	39.7	17
	3	31.7	26.5	32.1	24.5	33.2	25.5	46.5	30.2	24	35.7	14
	4	27	26	31.4	26.5	31.4	26.5	34.2	29.6	25.5	28.7	10

Table 5.3 Natural convection with aluminium fins

ar sity (m^2)	Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
		DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
2	10	29.5	27.4	31.4	28.7	31.8	29	40.2	30.2	27	43.1	12
20	11	31.9	29.5	34.5	29	35	29.5	46.1	33.7	27.5	46.2	19
25	12	35.4	29.5	38.4	30	39.5	29.5	49.6	36.4	27.5	44.4	21
30	1	37.2	29	42.5	30	40.2	29.7	48.7	40.7	28	44.1	23
62	2	36.2	28.5	39.4	29	40.1	29.5	45.5	38.4	27.5	42.5	16
78	3	30.2	26.5	32.8	27	33	27	38	31.5	25.5	36.9	12
47	4	30.4	26	32	27	32.5	27.5	33.8	31.2	25.5	32.1	10

Table 5.4 forced convection with aluminium fins

...sity ...)	Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
		DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
	10	30.5	28	33.2	29	34	29.5	46.5	31.2	28	39.5	15
	11	31.8	28	38	29.5	35.5	30	49.2	31.4	27	40.3	18
	12	34.3	28.5	39	29.5	40	30	54.5	36.5	28.5	43.4	24
	1	36.2	28.5	46	29.5	46.2	29.8	59.2	39.7	29	46.1	28
	2	34.7	28	38.7	29	39.2	29	55.7	37.5	28.5	42.2	20
	3	33.5	27.5	35.6	28.5	36	28.5	50.2	35.2	27	40.4	17
	4	31.8	26	34.7	26.5	35.5	26.5	40.2	32.5	25	37.4	10

Table 5.5 Natural convection with galvanised iron fins

Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
	DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
10	31.2	26	32.1	26	32.5	26.5	43.4	31.2	25.5	38.7	9
11	33.4	26.5	35.6	27.2	36.3	27.5	54.3	34.1	27	40.6	11
12	36.1	27.5	38.8	28	39.5	28	56.3	37.7	27.5	41.7	15
1	37.6	28	41.1	28.5	42.2	29	57.6	39.8	28.5	42.4	19
2	34.3	27.5	37.1	28	38.4	28.5	55.1	37.8	27.5	40.6	14
3	32.1	26.5	33.6	27.3	34.3	27.5	53.2	32.9	26.5	39.7	10
4	31.8	26	32.4	26.5	33.2	27.5	42.1	31.6	26	36.5	7

Table 5.6 Forced convection with galvanised iron fins

)	Time (hrs)	Collector Inlet air temperature °C		Collector outlet air temperature °C		Dryer inlet temperature °C		Plate temperature °C	Dryer outlet °C		Glass temperature °C	Moisture removed per hour (grams)
		DBT	WBT	DBT	WBT	DBT	WBT		DBT	WBT		
	10	28.5	26.5	30.6	27	31.2	27.5	36.5	30.1	26.5	38.8	13
	11	30.1	27	35.3	27.5	33.5	27.5	47.5	32.1	27	44.4	14
	12	35.7	28.5	39.4	29.2	42.5	29.5	49.7	37.9	28.5	45.2	17
	1	36.8	29	44.9	29.5	43.1	29.5	50.4	40.8	29.2	46.3	22
	2	34.3	28.2	38.3	28.5	39.2	29	46.5	37.3	28	43.2	24
	3	31.4	28	33.1	28	33.5	28.5	40.2	32.4	27.8	39.3	19
	4	30.5	26.5	32.6	27	33.1	26.8	34.8	31.5	26.5	34.2	15

5.9 CALCULATION

5.9.1 Mass flow rate

The mass flow rate of the system is calculated by using the following formula,

$$m = \rho AV$$

m - Mass flow rate in kg/s

ρ – Density of the air (1.225 kg/m^3)

V – Velocity of the air flowing through the chimney outlet in m/s

A – Area of the chimney outlet in m^2

The experimental data is as follows,

$\rho = 1.225\ kg/m^3$.

V = 4.2 m/s

A= 0.04m^2

Therefore,

m = 1.225*4.2*0.04

= 0.2058kg/s

5.9.2 Determination of moisture content:

The following calculations are done for the table 5.2. Forced convection without fins.

The moisture content on wet basis is calculated as follows,

$$Mwb = \frac{Mt - Md}{Mt} \cdot 100$$

M_t = 500kg (for forced convection without fins)

M_d=404kg (for forced convection without fins

$$Mwb = \frac{500 - 404}{500} \cdot 100$$

$$= 19.2\%$$

The moisture content in the chillies after drying is 19.2%

5.9.3 Heat utilization factor (HUF)

This is the ratio of temperature decrease to cooling of the air during drying and the

$t_0 = 36.3\ ^0c$

$t_1 = 44.7\ ^0c$

$t_2 = 37.5^0c$

$$HUF = \frac{t1-t2}{t1-t0}$$

= (44.7-37.5)/44.7-36.3)

= 0.08571

5.9.4 Coefficient of performance (COP)

$$COP = \frac{t2-t0}{t1-t0}$$

= (37.5-36.3) / (44.7-36.3)

= 0.1428

Where,

t_2 = DBT of exhaust air

t_1 = DBT of drying air

t_0 = DBT of ambient air

COP + HUF = 1

0.1428 + 0.8571 = 1

5.9.5 Relative Humidity (Φ)

$$\Phi = (P_v / P_s) * 100$$

$$Pv = Pw - \frac{(Pb - Pw) * (td - tw)}{1544 - 1.44\, tw}$$

Relative humidity of collector inlet temperature (without fins)Table 1, during maximum temperature,

$t_d = 36.3\ ^0c$

$t_w = 28.5\ ^0c$

$P_b = 1.013$ bar

$P_w = 0.03850$ bar

$P_s = 0.05940$

Therefore,

$$P_v = 0.03850 - \frac{(1.013 - 0.03850) * (36.3 - 28.5)}{1544 - (1.44 * 28.5)}$$

$= 0.03340$ bar

$\Phi = P_v / P_s$

$= \{0.03340/0.05940) * 100$

$= 56.23\ \%$

5.9.6 Humidity ratio or specific humidity (w)

$$w = 0.622 \frac{Pv}{Pb - Pv}$$

$= 0.622\ (0.03340 / (1.013-0.03340)\ )$

$= 0.0212$ kg/kg of dry air

5.9.7 ENTHALPY (h)

$$h = 1.022\ t_d + w\ \{h_{fg} + 2.3\ t_{dp}\}$$

$t_d = 36.3\ ^0c$

hfg = 2440.2KJ/kg (corresponding to Pv from steam tables)

$$h = 1.022(36.3) + 0.0212\ (2440.2 + 2.3*26)$$

$$= 90.01\ KJ/kg$$

Table 5.7 Summary of moisture content for all readings

ble	**H.U.F**	**C.O.P**	**Weight of sample after drying in grams**	**Final moisture content reduced (wet basis)**
ble5.1	0.4643	0.5357	71	14.2%
ble 5.2	0.08571	0.1428	96	19.2%
ble 5.3	0.4166	0.538	113	22.6%
ble 5.4	0.65	0.35	132	26.4%
ble 5.5	0.5217	0.4782	85	17.1%
ble 5.6	0.3650	0.6349	114	24.8%

Table 5.8 Relative humidity and humidity ratio for natural convection without fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
65.67	0.0185	62.95	0.0189	69.43	0.0201	62.96	0.0171
58.77	0.02050	53.77	0.02095	59.43	0.0219	53.72	0.01933
55.32	0.02016	49.76	0.0202	59.75	0.0227	48.40	0.01901
57.36	0.02105	55.19	0.0224	61.37	0.0236	51.27	0.02040
64.07	0.02031	51.28	0.0197	66.63	0.0219	56.76	0.01899
60.66	0.01811	57.50	0.0188	65.56	0.02044	59.64	0.01790
64.44	0.01905	67.13	0.0219	72.90	0.02244	58.87	0.01736

Table 5.9 Enthalpy for drying chilli for natural convection without fins

Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving the drying chamber
Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
KJ/kg	KJ/kg	KJ/kg	KJ/kg
78.93	80.53	82.8	74.18
87.27	90.53	92.05	84.90
87.23	89.81	94.52	85.75
89.61	94.96	97.06	89.54
85.01	87.18	89.71	82.68
78.34	81.79	85.02	77.911
80.54	89.71	89.78	76.22

Table 5.10 Relative humidity and humidity ratio for forced convection without fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidit y (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
94.05	0.0227	79.29	0.0233	69.36	0.02359	95.48	0.02254
89.21	0.0228	68.66	0.0220	66.14	0.0218	82.01	0.0197
68.31	0.02247	55.53	0.0222	57.09	0.02319	76.7	0.01867
56.01	0.02162	36.75	0.02058	35.50	0.0214	76.7	0.01831
63.82	0.02194	47.28	0.02134	46.11	0.0222	46.67	0.01553
66.79	0.01989	53.92	0.0163	54.27	0.01752	60.08	0.01633
92.45	0.02105	53.42	0.02	68.36	0.02	72.23	0.019053

Table 5.11 Enthalpy for drying chilli for forced convection without fins

Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving th drying chamber
Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
KJ/kg	KJ/kg	KJ/kg	KJ/kg
86.17	91.27	92.25	85.26
87.54	89.76	89.7	78.52
91.18	94.47	97.01	75.94
92.01	96.69	100.28	84.78
90.65	94.35	97.88	74.01
82.78	74.09	78.29	72.13
80.76	82.79	82.79	78.45

Table 5.12 Relative humidity and humidity ratio for natural convection with Al fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
85.2	0.02246	81.82	0.0241	81.32	0.0245	78.2	0.0214
83.89	0.0254	66.68	0.0233	66.95	0.0241	62.45	0.0208
65.038	0.0239	54.6	0.0236	48.34	0.0222	50.9	0.0196
54.72	0.0222	40.75	0.0219	46.78	0.0223	38.57	0.0187
56.43	0.0216	46.59	0.0212	46.29	0.0219	43.74	0.0188
75.03	0.0204	64.07	0.0203	63.09	0.0202	62.13	0.0182
70.8	0.02032	68.12	0.0206	68.39	0.0213	63.62	0.0183

Table 5.13 Enthalpy for drying chilli for natural convection with Al fins

Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving the drying chamber
Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
KJ/kg	KJ/kg	KJ/kg	KJ/kg
87.044	93.25	94.74	85.14
97.29	94.6	94.74	87.3
97.11	99.56	94.74	87.176
94.46	99.34	94.74	89.35
92.016	94.346	94.74	87.078
82.85	85.015	94.74	78.36
80.6	85.054	94.74	78.37

Table 5.14 Relative humidity and humidity ratio for forced convection with Al fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
82.83	0.02315	79.29	02.0233	71.99	0.0245	78.59	0.0228
75.13	0.0225	68.66	0.0220	67.21	0.02495	71.330	0.02092
68.31	0.02247	55.53	0.0223	48.70	0.02301	55.19	0.02153
56.02	0.0216	36.75	0.0205	30.71	0.01995	45.59	0.0211
63.82	0.02194	47.28	0.02134	47.28	0.02135	51.25	0.0211
66.79	0.0198	53.92	0.0163	57.27	0.0217	53.30	0.01929
92.44	0.0210	68.36	0.0200	49.740	0.01827	54.76	0.01698

Table 5.15 Enthalpy for drying chilli for forced convection with Al fins

o	Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving th drying chamber
	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
it	KJ/kg	KJ/kg	KJ/kg	KJ/kg
	89.86	94.67	97.185	89.83
	89.79	96.97	99.72	85.08
	92.113	96.92	99.48	92
	92.016	96.55	98.094	94.33
	89.64	94.38	94.36	91.95
	87.32	92.04	92.03	84.89
	80.54	82.64	82.6	76.18

Table 5.16 Relative humidity and humidity ratio for natural convection with GI fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
66.50	0.01922	61.96	0.01884	62.78	0.01955	63.62	0.01837
58.54	0.01916	52.64	0.01948	51.28	0.01973	57.99	0.01976
52.07	0.01981	44.48	0.01959	42.20	0.0193	46.13	0.01914
48.65	0.02011	39.3	0.01956	37.98	0.02006	43.24	0.02012
59.67	0.02058	50.51	0.02032	47.95	0.02071	45.78	0.01909
64.77	0.01972	61.85	0.02052	59.67	0.02058	60.86	0.01937
63.44	0.01897	63.27	0.01953	64.86	0.02105	64.49	0.01905

Table 5.17 Enthalpy for drying chilli for natural convection with GI fins

o	Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving th drying chamber
	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
t	KJ/kg	KJ/kg	KJ/kg	KJ/kg
	80.56	80.52	82.74	78.38
	82.69	85.80	87.18	84.95
	87.19	89.44	89.18	87.11
	89.50	91.76	94.20	91.83
	87.27	89.53	91.90	87.11
	82.76	86.37	87.29	82.72
	80.53	82.75	87.33	80.56

Table 5.18 Relative humidity and humidity ratio for forced convection with GI fins

Air inlet to collector		Air outlet to collector		Air inlet to drying chamber		Air leaving the drying chamber	
Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)	Relative humidity (Φ)	Humidity ratio (w)
%	kg/kg	%	kg/kg	%	kg/kg	%	kg/kg
85.61	0.0212	75.83	0.0212	75.48	0.0219	75.61	0.0205
78.8	0.0214	55.32	0.0201	63.4	0.02093	67.6	0.0206
58.55	0.0218	47.43	0.0216	38.93	0.02092	49.76	0.0209
56.35	0.0223	32.75	0.0199	37.28	0.02067	42.84	0.021
63.34	0.0219	48.31	0.0207	47.28	0.02134	49.76	0.0202
77.41	0.0227	68.14	0.022	68.92	0.0228	70.65	0.0219
73.3	0.0204	65.05	0.0204	61.53	0.0198	67.84	0.0199

Table 5.19 Enthalpy for drying chilli for forced convection with GI fins

Air inlet to collector	Air outlet to collector	Air inlet to drying chamber	Air leaving th drying chamber
Enthalpy (h)	Enthalpy (h)	Enthalpy (h)	Enthalpy (h)
KJ/kg	KJ/kg	KJ/kg	KJ/kg
82.93	85.12	87.43	82.86
85.15	87.23	87.32	85.04
92.04	95.36	96.73	91.92
94.48	96.6	96.7	95.28
90.64	91.9	94.35	89.51
89.81	89.73	92.15	88.8
82.83	85.02	84.08	82.78

CHAPTER 6

PERFORMANCE ANALYSIS AND DISCUSSION

The thermal performance of solar-assisted dryer is studied for supplying heat to dry green chilies. The main objective of the project is to increase the performance of the solar collector .The is an air-heater and is tested with and without fins. To improve the performance of the dryer, the collector is integrated with fins. The fins used here are aluminium and galvanized iron which is placed between the collector plate and the base plate. The air flows in the same direction on both sides of the absorber plate thus providing more surface area for heat transfer to the air compared to the one without fins. Here we conduct experiment for both natural and forced convections. From the observations it is understood that the collector with fins has higher performance than the collector without fins.

6.1 ALUMINIUM FINS

Adding aluminium fins into collector will improves heat transfer to the air but reduce natural convective effect at early stage. However, drying rate speeds up in the latter stage where fins promote more regions of natural convective currents to the air. This proposal of using aluminium fins as an alternative thermal enhancement method for collector makes it as simple and effective.

Increasing the medium velocity causes more turbulence, which improves convective heat transfer. However, as they move faster, the increase in heat transfer starts to level off and medium friction losses continue to rise. Eventually the amount of energy needed to overcome friction loss is not worth the small thermal gain. The maximum temperature difference of the collector using these fins is 9.1 degree Celsius.

Aluminium has a unique and unbeatable combination of properties that make it into a versatile, highly usable and attractive construction material.

Weight: Aluminium is light with a density one third that of steel, 2.700 kg/m3.

Strength: Aluminium is strong with a tensile strength of 70 to 700 MPa depending on the alloy and manufacturing process. Extrusions of the right alloy and design are as strong as structural steel.

Elasticity: The Young's modulus for aluminium is a third that of steel (E = 70,000 MPa). This means that the moment of inertia has to be three times as great for an aluminium extrusion to achieve the same deflection as a steel profile.

Machining: Aluminium is very easy to machine. Ordinary machining equipment can be used such as saws and drills. Aluminium is also suitable for forming in both the hot and the cold condition.

Corrosion resistance: A thin layer of oxide is formed in contact with air, which provides very good protection against corrosion even in corrosive environments. This layer can be further strengthened by surface treatments such as anodizing or powder coating.

Conductivity: The thermal and electrical conductivities are very good even when compared with copper. Furthermore, an aluminium conductor has only half the weight of an equivalent copper conductor. The thermal conductivity of pure aluminium is about 300W/mK. But pure aluminium is not possible, only the aluminium coated with oxide layer which decreases the thermal conductivity around 25 to 33 W/mK.

Linear expansion: Aluminium has a relatively high coefficient of linear expansion compared to other metals. This should be taken into account at the design stage to compensate for differences in expansion.

Reflectivity: Aluminium is a good reflector of both light and heat.

6.2 GALVANIZED IRON FINS

Comparing to the aluminium the thermal conductivity is slightly less for GI material which is around 18W/mK. The heat transfer is also less compared to the previous one. However considering the cost of the material the GI fins are effective. Some of the properties are given below. The maximum temperature difference of the collector using these fins is 8.1degree Celsius.

Formability: There is no mechanical properties change with coating and so superior formability of the base metal is attained.

Welding: Same weld ability as that of hot rolled and cold rolled base metal if spot and seam

Corrosion: Oxidation of zinc is inhibited by chemical treatment or oiling, so it has good corrosion resistance. Even if base metal is exposed by scratches during working, red rust is delayed.

Others: Products with properties of anti-fingerprint, lubricity, surface conductivity etc. are available.

6.3 RESULT AND DISCUSSION

The graphs for the tabulated readings were plotted using Microsoft Excel.

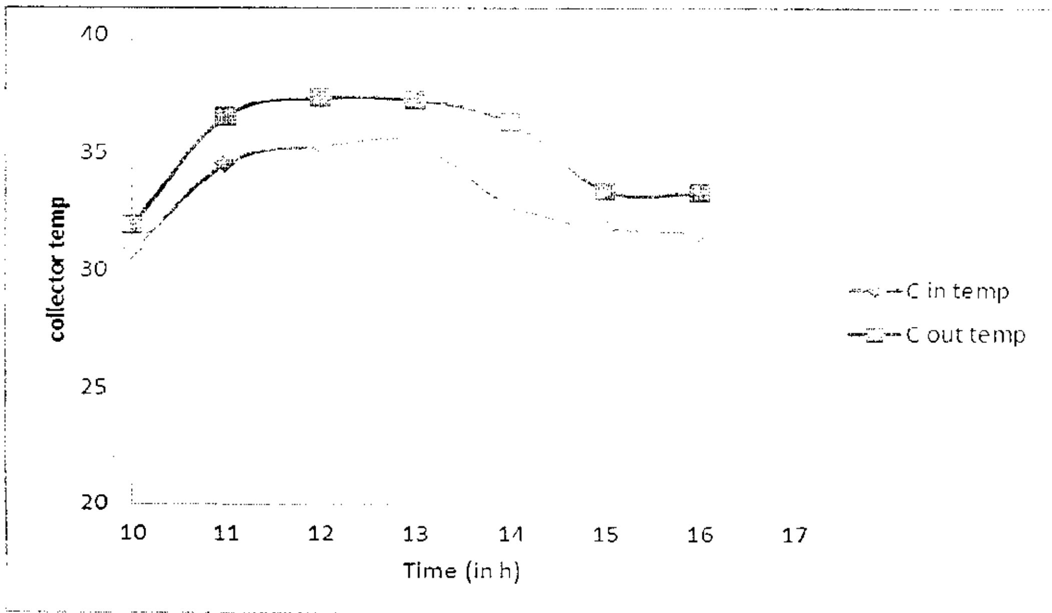

Fig 6.1 Time Vs Collector temperature (natural)

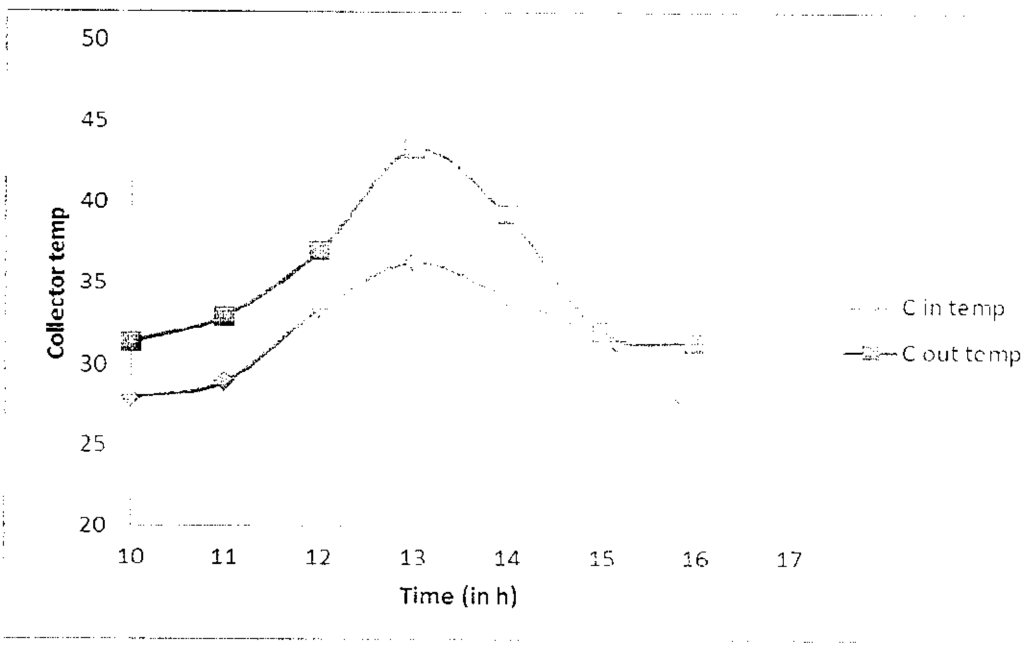

Fig 6.2 Time Vs Collector temperature (forced)

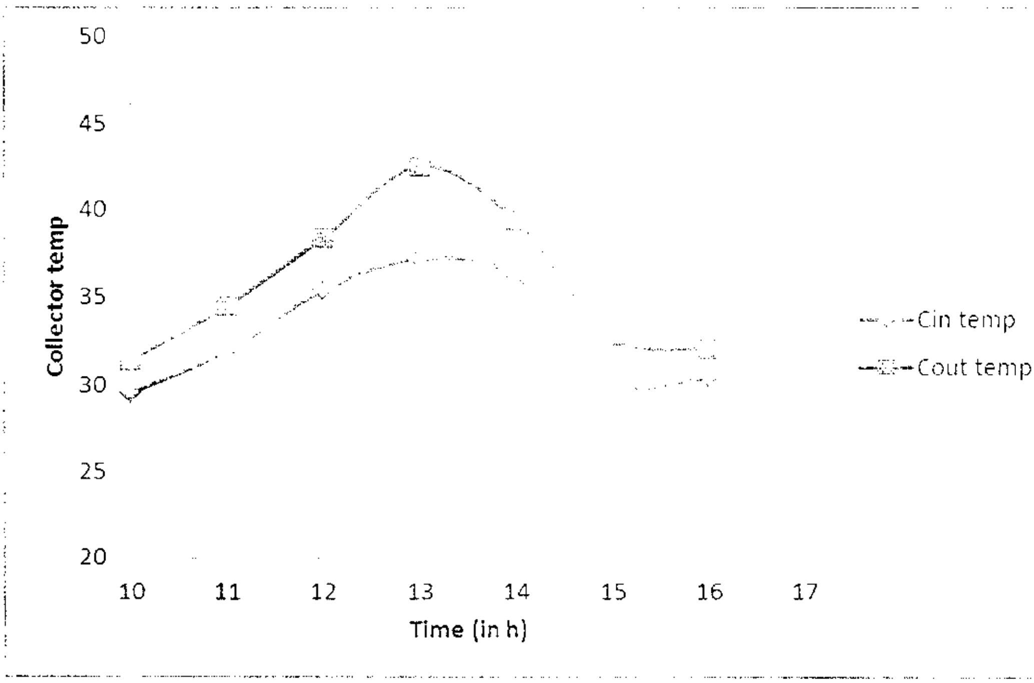

Fig 6.3 Time Vs collector temperature (with al fins)

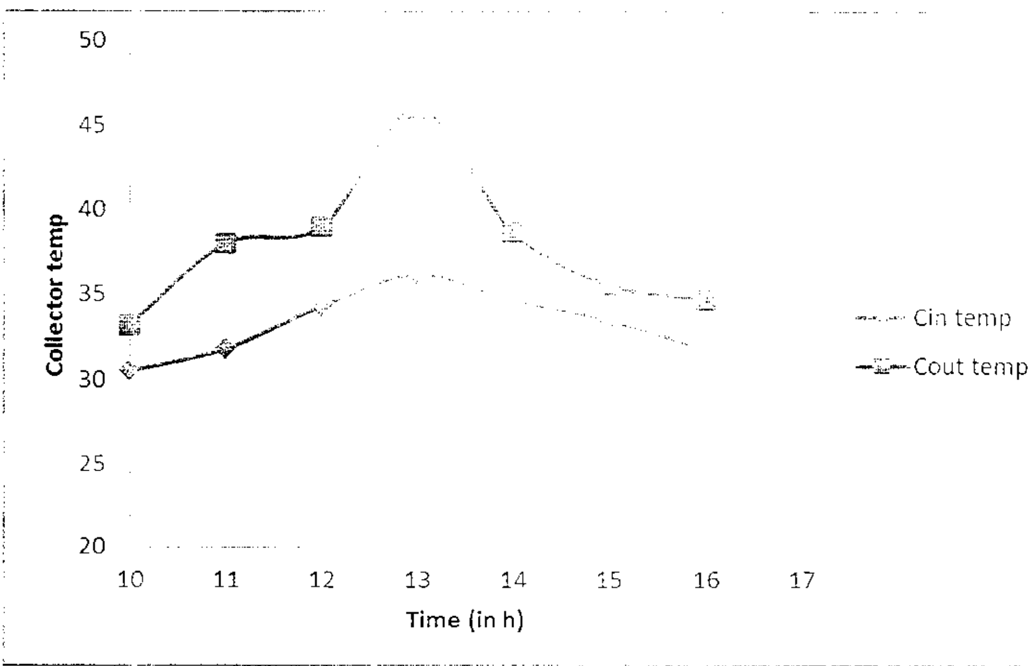

Fig 6.4 Time Vs collector temperature (with al fins)

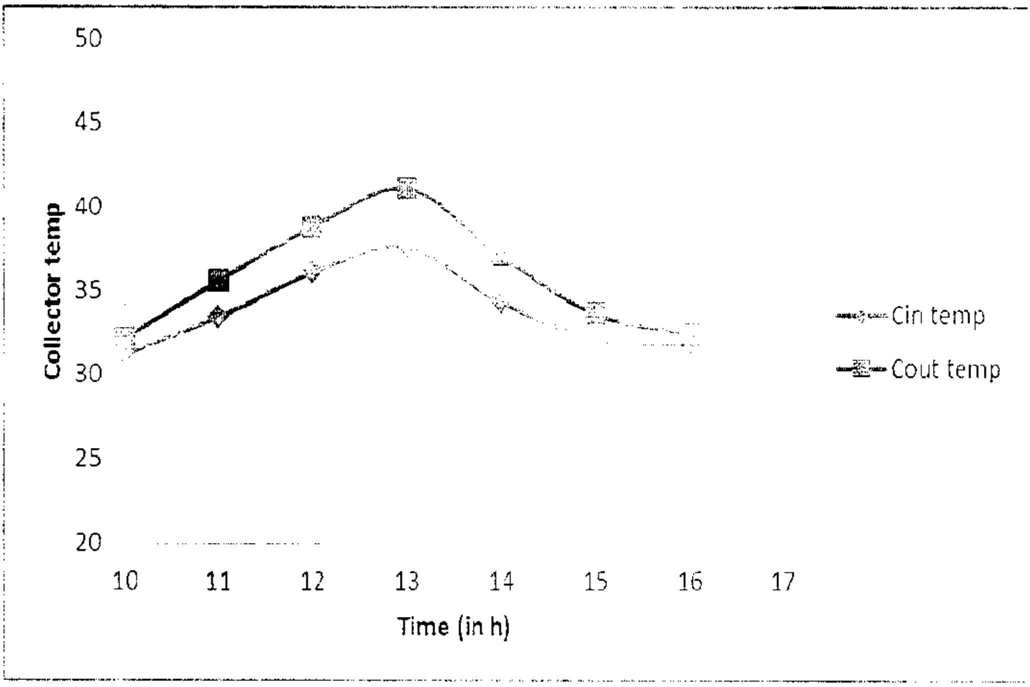

Fig 6.5 Time Vs collector temperature (with GI fins)

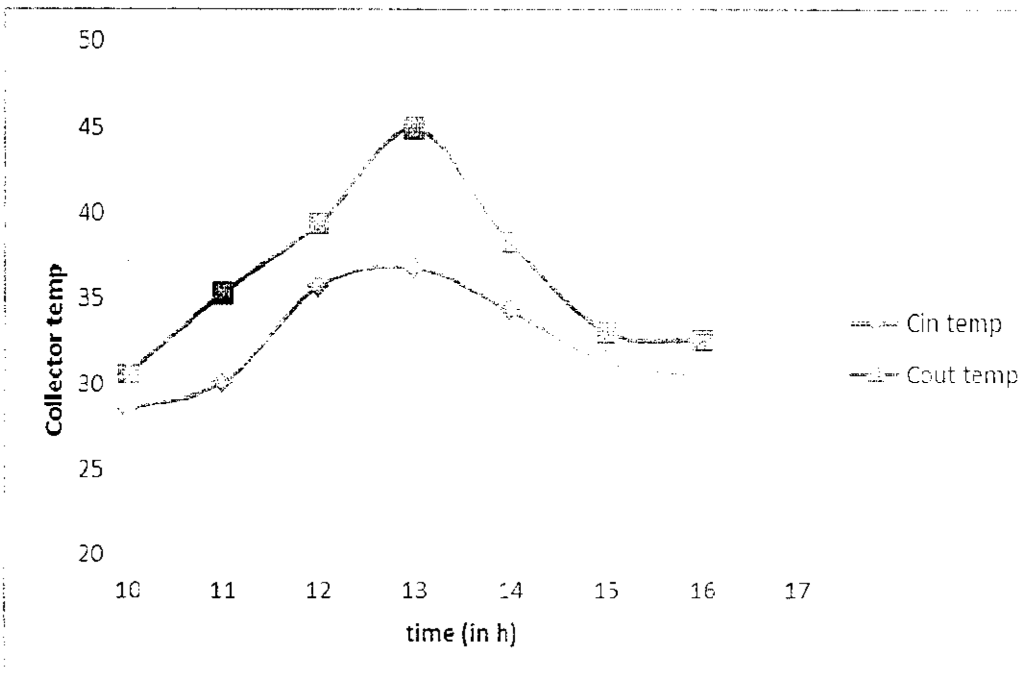

Fig 6.6 Time Vs collector temperature (with GI fins)

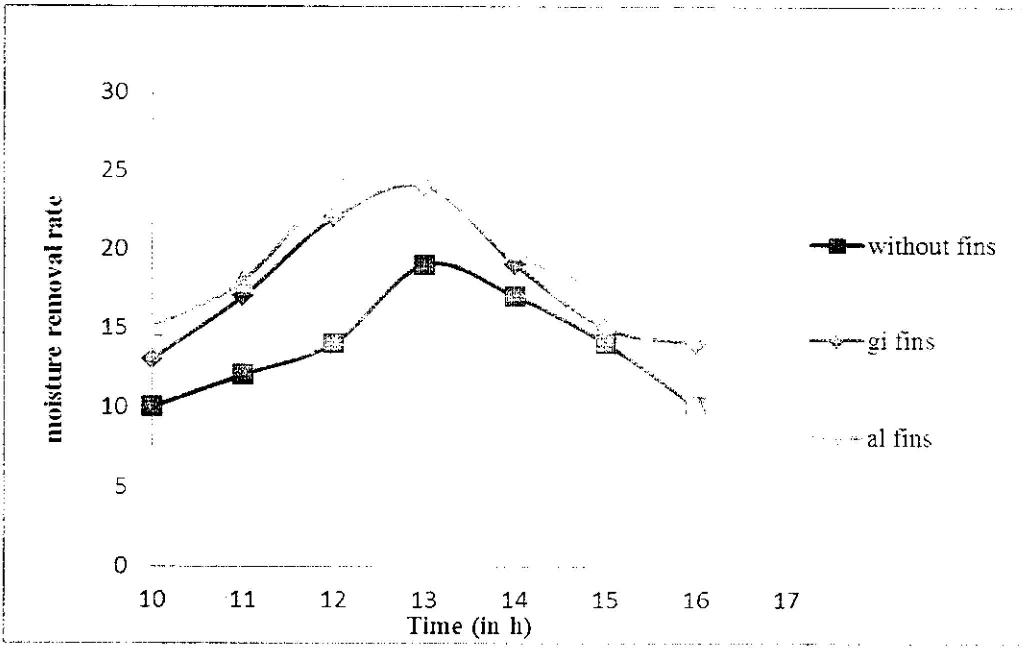

Fig 6.7 Time Vs Moisture removed (forced)

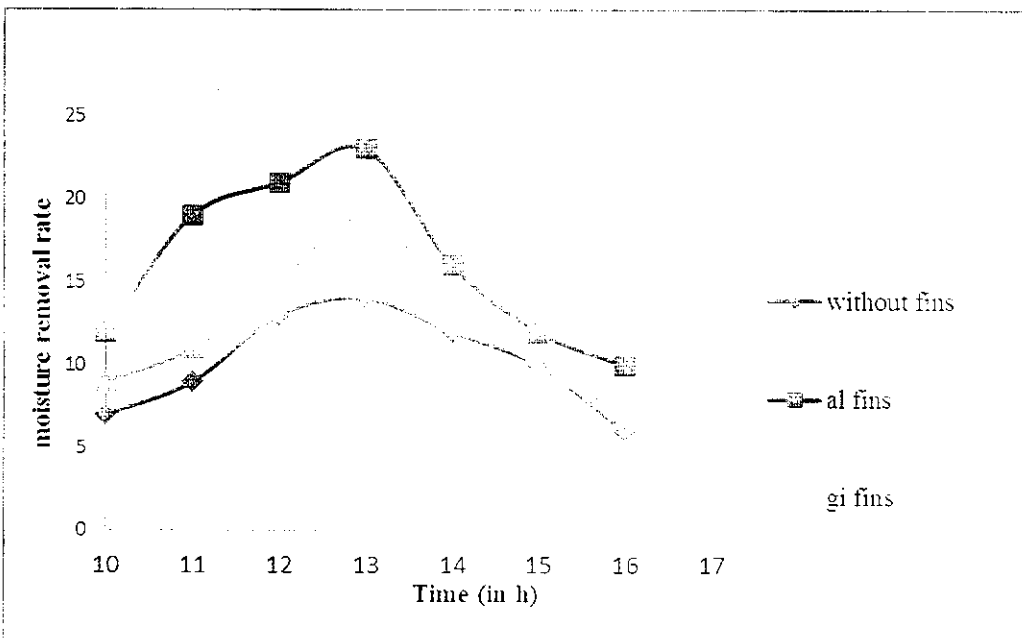

Fig 6.8 Time Vs Moisture removed (natural)

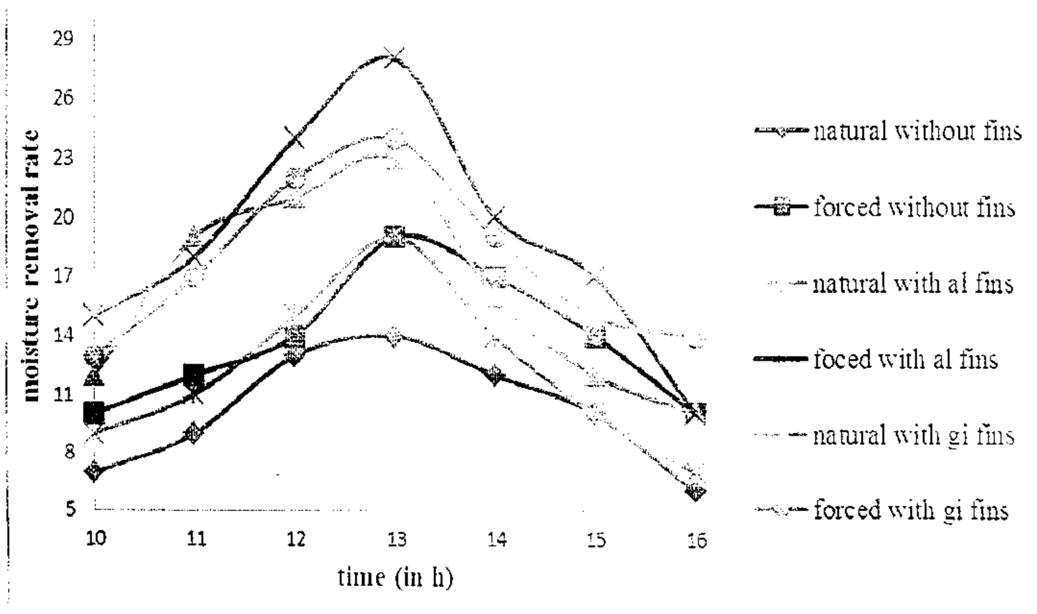

Fig 6.9 Comparison of all moisture removal

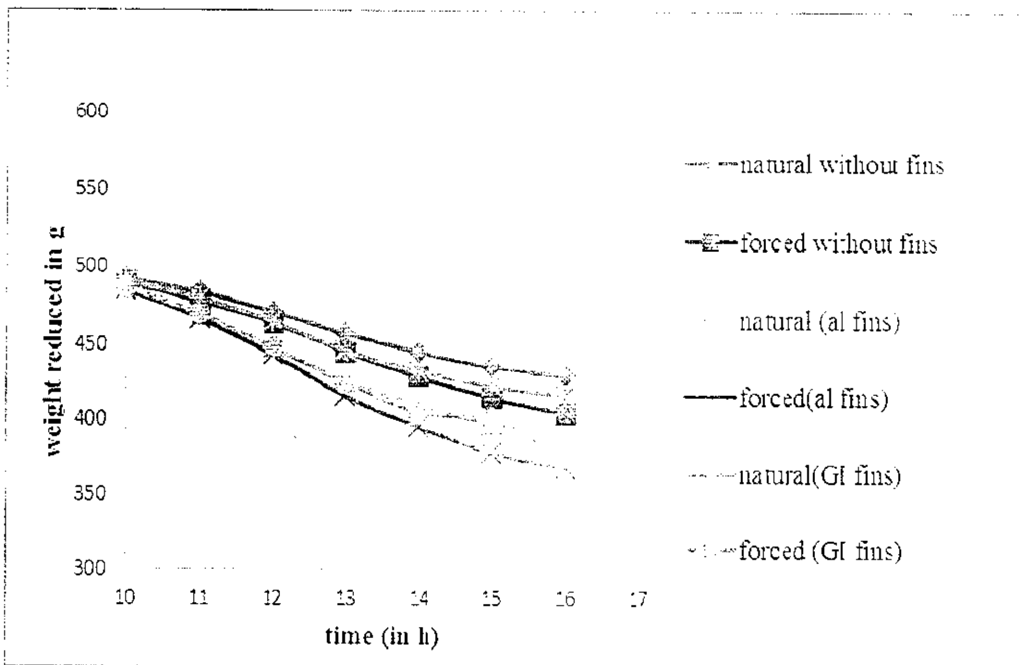

Fig 6.10 Time Vs Weight reduced

From the graphs drawn from fig 6.1 to 6.10 the performance of the drier is shown corresponding to inlet and outlet temperature of collector , moisture removal with respect to time. All these graphs contain the values conducted for both natural and forced convection.

In both, the experiment was done with and without fins. Following are the cases to be considered.

Case 1: natural convection without fins

Case 2: forced convection without fins

Case 3: natural convection with Aluminium fins

Case 4: natural convection with GI fins

Case 5: forced convection with Aluminium fins

Case 6: forced convection with GI fins

From fig 6.1 to fig 6.6 the collector temperatures for both inlet and outlet air is shown. It is observed that the range of temperature difference is maximum (9.1°C) for aluminium compared to all observations shown from table 5.1 to 5.6. Similarly the temperature difference for collector having GI fins is 8.1° C. From the observations made the performance of the collector is increased with implementing the fins .

From the graphs drawn it is clear that the moisture removal is high in forced convection especially using fins. In fin type the aluminium fins has higher thermal conductivity than GI fins. Hence the moisture removal is high for aluminium fins. It is inferred from the figure 6.7 and 6.8 the moisture removal is high only for forced convection (that is only for aluminium fins). In considering the economic problem the exhaust fan has additional energy, so the drier can also used for natural convection in case of no power .So the drier performance is increased by using forced convection with different heat storage material in collector (here fins are used).the project is done for aluminium and GI fins .the storage materials can be changed like water , gravels, river sand etc., The weight reduction in open sun drying is nearly 445g out of 500g. From the results shown here the air dryer is better than open sun drying which also prevents the crops or grains external matter like dust, insects etc.

CHAPTER 7

CONCLUSION

- The performance of a solar air heater without fins is less compared to the performance of a solar air heater with fins.
- The performance of the air heater is dependent on the collector area, fan speed, air mass flow rate and heat storage materials used.
- The performance of the air heater is dependent on the temperature difference between the inlet air of the dryer to the ambient inlet air temperature. Therefore, the efficiency will be maximum when the inlet air temperature is more than the ambient air temperature. The fluid conduction has no effect on the overall performance of the collector. Increased air flow ratio improves the dryer efficiency.
- The drying chamber air temperature is maximum during the peak sun shine hours (11 am to 1 pm).
- The drying chamber operates in the temperature range of 38^0c to 45^0c which is an optimum temperature for drying chilies in our experiment. This temperature can be varied by having different heat conducting materials.
- This performance improvement study will be useful in the later stage to examine the thermal behavior of the whole dryer and to develop an industrial solar dryer for drying agricultural products.
- The collector performance is increased with the integration of heat storage materials. In this project the integration of the fins increases the performance of the collector
- The drier performance is high for the collector having aluminium fins. The galvanized iron fins also has considerable efficiency compared to aluminium. From the results and graphs it is understood that the forced convection mode of drying is far better than the natural convection.

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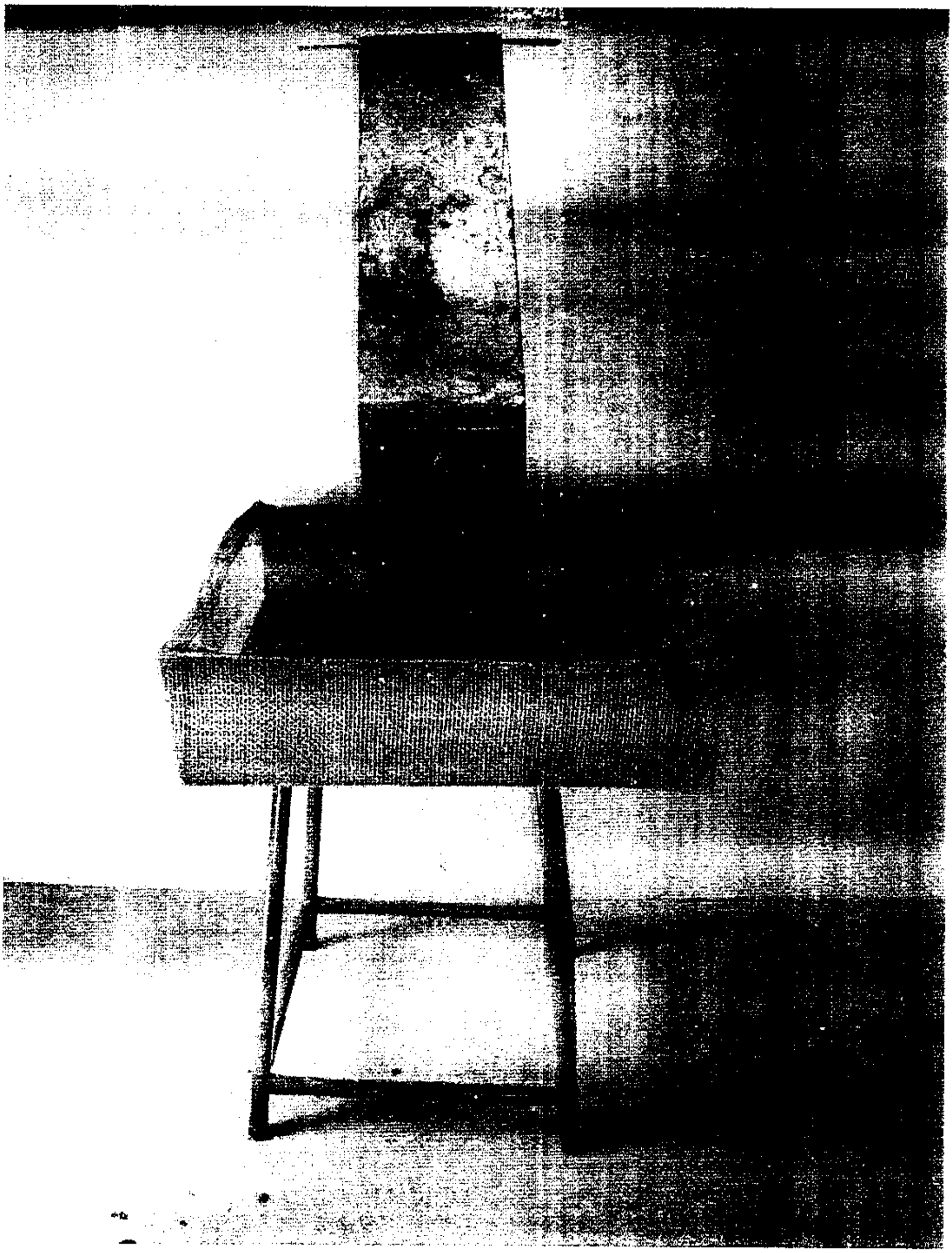
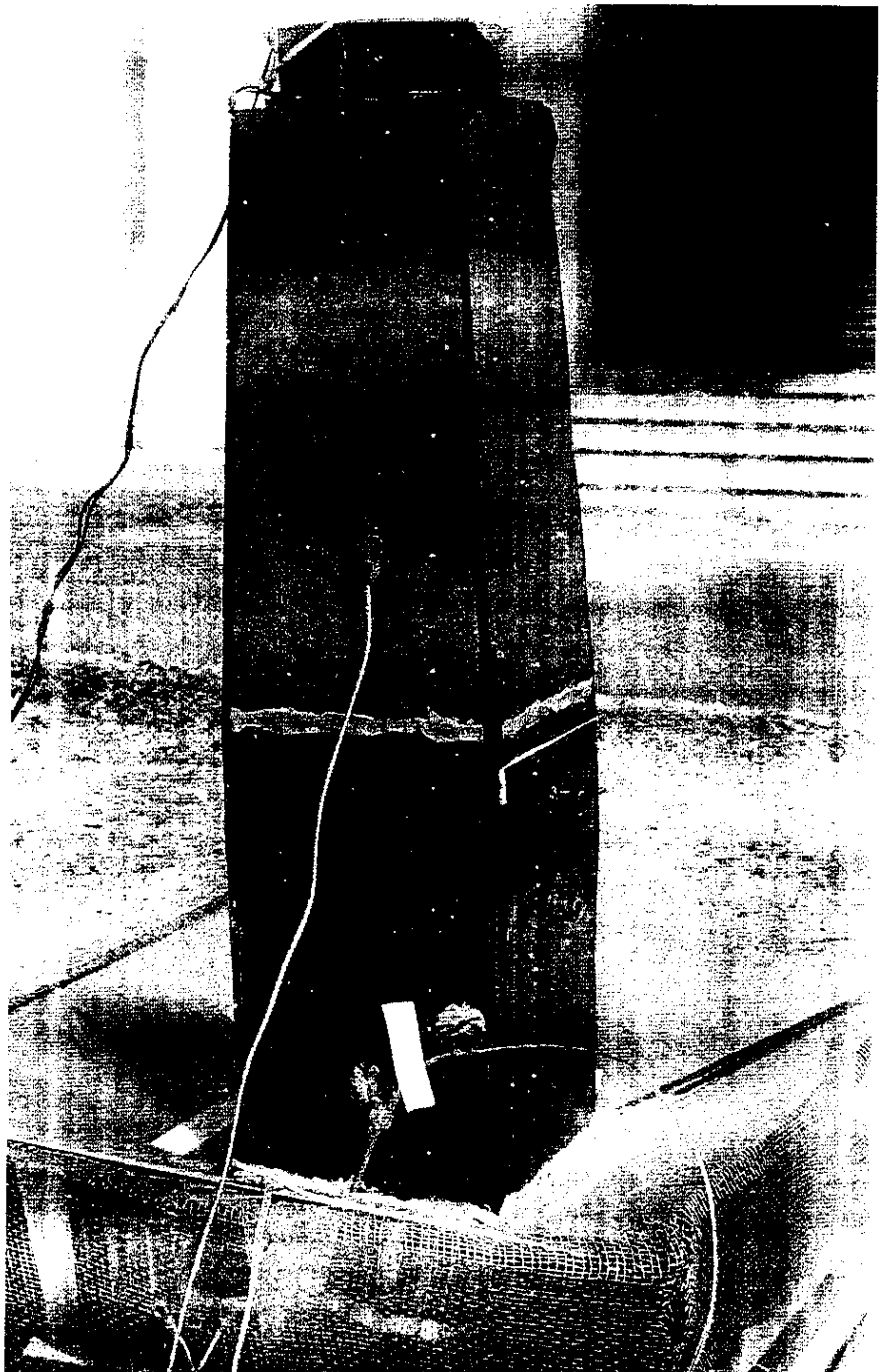
PHOTOGRAPHS



SOLAR DRYER



DRYER WITH FINS IN SOLAR COLLECTOR

DRYING CHAMBER LOADED WITH CHILLIES