DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF SOLAR TUNNEL DRYER

DISSERTATION

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In

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By

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May-2010

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&

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CANDIDATE'S DECLARATION

I, here by declare that the dissertation

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(BHONDE K. S.)

Place: **Parbhani**

Date: 29 / 11 /2010

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CERTIFICATE-I

This is to certify that the dissertation entitled **"DESIGN, FABRICATION AND PERFORMANC EVALUATION OF SOLAR TUNNEL DRYER"** submitted to Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering**) in **Agricultural Process Engineering** embodied the results of the bonafied study carried by **BHONDE KAILAS SUKHADEO Reg.No AE08/M01** under my guidance and supervision. I also certify that the dissertation has not been previously submitted by him for the award of Degree or Diploma of any University or Institute.

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CERTIFICATE-II

This is to certify that the dissertation entitled **"DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF SOLAR TUNNEL DRYER"** submitted by **BHONDE KAILAS SUKHADEO** to the Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY (Agril. Engg.)** In the subject of **AGRICULTURAL PROCESS ENGINEERING** has been approved by the student's advisory committee after oral examination in collaboration with external examiner.

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(Bhonde K. S.)

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ABBREVIATIONS

%	:	Per cent
&	:	And
approx.	:	Approximate
Avg.	:	Average
C.A.E.T.	:	College of Agricultural Engineering and Technology
cm	:	Centimeter
d.b.	:	Dry basis
D.C.	:	Direct current
Deptt	:	Department
dia	:	Diameter
e.g.	:	Example gratia
Engg	:	Engineering
et al.	:	And others
etc.	:	Etcetera
Fig.	:	Figure
g	:	Gram
g cm^{-3}	:	Gram per cubic centimeter
G.I.	:	Galvanized iron
h	:	Hours
i.e.	:	that is
kcal	:	Kilocalorie
km/h	:	Kilometer per hour
M	:	Metre
M. Tech	:	Master of Technology
M.A.U.	:	Marathwada Agricultural University
M.C.	:	Moisture content
M.S.	:	Mild Steel
M.T.	:	Metric tone
m/sec	:	Meters per seconds
m^2	:	Meter square

m^3	:	Cubic metre
Max	:	Maximum
min	:	Minute
Min.	:	Minimum
mm	:	Millimeter
MW	:	Mega Watt
No.	:	Number
^oC	:	Degree Celsius
^ok	:	Degree Kelvin
Rs	:	Rupees
s	:	Second
Sr. No.	:	Serial Number
Temp	:	Temperature
U.V.	:	Ultra violet
w.b.	:	Wet basis
w.b.	:	Wet-basis
W/m^2	:	watts per Square meter
µ	:	Micron

INTRODUCTION

CHAPTER I

INTRODUCTION

Chilly is botanically known as Capsicum annum L. *(Capsicum frutescen L).*The chilly is widely distributed in India. It is an indispensable condiment of every Indian home. It has primary origin in Mexico and a second origin in Guatemala. India is the largest producer of chillies in the world contributing 25 per cent of the world production around 97 per cent of the total production of chilly is consumed within the country and only 3 per cent is exported. Almost all the varieties of chillies that are cultivated in India as a cash crop belong to *Capsicum annum L.*

Harvested red chilly contain 72-78 per cent of moisture that should be reduced to 8-10 per cent by drying for the preparation of chillies of commerce ripe fruit are harvested at frequent interval 20-30 days and dried on floor after heaping in room for one day to maintain the uniform colour (Joy et al. 2001).

In India the chilly crop is grown on 4.41 lakh ha area out of which more than 25 per cent chilly crops is grown only in Maharashtra. All Marathwada district chilly is grown on wide scale. (Rohidas. et al. 2009). Marathwada is region of Maharashtra Geographically Marathwada region is situated between $17^{0}35'$N and $20^{0}40'$N latitude and $74^{0}40'$E and $78^{0}15'$E longitudes. The total geographical area of the region is 64,525 sqkm. (Kate 2008).

Chilly also called red Pepper belongs to the genus capsicum, under the solanaceae family. Chillies are referred to as chillies, chile, hot peppers, bell peppers, red peppers, pod peppers, cayenne peppers, paprika, pimento, and capsicum in different parts of the world. However, in general the chillies are the smaller-sized, more pungent types, while the somewhat larger, mildly to moderately pungent types are capsicums. The pungency is due to the active principle `capsicin' contained in the skin and the septa of the fruit. Chillies are valued principally for their high pungency and for their colour. Chilly forms an indispensable culinary spice in several parts of the world.

The chilly crop is grown from almost the sea-level up to an altitude of 1,500 -2100 meters in Tropical and subtropical regions, with an annual rainfall of 60-150 cm.

The chilly spice has innumerable uses for commercial, nutritional as well as medicinal. It is used for preparation of oleoresin that has great export potential and demand in the world market. Chillies are excellent source of vitamin, A, B, C and E with minerals like molybdenum, manganese, folate, potassium,thiamin and copper. In addition, medically used as pain killer, antibiotic as well as included in Ayurvedic medicines. The medicinal properties in chillies help to combat various disease like cancer, heart attack and Lung diseases.

India is the world's largest producer, consumer and exporter of chillies in the world. India also has the largest area under chillies in the world. Chillies are the most common spice cultivated in India. It is grown nearly in all parts of the country, hills and plains. Chilly production is spread throughout the length and breadth of the country, with almost all the states producing this crop. It can also be grown during the entire year at one or the other part of the country. However, the major arrival season extends from February to April. The crop planting starts from August and extends till October. While, the harvesting begins from December with 5 per cent of the arrivals usually reported in this month. The peak arrivals are reported in February to March. The market remains active till May. The major producers are Andhra Pradesh, Karnataka, MP, Orissa, Maharashtra and Tamil Nadu. Andhra Pradesh alone commands around 53.27 per cent of the chilly production in India. The major chilly growing districts of Andhra Pradesh are Guntur, Warangal, Khammam, Krishna and Prakasham. Chilly has well established spot markets. Guntur, Warangal, Khammam in Andhra Pradesh; Raichur, Bellary in Karnataka are the major spot markets at the production centers.

The varieties under cultivation differ in the size, shape, colour and pungency of the fruits. The fruits may be thin and long large and thick, short and bell-shaped, small and round. The unripe fruits may be green, creamy, yellow or orange. Similarly, the ripe fruits may be of different shades of red. The variety with bell-shaped fruits is the least pungent and is cooked as an ordinary vegetable. *Capsicum annum* and *G. frutescens* are the two principle species grown in India and the varieties of the former constitute the chief source of the dry chilly of commercial use. The world and India as a nation boasts of a bewildering variety of chillies. The major varieties of India are Birds Eye Chilly (Dhani), Byadagi (Kaddi), Ellachipur (Sannam S4 Type), Guntur Sannam S4 Type, Hindur S7, Jwala, Kanthari White, Kashmir Chilly etc. Sannam S 4 variety is most popular variety, with its annual production estimated to be around 3 lakh tons a year (www.reliancemoney.com.cmt/upload/research/PN_chilliespdf).

The preservation of surplus crops and food stuff can be regarded as the first and important technique of food processing. Among them, one of the most commonly used methods is drying. Drying is one of the important unit operations in the primary processing of agricultural produce. The basic objective of drying is to remove water from products to a level at which microbial activity is suppressed. Drying is the thermo-physical and physico-chemical operation by which the excess moisture from a product is removed making the product suitable for safe storage. In order to increase the shelf- life of product, its moisture content has to be reduced by drying to its equilibrium moisture content. Chilly is a highly perishable produce when it is harvested in a ripe condition Therefore, the produce is to be dried in such a way that it retains its physical characteristics with red colour and luster. Delay in drying results in the growth of micro flora and subsequent loss of quality leading to total spoilage. Sun drying is the most widely practiced agricultural drying operation in the world. The term sun drying is used to denote the spreading of the commodity in the sun on a suitable surface, hanging it from eaves of building and trees or as in the case of cereal crops, drying on the stalk by standing in stooks or bundles. The direct exposure to sunlight, or more precisely ultra violet radiation can greatly reduced the level of nutrients such as vitamins in the dried product. Ever increasing labour costs, improving quality standards and sometimes on uncertain climates lead to construction of artificial dryers. These dryers are capable of artificial drying. These dryers are capable of providing a high quality product independent of the weather and with a low labour requirement. They are not however, intrinsically suitable for the small scale farmer or the majority of agro industries in developing countries.

Solar drying differs from sun drying. Solar tunnel dryer structure often of very simple construction is used to enhance the effect of the insolation compared to sun drying. Solar drying can generate higher air temperature and consequential lower relative humidity, which are both conducive to improved drying rate and lower final moisture content of drying crops. Solar drying has several advantages such as less spoilage and less microbiological infection, thus leads to improve product quality. Solar tunnel dryers have been used to dry fruit, vegetables, root crops, medicinal plants and fish.

Various types of dryer or drying methods are available including solar, hot air, fluidized bed, heat pump, freeze and superheated steam. Reduction of moisture content soon after harvesting in crops through dehydration can improve the storage life of produce. Most of products are dried in a traditional way using sun drying this is profitable activity, but it has some problem due to rain damage, insect, dust and dirt contamination. This also results in deterioration in quality of produce but also affects appearance nutrient quality and shelf life adversely. Therefore there is a need for a system to dehydrate fruit vegetables under hygienic condition so as to extent their availability. Further, there is acute crisis of electric power and other forms of fuel like wood, kerosene oil and coal in Maharashtra.

Traditionally, the chilly is dried under sun in major production areas of the world but the major problem encountered in the sun drying is that the chilly remains at intermediate moisture levels for longer periods resulting browning of the product besides the product being amenable to dirt, dust and microbial infection. Solar dryers have higher drying efficiency. Solar drying of chilly is the most feasible drying method because chilly is very sensitive to temperature hence selecting the right drying technology can be the key to a successful operation.

Keeping in view these facts a study entitled "Design, Fabrication and Performance Evaluation of Solar Tunnel Dryer" is undertaken with following objectives.

1 To design solar tunnel dryer for Marathwada region.
2 To evaluate the performance of Solar tunnel dryer.
3 To compare drying rate of chilly with respect to solar tunnel dryer and open air sun drying.
4 To estimate the cost of solar tunnel dryer.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the literature related to solar drying methods, different type of dryers, dryer performance etc. The reviews given below are collected from selected set of scientific literature.

2.1 Solar tunnel dryer for chilly drying

Janjai *et al.* (1994) studied the fourteen Silpakorn type solar tunnel dryers installed at the Royal Project sites in northern Thailand. The dryers were used to dry various agricultural products in the Project. The performance of one of these dryers was investigated under the field condition. The dryer was used to dry 70 kg of chillies. Various sensors were installed to monitor parameters affecting the performance of the dryer. The chillies could be dried in 3 days with this dryer, compared to 5 days needed for the natural sun drying. In addition, these chillies being dried in the dryer were completely protected from rain and insects and dried chillies were of high quality.

Senadeera and Kaulgalage (1998) constructed a solar tunnel dryer at the Department of Mechanical Engineering of University of Maratuwa and dryer performance was evaluated with two chimneys. GI sheet and wooden frame covered with polyethylene Evaluation parameters are collection efficiency, system drying efficiency and pick up efficiency. Chillies were used as drying material. It was found that the second chimney gives better performance. This dryer is suitable to dry small quantities of material (up to 15 kg) at household or farm level. Chimney with wooden frame and polyethylene cover recorded higher efficiencies. Solar drying achieves higher drying rate compared with sun drying cost of drying is comparatively less.

Gauhar *et al.* (1999) Studied the solar tunnel dryer for chilly drying. They found that the no load tests clearly indicate that the drying temperature fluctuations could be minimized to a considerable extent by using DC/PV operated fan instead of AC operated fans. The drying time could be reduced by one third for chilly, with PV operated fans, for the same level of final moisture content and without affecting any considerable change in the quality of dried product. Furthermore, the air leaving the dryer was found to have still greater potential for drying more chillies. However, this should also be considered for other products, as this dryer is designed for multi product use.

Gauhar *et al.* (1999) designed and fabricated solar-biomass hybrid tunnel dryer. A biomass stove-heat exchanger chimney using briquetted rice husk as fuel complements the solar tunnel dryer and thus extends the working time of the dryer. Experiments were conducted to test the performance of the dryer, and chilly and mushroom were dried. During the load test conducted for chilly, 19.5 kg of ripe, fresh chilly, with an initial m. c. of 76 per cent (w.b.) was dried to a final m.c. of 6.6 per cent (w.b.) within 12 h. Similarly, the moisture content of 21 kg of fresh harvested mushroom was reduced from 91.4 per cent to 9.8 per cent during 12 h of drying. The result indicate that for both the products, drying was faster, and was within 12 h in normal sunny weather, against 2-3 days in 'solar-only' operation of a tunnel dryer and 3-5 days in open sun drying.

Hossain *et al.* (2005) designed an optimized solar tunnel for drying of chilly in Bangladesh. The simulation model was combined with the economic model of the solar tunnel dryer and adaptive pattern search was used to find the optimum dimensions of the collector and the drying unit. Two optimum designs are obtained.For design-1, both collector and drying unit are 14.0 m long and 1.9 m wide and for design-2, both collector and drying unit are 13.0 m long and 2.0 m wide. Both the collector and drying unit of basic mode dryer are 10.0 m long and 1.8 m wide. The capacity of optimum mode dryers is higher than the basic mode dryer and achieves a cost saving of 15.9 per cent. The payback period of the basic mode dryer is 4 years and optimum mode dryer is about 3 years. Sensitivity analysis showed that the design geometry is sensitive to costs of major construction materials of the collector and air temperature in the dryer. The main feature of the optimum design is a relatively long collector. There is no significant difference of efficiency between the basic mode and optimum mode dryers.

Hossain *et al.* (2007) used a mixed mode type forced convection solar tunnel dryer to dry hot red and green chillies under the tropical weather conditions of Bangladesh. The dryer consisted of transparent plastic covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using two fans operated by a photovoltaic module. The dryer had a loading capacity of 80 kg of fresh chillies. Moisture content of red chilly was reduced from 2.85 to 0.05 kg kg^{-1} (db) in 20 h in solar tunnel dryer and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg kg^{-1} (db) in improved and conventional sun drying methods, respectively. In case of green chilly, about 0.06 kg kg^{-1} (db) moisture content was obtained from an initial moisture content of 7.6 kg kg^{-1} (db) in 22 h in solar tunnel dryer and 35 h to reach the moisture content to 0.10 and 0.70 kg kg^{-1} (db) in improved and conventional sun drying methods, respectively.

Sharma (2009) carried out a thematic study in two selected villages. Todaijang and Nongba of Tamenglong district of Manipur and three selected villages Neotan, Neirong and Jatinkaike of Changlang district in Arunachal Pradesh by AFPRO Guwahati to promote the use of solar dryers among rural population which in turn would contribute to beneficial changes in women's lives in agricultural practices and in conservation of biomass. Different types of solar dryers-tunnel type and chimney type were installed in selected villages. Solar dryer for food products have been installed for the first time in these areas. SHG members used the dryers for drying various spices, fruits and vegetables such as turmeric long melon, tapioca, radish, banana, papaya, pineapple, maize, cooked rice, green leafy vegetables, cabbage, paddy and even meat apart from ginger and chillies. As King Chillies production is very high in Manipur and there is a very high demand of it, women groups of Manipur utilized the dryer for drying king chillies. Previously the villagers used to dry the chillies above the firewood but gradually they have changed their tradition after installation of solar dryers and it saved time and energy.

2.2 Solar tunnel dryer for agricultural products

Lutz *et al.* (1987) developed a multipurpose solar crop dryer for drying various agricultural products such as fruits, vegetables, medicinal plants etc. The newly developed system consists of a small fan, a solar air heater and a tunnel dryer. The simple design allows production either by farmers themselves, using cheap and locally available materials, or by small scale industries. Due to the low investment required, the solar dryer is predestined for application on small farms in developing countries. Depending on the crop to be dried and the size of the dryer 100 to1000 kg of fresh material can be dried within 1-7 days to safe storage conditions. The solar dryer was successfully tested in Greece, Yugoslavia, Egypt, Ethiopia and Saudi Arabia drying, grapes, dates, onions, peppers and several medicinal plants. Compared to traditional sun drying methods, the use of the solar dryer reduces drying time significantly and prevents mass losses. Furthermore, product quality can be improved essentially.

Amir *et al.* (1991) developed a multi-purpose solar tunnel dryer, for the use in arid zones, was modified to enable operation under tropical weather conditions. This type of dryer consists of a small centrifugal blower, a collector and a tunnel drying chamber. To prevent penetration of water into the construction and subsequent flooding, the solar dryer was installed on a wooden substructure. To heat the drying air during cloudy and rainy days, particularly in the rainy season, a biomass furnace with heat exchanger was integrated into the solar drying system. The construction consists exclusively of materials available in Java. Only low energy requirements are necessary to run the blower. Results showed that compared to natural sun drying, the drying time of cocoa, coffee and coconut could be reduced up to 40 per cent. The performance of the collector for heating the drying air was satisfactory. It could raise the ambient temperature from around 30 to 70°C at peak conditions. This is an adequate temperature for drying most agricultural products.

Tawon *et al.* (1996) studied the performance of the triangle solar tunnel dryer for drying of silkworm chrysalis under Mahasarakham conditions. The dryer consists of a transparent glass covered flat plate collector and a drying tunnel greenhouse, connected in a series to supply hot air directly into the drying tunnel greenhouse using a blower. This dryer has a loading capacity of 28 kg of silkworm chrysalis. The effect of the air rate through the dryer was examined. During the experiments silkworm chrysalises were dried to the final moisture content of 20 from 370 per cent d.b. In all the cases the use of the solar dryer leads to considerable reduction of drying time in comparison to sun drying, sample dried in the solar tunnel dryer were completely protected from insects, rain and dust and the dried samples were of high quality in terms from of colour and hygienic. This system can be used for drying various agricultural products.

Fuller and Charters (1997) built and tested a solar tunnel dryer in the Sunraysia district of Northern Victoria, Australia. A novel feature of the dryer is the microprocessor system used to control the exhaust fan. A tray containing a small sample of the crop is suspended from a load cell, and the output from this is used to continuously calculate the current moisture content of the crop. Using this estimation and inputs from sensors measuring the relative humidity of the air inside and outside the dryer, an appropriate decision is made on whether to activate the exhaust fan or not. The dryer was used to dry two loads of untreated grapes in the summer of 1992. Drying time was reduced by approximately 40 per cent compared to sun drying in both trials. Using a two stage control algorithm, fan operating time was reduced by 67 per cent compared to continuous fan operation and by 34 per cent if a light sensitive switch had been used to control the fan. Reduced fan operation also maximised the air temperatures achieved.

Garg and Kumar (2000) presented the modelling and thermal performance results of the collector of a semi-cylindrical solar tunnel dryer (STD). The performance has been estimated under natural circulation as well as under forced circulation mode. The volume low rate and the rise in the inlet air temperature have been optimized for natural circulation mode with respect to the design parameters, viz., length and radius of the collector. The performance of the collector has also been calculated for different tilt of the STD. All calculations have been made for Delhi climate ($25^0 58'$N Latitude). The development of the natural circulation type STD is very significant because it has certain advantages over the existing forced circulation type STD.

Condori and Saravia (2003) presented an analytical study describing the performance of a tunnel greenhouse dryer. Considering the greenhouse as a solar collector, a linear function between the incident solar radiation and the greenhouse output temperature is obtained. Using the dryer characteristic function, the dryer performance is evaluated as a function of the drying potentials. The results show that an almost constant production is obtained each day. The generalized drying curve concept is applied to the first tunnel cart, obtaining a result that is similar to the single chamber dryer case. The simulation tests with red sweet pepper show an improvement of 160 per cent in the production, compared with the single chamber dryer case, and an improvement around 40 per cent, if the double chamber dryer is considered.

Bala *et al.* (2003) conducted field level experiments on solar drying of pineapple using solar tunnel dryer at Bangladesh Agricultural University, Mymensingh, Bangladesh. The dryer consists of a transparent plastic covered flat plate collector and a drying tunnel connected in a series to supply hot air directly into the drying tunnel using two dc fans operated by a solar module. This dryer has a loading capacity of 120–150 kg of pineapple and a total of eight drying runs were conducted. In all the cases the use of the solar tunnel dryer leads to considerable reduction of drying time in comparison to sun drying. The pineapple being dried in the solar tunnel dryer were completely protected from rain, insects and dust, and the quality of the pineapple dried in the tunnel dryer was of quality dried products as compared to sun dried products.

Flores-Irigollen *et al.* (2004) describes a mathematical model that the dynamics of the heat transfer in an in flat table tunnel solar collector for air heating is proposed and validated. The model is distributed parameters, one-dimensional and unsteady-state. It considers the thermal inertia of a pebble bed acting as the absorber surface and is constituted by three equations that describe the temperature distributions of the three system components: polyethylene cover, transfer fluid (air) and absorber surface. To solve the governing equations, a novel numerical scheme that differs from the standard method of finite differences in the form of generating the discretization equations is proposed. In this scheme, the dimensionless versions of the equations are reduced to linear canonical forms of first order and then are solved analytically in small spatial domains to produce discretization equations in an explicit form. To validate the quality of the present model, some experimental tests in a 50 m long inflatable-tunnel solar collector were carried out.

Janjai *et al.* (2004) presented a simulation model of a PV-ventilated system for a solar tunnel dryer. Mathematical models of PV module and DC fan were formulated. Based on these models, computer programs were developed and used to simulate the performance of the system. The field data from the experiments were used as input for the program. It was found that the air flow rate calculated from the model agreed with those obtained from the measurement. These models can be used to predict the performance of the PV-ventilated system for different weather conditions. A simulation program of the PV-ventilated system has been developed. The program is based on the equations of I-V characteristic curves of PV module and DC fan. The mass air flow rate calculated from the program agreed well with that obtained from the measurement. The simulation program can be used to predict the performance of the system for different weather conditions.

Fadhela *et al.* (2005) analyzed the drying of the Sultanine grape variety by three different solar processes. Three drying kinetics have been established respectively in a natural convection solar dryer, under a tunnel greenhouse and in open sun. These tests show that the solar tunnel greenhouse drying is satisfactory and competitive to a natural convection solar drying process.

Elicin and Sacilik (2005) studied the solar tunnel dryer, the thin layer solar drying experiments of apple were carried out the under the conditions of Ankara. Turkey. During the experiments apples were dried to the final moisture content of 11 from 82 per cent w.b. in 1.5 days of drying in the solar tunnel dryer as compared to 2 days of drying in the open sun drying. The experimental drying data of apple slices obtained were used to fit the page, logarithmic and wang and singh models. The constants of drying models tested were determined by non linear regression analysis. Among the various model tested to represent the solar tunnel drying behaviour of organic apple one was selected which presented best statistical indicators, sample dried in the solar tunnel dryer were completely protected from insect, rain and dusts and the dried samples were of high quality in term of colour and hygienic. Since this system is simple in construction and can be constructed at a low cost with locally obtainable materials. It has been successfully used for drying various agricultural products such as vegetables and fruits by growers of Ankara.

Dipl and Achtari (2006) studied the propagation of different solar dryer, in Afghanistan. Like the first solar dryer it uses direct solar radiation. To create hot air in the collector part of the equipment with this design a PV-driven fan provides the necessary air flow over the fruit. It was tested drying apricots. Handling of the dryer is very similar to the traditional methods, as the fruit is simply spread on a flat surface. In this dryer 7 kg of apricots are dried within 3 to 4 days. This is very similar to when the fruit is spread in open air. But quality is much better through a more hygienic drying process: the fruit is protected against dirt dust and animals. They decided to start with small dryers of 2 m x 1 m. This way the device can easily be carried and placed on roof tops.

Sacilik and Keskin (2006) conducted the thin layer solar drying experiments of organic tomato using solar tunnel dryer under the ecological conditions of Ankara, Turkey. During the experiments, organic tomatoes were dried to the final moisture content of 11.50 from 93.35 per cent w.b. in four days of drying in the solar tunnel dryer as compared to five days of drying in the open sun drying. Experimental drying curves showed only a falling drying rate period. A non-linear regression procedure was used to fit 10 different thin layer mathematical models available in literature to the experimental drying curves. The models were compared using the coefficient of determination, mean relative per cent error, root mean square error and the reduced chi-square. The approximation of diffusion model has shown a better fit to the experimental drying data as compared to other models. The effect of the drying temperature and relative humidity on the drying model constant and coefficients were also determined.

Rathore *et al.* (2006) studied the solar drying of amla *(Emblica officinalis)* is becoming popular among the farmers and its area under cultivation is increasing. However, farmers are not getting adequate returns. Keeping this in view, a new approach for its drying through solar energy at economical cost has been developed. This approach includes installation of an amla shreder unit for removing stone from the fruit and a solar tunnel dryer for drying one ton of amla in a batch. This paper deals with design specifications and performance evaluation including cost economics of devices used for amla drying.

Sacilik (2007) performed an experimental study to determine the drying characteristics of hull-less seed pumpkin using hot air, solar tunnel and open sun drying methods. For the hot air drying, the test samples were dried in a laboratory scale hot air dryer at a constant air velocity of 0.8 m/s and air temperature in the range of 40–60^{0}C. For solar drying experiments, a solar tunnel dryer was constructed at a low cost with locally obtainable materials. The moisture transfer from the test samples was described by applying the Fick's diffusion model and the effective diffusivity was calculated. Temperature dependence of the effective diffusivity was described by the Arrhenius-type relationship. The experimental drying data of hull-less seed pumpkin were used to fit the Page, Henderson and Pabis, logarithmic and two-term models, and drying rate constants and coefficients of models tested were determined by non-linear regression analysis. Among the various models tested to interpret the drying behaviour of hull-less seed pumpkin, one was selected which presented best statistical indicators.

Sevda *et al.* (2007) studied a walk in type semi cylindrical poly house for drying di-basic calcium phosphate for 1.5 tons capacity per batch commissioned at the M/S Phosphate India Pvt. Ltd., Udaipur. The performance of the dryer during drying di- basic calcium phosphate has been analyzed through no load and full load test. In all air temperature in the solar tunnel dryer was higher than outside by 15-20^{0}C during sunshine h and the moisture content of approximately 1.5 tons of wet di-basic calcium phosphate loaded in the dryer in one batch was reduced form an initial value of 38-40 per cent to around 10-20 per cent in 18 h or 16 h depending upon solar insolation.

Goyal *et al.* (2007) drying kinetics of plum (control, blanching and blanching in 1 per cent KMS solution as pretreatments) in a tunnel dryer was studied at 55, 60 and 65 °C air temperatures. Drying of plum slices occurred in falling rate period. It was found that treated plum slices dried faster. Six thin layer drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of plum slices with high r^2 values. The effective moisture diffusivity (D_{eff}) of plum increased as the drying air temperature increased. The D_{eff} values were higher for treated samples than the control.

Tawon *et al.* (2008) conducted thin layer solar drying experiments of silkworm pupae using a solar tunnel dryer under the tropical weather conditions of Mahasarakham, Thailand. The dryer consisted of a transparent glass covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using a blower. During the experiments, silkworm pupae were dried to the final moisture content of 0.15 kg water kg^{-1} dry matter from 4.37 kg water kg^{-1} dry matter in 373 min at the corresponding air flow rate of 0.32 kg s^{-1}. Ten different thin layer drying models were compared according to their coefficient of determination to estimate drying curves.

Jose and Joy. (2009) stated that turmeric is one of the most ancient medicinal spices of the world. As its homeland, India acts as the largest producer, exporter and consumer of turmeric. The value of turmeric is due to its color and flavor, which is being given by curcumin, volatile oil and oleoresin. The end quality of turmeric is very much dependent on its post-harvest methods. Traditionally, open sun drying is the chief method adopted for processing. In the present investigation, freshly harvested turmeric rhizomes were collected from 30 stations and drying experiments were conducted by adopting three methods: (1) solar tunnel drying; (2) conventional drying; and (3) commercial drying. Various pre drying and post-drying treatments were conducted. The results proved that conventional processing could maintain the intrinsic quality up to a certain level, but extrinsic quality could not be achieved. Solar tunnel drying method is an effective alternative to traditional open sun drying, where retention of curcumin, volatile oil and oleoresin was high, with less drying time. The study also disclosed the importance of pre-drying and post-drying treatments and hygienic practices to be adopted during processing.

Janjai *et al.* (2009) presented experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. The dryer consists of a parabolic roof structure covered with polycarbonate plates on a concrete floor. Three fans powered by a 50-W PV module ventilate the dryer. To investigate the experimental performances of the solar greenhouse dryer for drying of peeled longan and banana, 10 full scale experimental runs were conducted. Of which five experimental runs were conducted for drying of peeled longan and another five experimental runs were conducted for drying of banana. The drying air temperature varied from 31°C to 58°C during drying of peeled longan while it varied from 30°C to 60°C during drying of banana. The drying time of peeled longan in the solar greenhouse dryer was 3 days, whereas 5–6 days are required for natural sun drying under similar conditions. The drying time of banana in the solar greenhouse dryer was 4 days, while it took 5–6 days for natural sun drying under similar conditions. The quality of solar dried products in terms of colour and taste was high-quality dried products.

Sethi and Arora (2009) improved a conventional greenhouse solar dryer of 6 m^2 x 4 m^2 floor area (east–west orientation) for faster drying using inclined north wall reflection (INWR) under natural as well as forced convection mode. To increase the solar radiation availability onto the product (to be dried) during extreme summer months, a temporary inclined wall covered with aluminized reflector sheet (of 50 μ thickness and reflectance 0.93) was raised inside the greenhouse just in front of the vertical transparent north wall. By doing so, product fully received the reflected beam radiation (which otherwise leaves through the north wall) in addition to the direct total solar radiation available on the horizontal surface during different h of drying. The increment in total solar radiation input enhanced the drying rate of the product by increasing the inside air and crop temperature of the dryer. Experimental performance of the improved dryer was tested during the month of May 2008 at Ludhiana (30°56'N) climatic conditions, India by drying bitter gourd (Momordica charantia Linn) slices. Results showed that by using INWR under natural convection mode of drying, greenhouse air and crop temperature increased by 1 to 6.7°C and 1 to 4°C, respectively, during different drying h as compared to, when INWR was not used and saved 13.13 per cent of the total drying time. By using INWR under forced conviction mode of drying, greenhouse air and crop temperature increased by 1–4.5°C and 1–3°C, respectively, during different drying h as compared to, when INWR was not used and saved 16.67 per cent of the total drying time.

Kulanthaisami *et al.* (2009) tested MPUAT design solar tunnel dryer for drying of coconut kernels. In order to solve the problem of hygiene and to effect faster drying rate, the MPUAT design solar tunnel dryer was installed at M/s Supa Farms, Chinniyampalayam, Coimbatore, Tamil Nadu. Solar tunnel dryer was semi cylindrical tunnel shaped structure covered with UV stabilized polyethylene sheet. The floor area (18.0 x 3.75 m) of the tunnel dryer was black coated to attain the maximum drying efficiency. The results showed that the temperature inside the solar tunnel dryer gets boosted up by 15-20°C more than the ambient.The solar tunnel dryer could be used for drying of agro industrial produces like coconut kernels, chilly and sago.

Shahi *et al.* (2009) developed solar poly tunnel dryer (SPTD) for fruit and vegetables consisted of drying chamber, drying tray and two chimneys. The relative humidity (RH) inside the SPTD varied between18 and 74 per cent as compared to outside RH, which ranged from 52 to 73 per cent. This resulted in efficient drying leading to lower RH. Thermal performance test for SPTD under full load no load testing condition were calculated and temperature inside the dryer was 80 and 74 per cent higher than ambient conditions respectively. SPTD was helpful in decreasing the time taken for dehydration by 50-70 per cent. The capacity of the SPTD dryer was 4-6 kg/batch and its total cost was Rs 300.

Gurlek *et al.* (2009) conducted the experiment on solar drying of tomato in Izmir, Turkey. For this purpose, new type tunnel solar dryer was designed and manufactured. Solar dryer consist of an air collector, drying chamber and air circulation system. Heated air in solar air collector was forced through the tomatoes by a blower. Rio grande type tomato was used for drying experiments. During the drying period drying air temperature by relative humidity, air flow rates, solar radiation and lose of mass were measured continuously in different part of the dryer. Drying time was examined with mass ratio as exponential and polyminal correlations twelve different mathematical models available in literature were compared using their co-efficient of determination of estimate solar drying curves. According to statistical analysis result, the two term drying model has shown a better fit to the experimental drying. The moisture content was reduced in four day. All drying processes occurred in the falling rate period. In addition the tomato samples of solar tunnel dryer were completely protected from birds, insect's rains dust.

Triebe (2009) observed that solar tunnel dryers are ideally suitable to preserve fruit which would otherwise perish by producing fruit leathers and fruit juice concentrates. These two products can conveniently be stored and transported as needed. Fruit leather has got a very popular market and can be profitably sold. Fruit leather also can be transformed further into a more valuable product by using chocolate or yoghurt coating there is a great unexplored market to be developed and it is proven that this can be developed in expensive and economically viable.

Bala (2009) conducted solar drying of Mushroom to investigate the performance of the solar tunnel dryer. The dryer consists of a transparent UV stabilized plastic covered flat plate collector and drying tunnel unit. The dryer is arranged to supply hot air directly into the drying tunnel using three dc fans powered by a 40 watt solar module. The products to be dried are placed in a single layer on a wire mesh in the drying tunnel to receive energy from both hot air supplied the collector and from the incident solar radiation on products. During the experimental period the minimum and maximum solar radiation were 273 W/m^2 and 885 W/m^2 respectively. The generated voltages for the 40 W solar modules were 4.5 V to 14.8 V. Temperatures in the drying chamber varied from

37 ^{0}C to 66.5^{0}C. Mushrooms were dried from about 89.41 per cent to 6.14 per cent moisture content (w.b.) in about 8 h. In the same drying period, the moisture content of mushrooms reduced from 89.41 per cent to 15 per cent in the traditional sun drying method.

Reza *et al.* (2009) conducted studies to optimize fish-drying process in a Hohenheim-type solar tunnel dryer to produce safe and high quality dried fish products. Five commercially important tropical marine fish species in the Bay of Bengal such as silver jew fish, Bombay duck, big-eye tuna, Chinese pomfret and ribbon fish were used and drying was performed at 45 to 50 and 50 to 55^{0}C temperature ranges. Moisture content of the fish samples reached 16 per cent after 36 and 32 h of drying at temperature ranges of 45 to 50 and 50 to 55^{0}C, respectively. Products produced at 45 to 50^{0}C were found to be excellent on the basis of flavor, color and texture. Their rehydration ability ranged from 65 to 80 per cent with minimum in big-eye tuna and maximum in silver jew fish. Values of total volatile base, peroxide and aerobic plate count of all the final dried products were within the acceptable limit.

2.3 Drying characteristics of chilly.

Heredia-Leon *et al.* (2003) studied the effect of low-temperature blanching and drying processes on the ultra structural and physical properties of Anaheim chilly pepper and optimum conditions to provide a final product with maximum firmness were determined. Lots of Anaheim pepper were blanched in water for 4 min at 48, 55, 65, 75 and 82^{0}C and maintained for hold times of 35, 45, 60, 75 and 85 min, blanched again for 4 min at 96^{0}C and dehydrated at 53, 60, 70, 80 and 87^{0}C. After treatment the samples were rehydrated in water at 30^{0}C. Rehydration ratio, texture and structural changes were evaluated. Optimization used a second-order rotatable central composite design. Texture and rehydration ratio were affected by blanching temperature and the interaction of blanching temperature with hold time ($p \leq 0.05$); drying temperature did not show a significant effect. The best results, i.e. those which gave greatest firmness, were obtained by blanching at 64^{0}C for 4 min, holding for 55 min after blanching, followed by a second blanching at 96^{0}C for 4 min and then drying at 70^{0}C.

Kaleemullah and Kailappan (2004) studied the effect of moisture content of chillies, on thermal conductivity, thermal diffusivity and specific heat in the moisture range of 329.44 to10.24 per cent (d.b.) The thermal conductivity and specific heat of chillies decreased linearly from 0.4900 to 0.0878 W/m K and 4172.02 to 1768.50 J/kg K, respectively whereas the thermal diffusivity increased from 3.1693 x 10^{-7} to 5.5136 x 10^{-7} m^2/s as the moisture content decreased from 329.44 to 10.24 per cent (d.b.) at 25^0C.

Arora and Bharti. (2005) conducted the mechanical drying of 'Punjab Lal', 'Punjab Surkh', 'Punjab Guchhedar', 'CH-1 Hybrid chilly' varieties at 45, 50, 55, 60 and 65^0C. One lot of chillies was pricked manually and the other was kept unpricked both the lots were given chemical treatment. After drying to a moisture content of 8 per cent (d.b.), the chillies were tested for capsaicin content, colouring matter and germination rate. The variety Punjab Lal in pricked form was found to be of the best quality when dried at 55^0C.

Oberoi *et al.* (2005) conducted the experiment on freshly harvested red chilly *(Capsicum annum L.)* of variety CH-3 and subjected to conventional sun drying (CSD) and drying in the batch-type dryer (BTD) using indirect hot air. A comparative study was conducted to evaluate 2 chilly drying methods with respect to temperature and time combination, quality parameters including the physico-chemical and microbial attributes. It look 25 h to bring down the moisture content of chillies from 361 to 10.1 per cent (db) in the BTD as against 10 days by the traditional sun drying technique for bringing down the moisture content to 9.9 per cent (db). The colour retention was significantly better in the chillies dried using BTD as compared to CSD. There was no difference in the oleoresin content but capsaicin content was lower in chillies dried under hot sun. There was nearly a 2 log (efu/g) reduction in total bacterial count in dryer dried chillies as compared to sun dried ones but no difference in the Lactobacilli colonies could be observed. A market reduction in yeast and fungal colonies in dryer dried samples as compared to sun dried samples could be seen. Escherichia coli and Salmonella were not observed in dried chilly samples using either of the drying methods. The results indicate that chilly dried in a BTD is better with regard to physico-chemical characteristics and relatively safe with respect to microbiology quality.

Kaleemullah and Kailappan (2006) studied the drying characteristics of red chilly in different layers of deep bed dryer (DBD) at 55^0C. It took 20, 21 and 23 h to dry chilly in bottom, middle and top layers (5 cm thick each) of DBD, respectively from its initial moisture content of around 310 per cent d.b. to the final moisture content of around 10.5 per cent d.b. at 55^0C of drying air temperature. The average capsaicin content and red colour value of dried chilly increased from 0.47 to 0.57 per cent and 18.7 to 23.3, respectively as the drying front of chilly moved from bottom to top layer of DBD. The Kaleemullah and page models can be used to predict the moisture ratio of chilly at different layers of DBD. The effective moisture diffusivity (D_{eff}) of chilly decreased from 1.8286×10^{-5} to 1.5231×10^{-5} m^2/h as the drying front moved from bottom to top layer.

Mehata and Amarjit (2006) determined the adsorption equilibrium moisture contents for red chilly. Experimentally in relative humidity range of 11–97 per cent at the temperatures of 20, 30, 40, and 50^0C. Six equilibrium moisture content models were fitted to the experimental data. The modified Oswin model was the best fitted equation for relative humidity range of 11–97 per cent for the adsorption data of red chilly.

Hossain *et al.* (2007) conducted Single-layer drying experiments under controlled conditions of temperature, relative humidity (RH) and air velocity to find out the effects of drying conditions and blanching on the drying rate and colour of Thai red chilly. Drying rate increased with an increase of drying air temperature and a decrease of RH. Air temperatures above 65^0C affected the colour of red chilly. Red chilly should be dried at an air velocity equal to or just above 0.50 m s^{-1}. Above this value, the drying rate becomes independent of air velocity. RH and air velocity have no effect on the colour of red chilly faster drying rate and higher colour value was found for the blanched sample rather than the un blanched sample. The Newton and the Page equations were fitted to the experimental data. The Newton equation was found to describe the single-layer drying of red chilly better than the Page equation. The drying rate increased with an increase of drying air temperature. Air temperatures above 65^{0}C affected the colour of red chilly. Hence, the temperature of 65^{0}C was found to be the maximum allowable drying air temperature for red chilly. Drying rate decreased with an increase of RH.

Hunje *et al.* (2007) studied the influence of different drying methods on seed quality of two varieties of chilly Byadagi kaddi and Dyavanur local in the Dept. of Seed Science & Technology, College of Agriculture, Dharwad. Chilly fruits dried by mechanical drying at air temperature of 35^{0}C recorded higher germination (90.37 per cent), root length (8.76 cm), shoot length (7.85 cm), seedling dry weight (197mg), vigor index (1494) and lower electrical conductivity (1.26 dSm^{-1}) thus indicating better seed quality. Red ripe fruits dried under sun also recorded better seed quality parameters, but lower seed quality parameters were recorded in shade drying. Between the varieties Byadagi kaddi variety recorded better seed quality parameters during drying over Dyavanur local chilly.

Pandey *et al.* (2008) studied the twenty one genotypes of chilly *(Capsicum annum L.)* for capsaicin, oleoresin, extractable colour and colour value during 2002-03 and 2004-05 to identify genotypes with less capsaicin and high colour content. Significant differences ($p<0.05$) were recorded within the genotypes during both the seasons for the quality parameters. The capsaicin content during 2 seasons ranged from 0.18 to 2.01 per cent. The oleoresin content varied from 9.0 to 21.8 per cent. The extractable colour ranged from 53.3 to 346.0 ASTA and the colour value ranged from 20790 to 139590 c. u. The genotype PBC-535 was identified with less pungency and high colour content. Multivariate cluster analysis based on Ward's method showed that the genotypes were mainly divided at the first node into 2 clusters with 12 and 9 genotypes, which were further sub divided into 2 groups.

Wiriya *et al.* (2009) studied the quality of dried chilly *(Capsicum annum)* in terms of color attributes and nutrients using a lab-scale tray dryer in order to reduce the quality loss caused by sun drying. Different drying temperatures from 50-70^{0}C, and a two-stage temperature regime (70^{0}C and 50^{0}C) were used to compare with the sun drying method. One-temperature regime provided low values of lightness, chroma and hue angle compared to sun drying. The two stage temperature provided bright-red colored dried chilly. Browning color of dried chilly was observed due to non-enzymatic browning reaction as reducing sugar was decreased. Not only did the maillard reaction provide a dark brown color, but thermal degradation and oxidation of a total phenolic compounds and ascorbic acid also provided an unacceptable colour of dried chilly. A drying temperature of 70^0C and a two stage temperature regime (70^0C for 4 h followed by 50^0C) in conjunction with soaking the chilly in different chemical pretreatments were used to promote the colour and nutrient preserving capacity. It was found that sodium metabisulfite preserved colour stability but not the nutritional compounds chillies were dried at an air temperature of 70^0C. Using sodium metabisulfite combined with calcium chloride provided the best colour attributes when two stage temperatures of 70^0C and 50^0C were used.

Tontand and Therdthai (2009) observed that chilly is a heat sensitive material and conventional hot air drying generally produces poor quality of dried chilly with unattractive colour. To improve the product quality, microwave assisted vacuum drying was studied. Red chilly, *Capsicum annum,* was pretreated by various treatments including blanching at 100^0C (6 min), soaking in 0.5 per cent citric solution (20 min), soaking in 2.0 per cent sodium chloride solution (20 min) with blanching and soaking in 0.5 per cent citric solution (20 min) with blanching. The pretreated samples were dried, using two different microwave powers and times. Results indicated that the chilly pretreated with 0.5 per cent citric acid solution and dried at 160 mm Hg pressure and 1120 W microwave power for 60 min yielded dried chilly containing similar colour to fresh chilly. Increasing the microwave power to 1,600 W and reducing drying time to 40 minutes tended to reduce redness, yellowness and lightness of dried chilly ($P \leq 0.05$). Therefore, pretreatment with citric acid or blanching was required to maintain colour of dried chilly when high microwave power was applied. For rehydration test, increasing microwave power and decreasing drying time could improve the weight gain ratio of dried chilly.

Desai *et al.* (2009) fabricated and evaluated a PAU model farm solar dryer for chilly drying in a selected village of Raichur district during 2006-07. It was observed that on an average 41.5 per cent of higher temperature was obtained in farm solar dryer over the ambient temperature. A total drying time of 30 h (4 - 5 sunny days) was required for chilly drying in farm solar dryer to reduce the m. c. from 76.5 per cent (w.b.) to about 9.0 per cent (w.b.) compared to that of 48 h for open sun drying to obtain the same level of moisture contents resulting in a net saving in drying time of 37.5 per cent for farm solar dryer over open sun drying.

2.4 Solar drying for Agricultural product

Bhattacharya *et al.* (2000) designed and fabricated a natural convection automatically controlled dryer for fruits and vegetables using heated air under a regional research and dissemination programme funded by the Swedish International Development Cooperation Agency (SIDA). The dryer could be operated during normal sunny days as a solar dryer, and during cloudy days as a hybrid solar/biomass energy powered dryer. Drying can also be carried out at night with energy for drying provided by biomass combustion alone. Experiments on loaded condition were conducted with banana and chilly (16 kg each). For operation with biomass energy alone, the drying duration and fuel consumption rates were about 20 h and 2 kg/h respectively for both banana and chilly. The required moisture content of banana and chilly were reached in the biomass-fuelled dryer within 18 and 22 h respectively, while they were required 66 and 48 h respectively for the natural sun drying.

Arnold and Karen. (2001) stated that pineapple is one of the major fruit exports of the Philippines. For most pineapple farmers, its production has always been the major source of livelihood. In Camarines Norte, one of the major pineapple producers, the variety that grows is the Formosa. Small-sized fruits, which are about 10 per cent of the production, are usually discarded and left to rot on the field. The development of the solar-biomass dryer has given the farmers an opportunity to process these surpluses i.e. to market dried pineapple products The solar-biomass dryer can dry a maximum of 50 kilograms of sliced pineapple fruit from a moisture content of 85 per cent w.b. down to 20 per cent w.b. for 18 h.

Sablani *et al.* (2002) dried fresh sardines obtained from local fishermen at Uzaiba using four different solar dryers and by traditional sun drying method. The internal dryer temperatures and mass of fish samples were monitored during drying operation. In addition ambient air temperature was also measured. Solar drying methods produced a better quality dried sardines compared to that of sun drying due to reduced insect infestation. In solar dryers the losses in dried product quantity due to dog, cats, rats and bird are also reduced significantly Drying rates achieved in various solar drying methods were comparable to sun drying. However the quality of dried fish was better in case of solar drying methods due to lower level of contamination from the sand and insects. The multi-rack dryer has a higher potential for commercialization due to large capacity having large surface area per unit land space. The project is continued to improve the design of multi-rack dryers.

Ho-Hsien *et al.* (2005) developed an experimental closed-type dryer associated with a photovoltaic system (PV). The transparent drying cabinet was designed with high transmittance glass to decrease the reflection of direct sunlight and to offer extra direct solar heating on the raw material during drying. Parallel wiring with a local electrical grid was necessary for switching purposes if there is insufficient battery backup during peak operation. Lemon slices were dried using the closed-type solar dryer and results were compared with hot air drying at 60^0C. The results indicate that the dried lemon slices using a closed-type solar dryer has better general levels of quality in terms of sensory parameters.

Karim and Hawlader (2006) reported the results of a performance study on v-groove solar air collector for drying applications. Experimental results indicate better thermal efficiency for a v-corrugated collector compared to a flat plate collector. Effects of operating variables on the thermal performance have been investigated. The results show that the temperature of the fluid at the exit of the collector decreases with flow rate resulting in an increase of efficiency due to decreased thermal losses to the environment. After a certain flow rate, these changes become less significant. Flow rate of 0.035 kg/m^2 s is recommended for most drying purposes in consideration of collector efficiency and outlet temperature Experimental and analytical results show a good thermal performance of a v-groove collector.

Balakrishnan and Banerjee (2006) stated that India is well suited for both solar thermal and solar photovoltaic programmes. The daily average solar energy incidence varies from 4 to7 kWh/m², and in general there are 250 to 300 days of sunshine per year in most parts of the country. Solar dryers can be utilized for at least 250 days a year. Solar drying as an entrepreneurial activity does not require full-time engagement and attention. The solar dryer unit, even if it is used for more than 250 days a year, needs only 1-2 h of labour a day. The unit has proven to be a very good income-generating source for SHGs or individuals who are already engaged in agricultural activities. Practical experiences so far reveal that the dryer should be used to its maximum capacity in order to make the enterprise cost-effective. While one food item is drying in the solar dryer, the entrepreneur needs to be preparing the next product to limit the unused time between drying two batches. In this way, the dryer can be utilised for upwards of 250 days in a year and for six h a day. Calculations, based on this scenario, suggest that that the capital charges, including depreciation, are Rs 5 per hour when the dryer is fully utilized and the initial costs written off over a ten-year period. Investment in a solar dryer provides an ideal source of income generation for poor women by producing value added products.

Gbaha *et al.* (2007) designed a direct type natural convection solar dryer. It was constructed in local materials (wood, blades of glass, metals) then tested experimentally in foodstuffs drying (cassava, bananas, and mango). It was about an experimental approach which consists in analyzing the behavior of the dryer. The study relates mainly kinetics and establishment of drying heat balances. The influence of significant parameters governing heat and mass transfers, such as solar incident radiation, drying air mass flow and effectiveness, was analyzed in order to evaluate its thermal performances. Experimental data can be represented by empirical correlations of the form M(t) ¼ Miexp(kt) for representation of drying process. The resolution of these drying equations makes possible to predict total drying time of each product. Moreover, this drying process allows reducing the moisture content of cassava and sweet banana approximately to 80 per cent in 19 and 22 h, respectively to reach the safety threshold value of 13 per cent. This value permits the conservation of these products about one year without deterioration.

Zomorodian *et al.* (2007) introduced a new approach for employing solar radiation as the main source of energy for paddy drying. The drying test was designed, fabricated and evaluated. The rough rice solar dryer was a cross flow and an active mixed-mode type with a new and an efficient timer assisted semi-continuous discharging system. The rig consists of six ordinary solar air heaters, an auxiliary electric heating channel, a drying chamber with an electrically rotary discharging valve and an air distributing system. The area of each collector was 2 m^2 (totally 12 m^2) and they were installed on a light frame tilted 45° towards the south. The drying system consisted of: an inlet bin, a drying chamber ended with a discharging valve, an outlet bin and a plenum chamber. The maximum overall efficiency of drying system was 21.24 (with average drying air temperature of 55°C) and the fraction of energy consumed by the auxiliary heating channel during the drying process compared with solar energy was only 6–8 per cent.

Khalil *et al.* (2007) constructed a drying system, consisting of three parts (solar collector, solar drying cabinet and air blower). Two identical air solar collectors having V-corrugated absorption plates of two air passes, a single glass cover was used. The total area of the collectors is 2.4 m^2. The dimensions of the drying cabinet are 1 x 0.33 x 2 m (width, depth, and height). The cabinet is divided into six divisions separated by five shelves. The distance between the shelves is 0.3 m except the upper one, which is 0.5 m from the roof. Each shelf is 0.95 x 0.3 m and is made of metallic mesh. The drying chamber walls are made of aluminum plate except the southern side, which was fixed with glass plate having the dimensions 1 x 2 0.002 m. Two types of fruit and one type of vegetables were dried during the present work. These were grapes, apricots, and beans. The moisture content of apricot was reduced from 80 to 13 per cent within one day and a half of drying. Moisture content of grapes was reduced from 80 to 18 per cent in two and a half days of drying, while that of beans was reduced from 65 to 18 per cent in one day only.

Ferreira *et al.* (2007) stated that artificial dryers promote a high-quality food drying, in spite of the considerable energy consumption. Solar dryers use only solar energy to heat the drying airflow; nevertheless, it is not possible to control the airflow thermal conditions. Hybrid solar dryers arise as an interesting option to reduce the drying costs (compared to the artificial dryer's costs). Hybrid solar dryers improve the quality of the final product due to the control of the thermal drying condition. The dryer can be used to dry up to 12 kg of bananas. The thermal characteristics of the drying air were relatively stable, providing a final product quality similar to that obtained in an artificial dryer. The economic viability of the dryer was demonstrated. Compared with an artificial dryer, an economy of energy of approximately 38 per cent was obtained.06 M aria.

Janjai *et al.* (2008) developed a solar dryer for drying herbs and spices using hot air from roof-integrated solar collectors. The dryer is a bin type with a rectangular perforated floor. The bin has a dimension of 1.0 x 2.0 x 0.7 m. Hot air is supplied to the dryer from fiberglass-covered solar collectors, which also function as the roof of a farmhouse. The total area of the solar collectors is 72 m^2. To investigate its performance, the dryer was used to dry four batches of rosella flowers and three batches of lemon-grasses during the year 2002–2003. The dryer can be used to dry 200 kg of rosella flowers and lemon-grasses within 4 and 3 days, respectively. The products being dried in the dryer were completely protected from rains and insects and the dried products are of high quality. The solar air heater has an average daily efficiency of 35 per cent and it performs well both as a solar collector and a roof of a farmhouse.

Mehdi and Ali (2009) conducted thin layer solar drying of *Cuminum cyminum* grains by means of a solar cabinet dryer. This system was employed in two drying states (mixed and indirect) and four levels of drying air flow rates (f : passive and f , f , f : active). The average initial moisture content of the plant for all 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} drying tests were about 43 per cent on dry basis and the drying was performed continuously, in each test, for a period of 90 min. Drying rate of different drying methods as well as thermal efficiency of solar collector were obtained.

Chandak *et al.* (2009) used solar dryers for food processing, especially making amla candy, since last five years. First dryer is an innovative design with combined draught, natural and induced with fan. This dryer works well when fan induces draught. However when there is no power, the dryer works with natural draught but system under performs as the airflow is drastically reduced. In rural areas in Maharashtra Power cuts were increased to almost 14 h a day and practically no power is available to run fan during daytime when Sun is available. To counter this problem author has come up with a new design of solar dryer, which uses turbo ventilator for creating draught. Turbo ventilator runs on external wind and creates necessary draught and maintains good airflow through the solar dryer giving excellent performance.

Rao *et al.* (2009) stated that with the development of commercial technology in cabinet dryers, a new economic social activity emerged out in the rural areas in the field of agri-horticulture through processing of fruits, vegetables, spices, medicinal plants on micro level. Fifty food products of fruit and vegetables are processed in SEED commercial dryer on pilot scale by the application of food science and technology techniques for long shelf life and preservation. The technology is successfully commercialized through establishing the rural micro enterprises in 13 states in the country, starting from Ladak in North to Trivandrum in South. These enterprises not only generate the income and job opportunities to rural women and unemployed youth but also process the products with zero energy costs and with clean green energy. This obtained recognition from Ministry of New & Renewable Energy, Government of India and obtained a sanction of 50 per cent subsidy on the cost of dryers. The importance, strategies and the promotional methods of solar food processing products in the domestic and export markets are discussed.

Hassanain (2009) evaluated Simple solar drying system suitable for different agricultural fresh commodity to dry banana pulp. The drying system mechanism was flexible; it was constructed from cheap and available materials (i.e. wood, glass plastic and metals). It composed solar collector, drying chamber and solar chimney and/or blower. The air type solar collector was mounted fixed all the year around at 30°. The drying chamber was flexible to be 0° and 90° with the horizontal axis. Simple passive and active designs were followed to enable save energy requirement for fan operating. Banana moisture reduction rate, drying coefficient, of banana and the drying system efficiency were determined. This investigation on the solar drying system was carried out at Ismailia, Egypt. The study found that, the horizontal dryer chamber was speeding banana drying over the vertical one for active and passive within the time of drying for the site and time of investigations. Drying system efficiency for the forced convection was higher for the first day comparing with the following days due to the fast drying in the moisture falling stage.

Pande (2009) studied the performance on PV winnower cum dryer, a device developed for post harvest application, were carried out both as a winnower and as a dryer. As a winnower 200-300 kg grain could be separated in a clear day form threshed material. The device was found of immense utility when there was lull in the natural wind. Used generally for this purpose. The winnower was also used in the development of a dryer to enhance the utility of the system and year round application. The major advantage was the regulation of the temperature inside the drying bin due to enhancement in the speed of the fan with more irradiance and thus providing appropriate condition for drying of fruit and vegetables. A pre heating tunnel was incorporated in the system for reducing the thermal gradient inside the drying bin. The system was successfully used for dehydrating graded carrot, spinach, coriander leaves ber and local fruit Kachra slices with retention of colour and aroma with the incorporation of a battery and illumination system the PV winnower cum dryer has a tremendous potential in rural areas.

MATERIAL AND METHODS

CHAPTER III

MATERIAL AND METHODS

The agricultural and industrial products dried under the solar tunnel dryer are safe from unfavorable environment like high wind velocity, hail storms, heavy rainfall etc. The loading and unloading in solar tunnel dryer is easy and also a large quantity of material which require moderate temperature i.e. 60^0C for drying can easily be dried in the tunnel dryer where incident radiation over the glazing material can transmit inside the drying chamber and boost up temperature of air enclosure. Local climate and materials must be taken into account to reach at most appropriate dryer design.

It is well known that availability of suitable temperature and moisture removal facilities are necessary for the satisfactory drying to pre determined level. The solar tunnel dryer based on greenhouse approach permits all essential energy requirements for drying agro-industrial as well as for drying agricultural products.

The details of the methodology followed during the investigation are furnished below.

3.1 Raw material

Freshly harvested ripe B.G.Shital varieties of chilly were obtained from Parbhani.

3.2 Determination of physical properties

The physical properties of chilly such as shape, length, diameter, bulk density, and surface area was determined. The determination of physical characteristics of chilly was conducted before and after the drying of samples.

3.2.1 Shape

The identification of the shape of the chilly was done by tracing the longitudinal and lateral cross sections of the fruit and then comparing with the shapes listed on standard charts. Using standard charts the shape of the product was defined.

3.2.2 Length and diameter

The length and diameter of chilly was measured with the help of digital venire caliper.

3.2.3 Bulk density

The bulk density of chilly was determined by measuring the volume of a known volumetric box. Chilly was weighed with the volumetric box and the minus weight of volumetric box form weight chilly and volumetric box gave weight of sample. The bulk density was determined by using the weight to volume of the sample.

3.2.4 Surface area

The chilly was carefully cut using a knife. The cut skin layers were then placed on a graph sheet and the outlines are traced by using a sharp lead pencil. The summation of number of squares within the outline on the graph sheet gave the surface area of chilly.

3.2.5 Colour

The colour of dried chilly was observed visually.

3.2.6 Weight

The weight of chilly was taken with the help of electronic balance.

3.3 Experimental site

The solar tunnel dryer was designed, fabricated and installed at the Department of Agricultural Process Engineering, College of Agricultural Engineering & Technology Parbhani. Geographically Parbhani is situated at 19°16' North latitude and 76°47' East longitude with an elevation of 409 m above sea level.

3.4 Climatic and weather conduction of Parbhani.

The average maximum temperature in Rainy season ranges from 30-45°C, 30°C in winter and 36.25°C in summer. May is generally hottest month with maximum temperature reaching above 45°C for a short 5-8 days. Humidity varies from 37.2 to 74.7 per cent.

3.5 Solar Tunnel Dryer

Solar Tunnel Dryer consists of basically a drying tunnel, small axial flow fan, metal duct, and covered with a transparent UV stabilized polyethylene plastic sheet of 0.2 mm thickness with a transmittivity of 92 per cent for visible radiation. The top surfaces of the collector and drying chamber were designed in curved shape in order to increase the area of radiation. It was made to open and close easily for the functions of spreading the drying commodity and cleaning the polyethylene cover.

It was positioned in east-west direction. The capacity of the tunnel dryer was 50 kg of chilly, and 4 cm thickness of the spreading layer.

Before conducting an experiment the experimental set up was allowed to run till steady drying temperature was attained. Chilly was dried from an initial moisture content of 80 per cent (w.b.) to a final moisture content of 8 per cent (w.b.) for safe storage.

3.6 Theoretical consideration for design of solar tunnel dryer

Assumptions

The assumptions of certain parameters were made for design of solar tunnel dryer, which includes:

1	Weight of selected product taken for drying, kg	= x
2	Initial moisture content of selected product in per cent (w.b.)	= m_1
3	Final moisture content of selected product in per cent (w.b.)	= m_2
4	Ambient air temperature (^{0}C)	= T_1
5	Temperature inside the solar tunnel dryer (^{0}C)	= T_2
6	Temperature at outlet of dryer (^{0}C)	= T_3
7	Total drying time, h	= t
8	Specific heat of water , kcal/kg °C	= C_p
9	Specific heat of product , kcal/kg °C	= C_d

10	Specific heat of air (C_a), kcal/kg °C	= 0.2400
11	Latent heat of vaporization of water, kcal/kg	= λ
12	Density of exit air (ρ_e), kg/ m^3	=1.0539
13	Density of air at 0^OC (ρ_0), kg/ m^3	= 1.29
14	Gravity constant, m/s^2	= 9.8
15	Temperature of air at 0^OC(T_0), 0^O K	= 273
16	Overall thermal efficiency of solar tunnel dryer, per cent	= η
17	Global solar radiation for Parbhani region (k), $Kcal/hr/m^2$	= 750

Quantity of water to be removed

Amount of initial water content (M), kg $= \frac{(m_1 \times x)}{100}$

Weight of bone dry product (M_d), kg $= x - M$

Initial moisture content (d.b.), per cent $= \frac{m_1}{(100 - m_1)} \times 100$

Final moisture content (d.b.), per cent $= \frac{m_2}{(100 - m_2)} \times 100$

Weight of water to be removed (M_w), kg $= \frac{(m_1 - m_2)}{(100 - m_2)} \times x$

Total energy required Q, kcal

$$Q = M_d \times C_d \times (T_2 - T_1) + M \times C_p \times (T_2 - T_1) + M_w \times \lambda$$

Energy required per hour Q_t, kcal/h

$$Q_t = \frac{Q}{t}$$

Collector area of solar tunnel dryer required A_c, m^2

$$A_c, = \frac{Q_t}{k} \times \frac{1}{\eta} \times \frac{100}{68}$$

It has been found that about 68 per cent area of semi spherical shaped solar tunnel dryer is able to receive sunlight where as remaining 32 per cent area is under shadow and energy loser.

Dimensions of solar tunnel dryer

Area of solar collector = Area of semi-cylindrical shape of solar tunnel dryer

Area of semi-cylindrical shape of solar tunnel dryer (a), m^2 $= \pi \times r \times (r + l)$

Diameter (d) of solar tunnel dryer = d

Radius of solar tunnel dryer (r), m $= \frac{d}{2}$

Length of solar tunnel dryer (l), m $= A_c/d$

Drying area of solar Tunnel dryer (a), m^2 $= l \times d$

3.7 Assumption for Design of Chimney

1	Weight of product taken, (x)	= 50
2	Initial moisture content, (m_1)	= 80 per cent
3	Final moisture content, (m_2)	= 8 per cent
4	Latent heat of vaporization, (λ)	= 540 kcal/kg°C
5	Specific heat of air, (Ca)	= 0.2400 kcal/kg°C
6	Ambient temperature, (Ta)	= 33°C
7	Temperature inside the chimney of dryer	= 50°C
8	Temperature of air at 0°C, (T_0)	= 273 K
9	Density of exit air, (ρ_e)	= 1.0539 kg/m^3
10	Density of air at 0°C, (ρ_a)	= 1.29 kg/m^3

11	Height of chimney (assumed), (H)	= 0.3048 m
12	Gravity constant, (g)	= 9.81 m/s^2
13	Time, (t) of drying	= 26 h.

3.7.1 Design of Chimney

We have, Quantity of water to be evaporated, (m_w) = 39.13 kg

Quantity of air needed to absorb m_w kg of water

$$(Qa) = (m_w \times \lambda)/Ca \times \rho_a \times (Te\text{-}Ta)$$

$$= (39.13 \times 540)/[0.2400 \times 1.29 \times (50\text{-}33)]$$

$$= 4014.71\ m^3$$

Now, Qa amount of moist air is needed to be removed in 26 hours.

Rate of exit air $= 4014.71 / (26 \times 60 \times 60)$

$$= 0.0429\ m^3/s$$

Draft produce if we assume height of chimney = 0.0609 m (2 of 0.3048 m)

$$(D_1) = H \times g \times (\rho_a - \rho_e)$$

$$= 0.609 \times 9.81 \times (1.29 - 1.0539)$$

$$= 1.41192\ kg/m^2$$

But actual draft, (D_2) $= 0.3048 \times 1.41192$

$$= 0.4304\ kg/m^2$$

Velocity of exit air, v $= \sqrt{(2D_2/ \rho_e)}$

$$= \sqrt{(2 \times 0.4304/1.0539)}$$

$$= 0.9038\ m^3/s$$

Thus if assumed this exit air is being carried by two chimney

$$(Q) = 0.0429 / 2$$

$$= 0.02145 \text{ m}^3/\text{s}$$

We have, $(Q) = A \times V \times K$

$$(A) = Q / (V \times K)$$

$$= 0.02145 / (0.9038 \times 0.4)$$

$$= 0.05934 \text{ m}^2$$

Diameter of chimney $(d) = \sqrt{[(0.05934 \times 2)/\pi]}$

$$= 0.19436 \text{ m for two chimney}$$

Diameter of chimney $= 0.19436 / 2$

$$= 9.72 \text{ cm of each chimney}$$

Table 3.1 The dimension of solar tunnel dryer

Parameter	Unit
Dryer length	5.19 m
Dome height	0.61 m
Width	1.22 m
Drying area	5.49 m^2
Air temperature	55^{O}C
Drying tray (l x w x h)	1.21 x 0.61 x 0.09 m

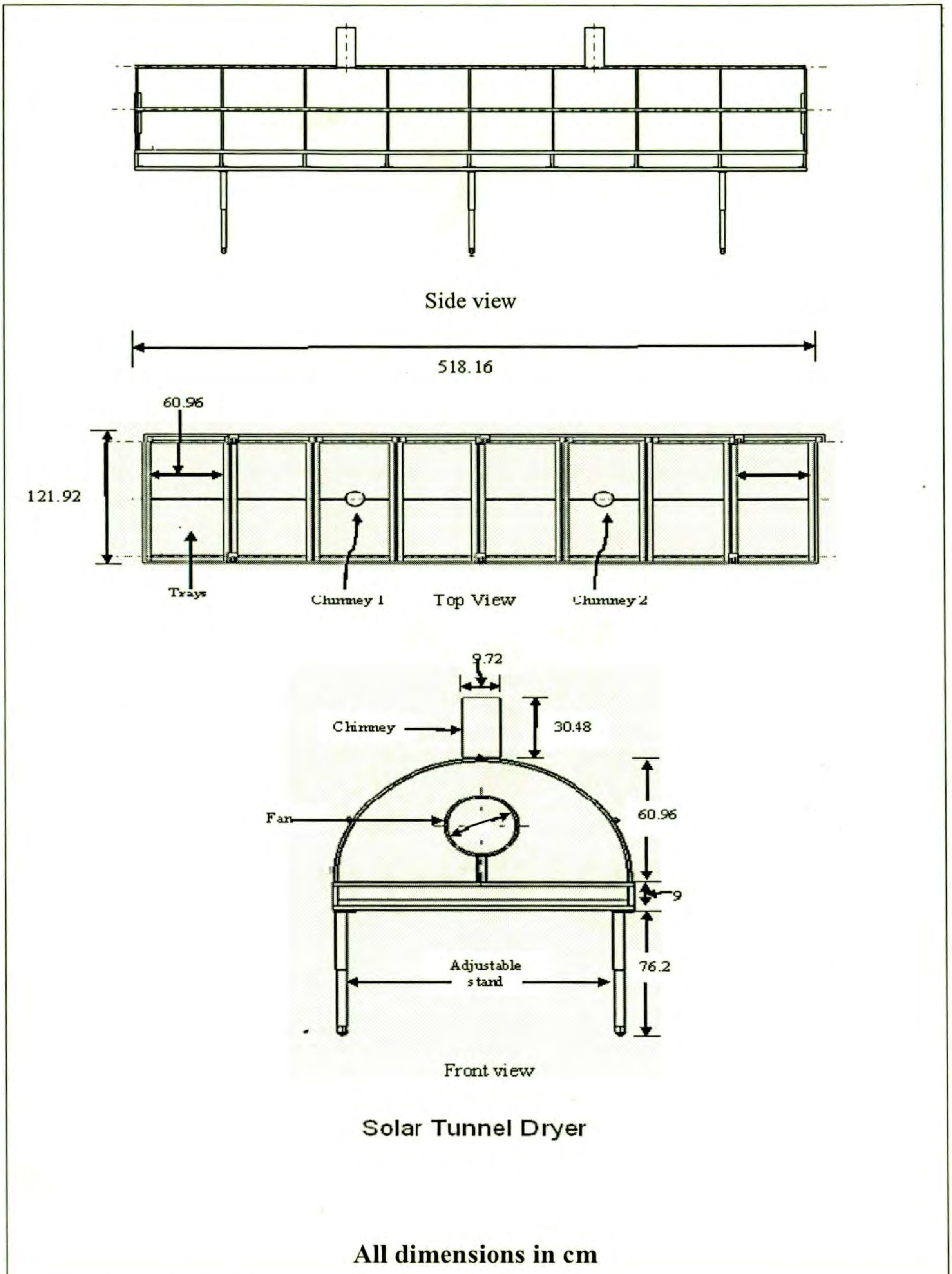

Fig 3.1 **Schematic diagram of solar tunnel dryer**

Plate 3.1 : Frame of solar tunnel dryer

Plate 3.2 : Isometric view of solar tunnel dryer

3.8 Instrumentation for drying experiments and evaluating

Instruments, which were used during performance evaluation of solar dryer, are described as follows.

3.8.1 Measurement of relative humidity

A Hygrometer manufactured by BARIGO was used for measuring relative humidity. It has range of 0 to 100 per cent of relative humidity. (Plate 3.3)

3.8.2 Measurement of solar intensity

solarimeter was used for measurement of solar intensity. It has a sensor which senses the solar radiation falling over its surface and displays the insolation in W/m^2. (Plate 3.4)

3.8.3 Measurement of temperature

Ordinary glass mercury thermometer having temperature range from 0-110^{O}C were used for measurement of maximum and minimum temperature. (Plate 3.5)

3.8.4 Measurement of Air velocity

Anemometer was used for measurement of the air flow rate along the tunnel, velocity of the exit air and ambient velocity of air. (Plate 3.6)

3.8.5 Measurement of weight chilly

Electronic weight balance was used for measurement of weight of chilly. (Plate 3.7)

3.8.6 Measurement of chilly Length and diameter

Digital veniré caliper was used for measurement of the Length and diameter of the chilly. (Plate 3.8)

3.8.7 Determination of initial moisture of chilly

Hot air Oven was used for determination of initial moisture of chilly. (Plate 3.9)

Plate 3.3 : Hygrometer

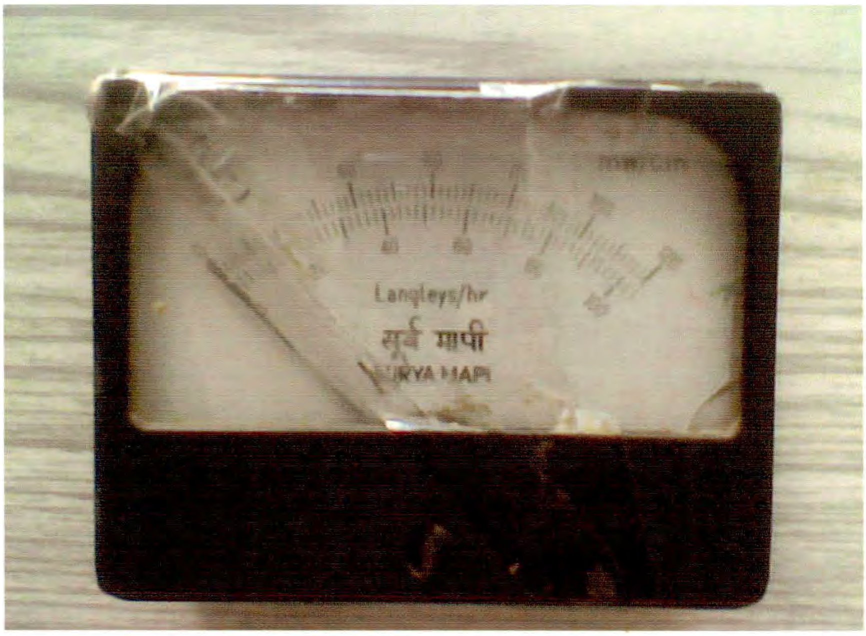

Plate 3.4 : Solari meter

Plate 3.5: Ordinary glass mercury thermometer

Plate 3.6: Anemometer

Plate 3.7: Weight balance with moisture box

Plate 3.8 : Digital Vernire caliper

Plate 3.9 : Hot Air Oven

3.9 Component solar tunnel dryer

3.9.1 Covering material

There are several materials used for glazing of solar tunnel dryer. The criteria for the selection of glazing material are quality and quantity of light transmitted, strength, weather resistance ability, surface condensation properties and cost. Glass is the most reliable material with a view of light transmission, but it is a heavy and susceptible to crack-ness and it is costly. Most of the plastic materials used for dryer glazing are adversely affected by ultra violet (UV) radiation. Therefore, it must be ensured that the plastics glazing material adequately stabilized against ultra violet radiation. PVC film has better infrared properties and long life, but it is susceptible to dirt accumulation and is less expensive. So, ultra violet stabilized polythene sheet is the best glazing material among all the materials, viewing to strength and stability characteristics 200 micron UV stabilized polythene sheet was selected.

3.9.2 Base frame

The solar tunnel dryer base frame was made up of MS angle (20 x 20 x 3 mm) and MS flat (20 x 3 mm). Base frame has a size of 5.19 m x1.22 m.

3.9.3 Drying floor

Floor of solar tunnel dryer was made painted black for better absorption of solar radiation. The size of drying floor is 5.19 m x 1.22 m.

3.9.4 Hoops

Hoops are the integral part of the structure of solar tunnel dryer. These are hemi spherical in shape and are formed using bending round M.S. iron round pipe (6 mm diameter and desired length). The long pipes are uniform bending achieved in hemi spherical shape. These hoops are attached to the rectangular base.

3.9.5 Ridge line

Ridge line are pipes of diameter of 6 mm and 5.19 m length which are placed at the top of hoop for strengthen the entire frame structure of solar tunnel dryer and also maintaining an equidistance between the hoop frame.

3.9.6 Adjustable stand

Adjustable stand with six legs made up of two section ms square pipes. Outer square pipe was MS angle (40 x 40 x 3 mm) and inner square pipe was (32 x 32 x 3 mm). It was used for supporting entire structure and adjusts height of structure form ground level.

3.9.7 Tray supporter

These were total nine numbers L angle tray supporter for support the tray and easy movement of tray for loading and unloading red chilies.

3.9.8 Rolling wheel

It has six numbers of rolling / moving wheels of each legs of tray supporter for easy movement of entire structure.

3.9.9 Tray

Tray consists of G.I. sheet tray wall and wire mesh. There were total eight numbers of trays. Wire meshes size of 10 x 10 mm. Each tray capacity was 6.250 kg chilly with of 4 cm thickness.

3.10 Micro-climatic variations

For study the micro-climatic variations inside a solar tunnel dryer, the following parameters are selected for monitoring.

1. Temperature profile under no load and subsequently during load.
2. Moisture content.
3. Relative humidity.
4. Solar insolation.

3.10.1 Temperature profile under no load and subsequently during full load.

No load test (fan operated and without fan operated)

No load test (fan operated and without fan operated) with the view to find out the temperature profile at the different tray inside the solar tunnel dryer i.e. maximum temperature attended without any heat loss from solar tunnel dryer. The observations of temperature under no load test were made at an interval of one hour, starting from 9:00 h to 17:00 h in the month of March and May. In this condition, eight thermometers inside and one thermometer outside the solar tunnel dryer were used. Thermometers one to eight were used for measurement of temperature inside solar tunnel dryer. Thermometer number zero was used for measurement of ambient air temperature.

3.10.2 Full load test (fan operated and without fan operated)

Full load (fan operated and without fan operated) test of solar tunnel dryer was conducted for evaluating the performance in actual loaded condition. Under this condition the useful heat was extracted and utilized to remove the moisture from material. Red chilly with known initial moisture content was taken for study and loaded in the trays of solar tunnel dryer. Material was spread in 4 cm thick in trays. Total eight trays were provided to accommodate 50 kg of material at a time in each batch. The data on moisture content, weight reduction, drying time, air temperature, etc. analyzed for calculating drying rate and drying efficiency as fallows.

a) Drying rate: The drying rate was calculated using the formula.

$$\text{Drying rate} = \frac{\text{Mass of moisture removed, (g)}}{\text{Time taken (h) x bone dried mass, (g)}} \text{ x } 100$$

b) Dryer efficiency: The efficiency of dryer was calculated using the formula

$$\text{Dryer efficiency } (\eta_{dryer}) = \frac{M_e \text{ x } L}{I_{av} \text{ x } A \text{ x } t} \text{ x } 100$$

Where,

Me = Moisture evaporated, kg

L = latent heat, kJ/kg

t = Drying time, s

A = Aperture area, m^2

I_{av} = Average solar radiations, k W/m^2

The inside and outside temperature and outside solar insolation of solar tunnel dryer was measured with the help of thermometer and Solarimeter. The observations of temperature and solar insolation were made at an interval of one hour starting from 9:00 h to 17:00 h. Thermometers number one to eight were used for measurement of temperature of eight trays inside solar tunnel dryer and thermometer number zero and nine was used to measure ambient air temperature and sun dried chilly bed temperature respectively. The positions of thermometer are given in Appendix-B.

3.10.3 Moisture content

Initial moisture content of the red chilly was measured by oven dry method. Sample of the product were taken and weighted. Then they were placed in the moisture boxes which were placed in the oven at temperature of 105 ^{0}C for 24 h. Then the samples were again weighted and their moisture content was determined as per following standard formula.

$$\text{Moisture content (per cent d.b.)} = \frac{\text{Mass of water evaporated, (g)}}{\text{Bone dry weight of sample, (g)}} \times 100 \quad \text{.... (2)}$$

$$\text{Moisture content (per cent w.b.)} = \frac{\text{Mass of water evaporated, (g)}}{\text{Mass of sample before drying, (g)}} \times 100 \quad \text{... (3)}$$

After every one hour the moisture content was measured by knowing the quantity of moisture removed during a period, with the help of simple balance. Moisture content was determined by using following formula

$$m_t = \left(100 - \frac{m_w\,(100-m_i)}{m_w - w} \right)$$

Where,

m_t = moisture content per cent,(w.b.) at any time period t.

m_i = initial moisture content per cent, (w. b.)

m_w = initial mass of product (g)

W = mass of moisture removed at any time period t (g).

3.10.4 Relative humidity

The ratio of actual vapour pressure in air water mixture and the saturated water vapour at same temperature is known as the relative humidity of air and expressed in per centage. It is largely dependent on atmospheric temperature. During experiment the relative humidity was measured by hygrometer and recorded.

3.10.5 Solar Insolation

Solar insolation is an important parameter in energy balance of atmosphere and earth surface. All bodies emit energy in the form of electromagnetic waves, when they are at a temperature above absolute zero. The source of this thermal radiation or temperature radiation is in the molecular motion. During collision or more generally as a result of inter action between molecules; part of this energy is transformed into radiation. The emission and the absorption of thermal radiation are governed by the temperature and nature of emitting and absorbing substance. It is expressed in W/m^2.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The results of the experimental studies are presented and discussed under the various section of this chapter.

4.1 Physical properties of *B.G.Shital* chilly

The physical properties *viz.* shape, surface area, length, diameter, bulk density, of chilly were determined.

4.1.1 Shape

The shape of the chilly was found to be conic.

4.1.2 Surface area

The surface area of the fresh chilly was determined to be 1402 mm^2 and in case of dried chilly it was 1343 mm^2.

4.1.3 Length

The average length of fresh chilly was found to be with stalk 98.99 mm and that of dried chilly was 95.26 mm and The average length of fresh chilly was found without stalk 69.76 mm and that of dried chilly was 67.68 mm.

4.1.4 Diameter

The average diameter of fresh and dried chilly was found to be 9.28 mm and 8.68 mm.

4.1.6 Bulk density

The bulk density of fresh chilly was found to be 0.205 g cm^{-3} and in dried chilly it was recorded as 0.067 g cm^{-3}.

Table 4.1: Physical properties of fresh and dried *B.G. shital* chilly

Sr. No.	Properties	Fresh	Dried
1	Surface area (mm^2)	1402	1343
2	Length with stalk (mm)	98.99	95.26
	Length without stalk (mm)	69.76	67.68
3	Diameter (mm)	9.28	8.68
4	Bulk density ($g\ cm^{-3}$)	0.205	0.067

The solar tunnel dryer equipped with various means responsible for enhancing drying rate has been evaluated under no load (fan operated and without fan operated) and load (fan operated and without fan operated) for drying red chilly. Its overall performance in terms of maximum temperature attended, drying behaviors, time of solar tunnel drying has been made.

4.2 Design and construction of solar tunnel dryer

The dimension of the solar tunnel dryer was worked as 1.22 m x 5.19 m for drying 50 kg of fresh red chilly.

4.3 Design and construction of chimney

The size of chimney was decided on the basis of draft produced by difference in hot air inside the dryer and ambient air outside it. The chimney was designed for maximum flow rate required for drying product. The design specifications of solar tunnel dryer and chimney are given in Table 4.2

Table 4.2: Design details of solar tunnel dryer for drying of red chilly

Sr. No.	Components/ Particulars	Specifications
1.	Product dried	Red chilly
2.	Loading capacity	50 kg
3.	Initial moisture content	80 per cent (w.b.)
6.	Final moisture content	8 per cent (w.b.)
7.	Drying period required	26 h
8.	Collector material (cover)	UV polythene 200 micron sheet
9.	Orientation of tunnel	E-W direction
11.	No. of Chimneys	2
12.	Size of chimney (Diameter and Length)	0.0972 m and 0.3048 m
14.	Length of solar tunnel dryer	5.19 m
15.	Width of solar tunnel dryer	1.22 m
16.	Area of solar tunnel dryer	6.34 m^2
17.	Area of semi-cylindrical shape of solar tunnel dryer	11.115 m^2

Table 4.3: cost of individual components of solar tunnel dryer.

Sr. No.	Particulars	Qty	Rate (Rs)	Amount (Rs)
(A)	**Components of solar tunnel dryer**			
1	Frame (5.19 x 1.22 m) M.s. square pipe (25x25x3 mm)	12.81 m	196.88	2520
2	M.s. Round solid bar (6 mm dia)	18.90 m	98.42	1860
3	Tray supporter			
	M.s. T angle (25x25x3 mm)	17.07 m	49.21	840
	M.S. L angle (25x3x3 mm)	3.048 m	65.62	200
4	Adjustable stand			
	a) Outer pipe (40x40x3 mm) M.S. square pipe	3.048 m	131.24	400
	b) Inner pipe (32x32x3 mm) M.S. square pipe	3.048 m	98.43	300
5	G.I. wire mesh of tray (20 gauge 10x4mm hole size)	6.503 m^2	269.11	1750
6	G.I. sheet of tray wall (20 gauge)	2.787 m^2	430.58	1200
7	Roller steel wheel (10.16 cm.dia)	6 No	100	600
8	M.S. sheet chimney	2 No	100	200
9	Coloring	----	---	830
10	Black board paint	1 liter	120	120
11	Labour charges	----	----	1900
(B)	**Electrical component**			
12	Fan (D.C. operated) 12 v	1 No	500	500
13	Battery 12 v, 150 Amp	1 No	9000	9000
14	Photovoltaic panel 18 v 1.5 Amp 60 W	1 No	14000	14000
	Total Rs.	----	-----	36220

4.4 Performance evaluation of solar tunnel dryer for drying red chilly.

Performance evaluation and testing of the solar tunnel dryer was carried out under no load and load conditions during the month of April and May 2010 for drying red chilly. Sun drying was carried out as control test. four tests were carried out for no load test (fan operated and without fan operated), load test (fan operated and without fan operated) and open sun drying.

4.4.1 No load test of solar tunnel dryer (fan operated and without fan operated)

The performance of solar tunnel dryer without product was carried out in order to find out maximum stagnation temperature on attended eight trays inside the dryer, air flow velocity in first chimney, in second chimney and outside solar tunnel dryer. This is useful for predicting effectiveness of solar tunnel dryer for drying products. This was evaluated by measuring solar insolation, ambient temperature, ambient relative humidity and relative humidity inside the dryer.

4.4.2 Temperature, solar insolation, velocity and moisture variation

During no load test (fan operated and without fan operated) it was empty, i.e. no red chilly were placed in the solar tunnel dryer for drying. The testing on no load fan operated and without fan operated was done for two days in April and May, 2009.

4.4.3 No load fan operated test

It was observed that in no load fan operated test the minimum inside temperature was 47°C at 17:00 h in the month of May while maximum temperature attended inside the tunnel dryer was 66.5°C at 13:00 h Corresponding, minimum ambient temperature was 37°C at 17:00 h while maximum ambient temperature was 40°C at 13.00 h

It was observed that in no load fan operated test there was increase in the temperature by 26.5°C at 13:00 h inside the solar tunnel dryer as compared to corresponding ambient air temperature in the month of May as shown in Fig 4.1. Data is presented in Appendix-G.

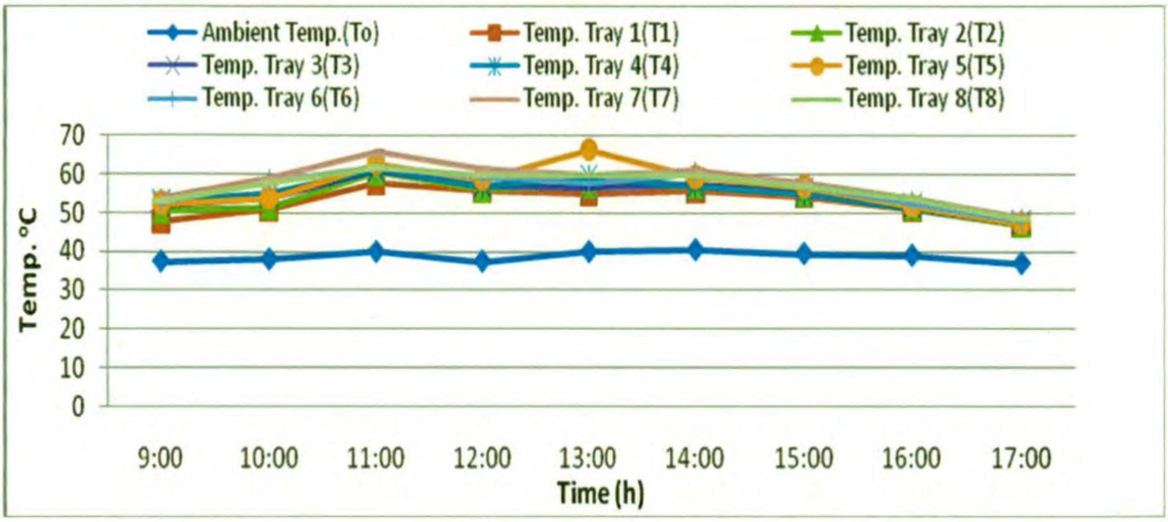

Fig 4.1: Variation of temperature with time inside and outside the solar tunnel dryer under no load fan operated test.

It was recorded that the minimum and maximum solar insolation was 260 W/m^2 at 17:00 h and 790W/m^2 at 13:00 h respectively. As shown in Fig 4.2. Data is presented in Appendix-G.

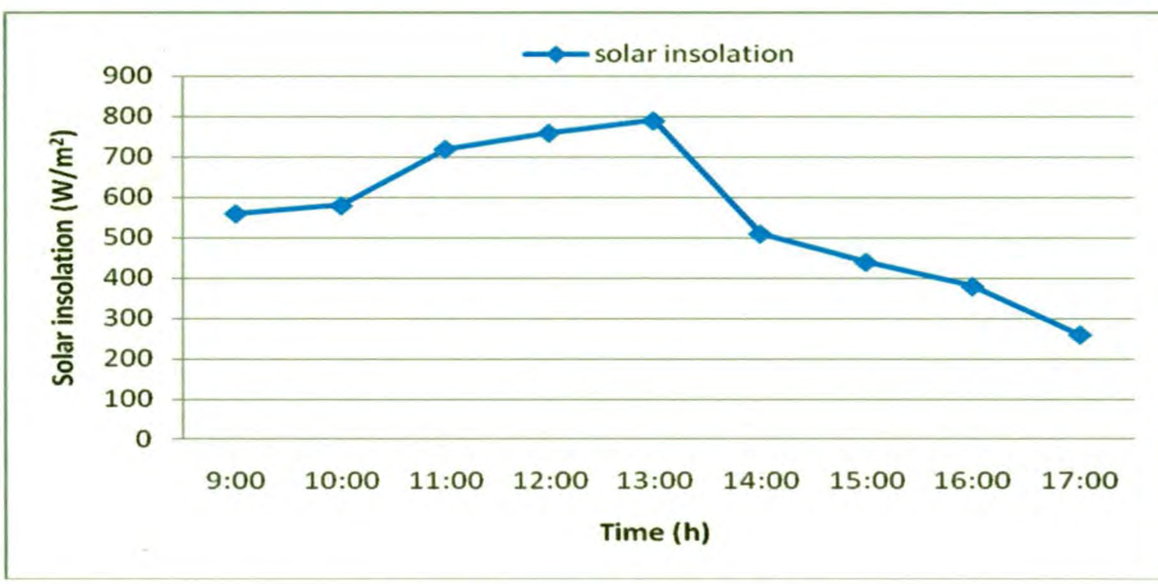

Fig 4.2: Variation of solar insolation with time for no load fan operated test.

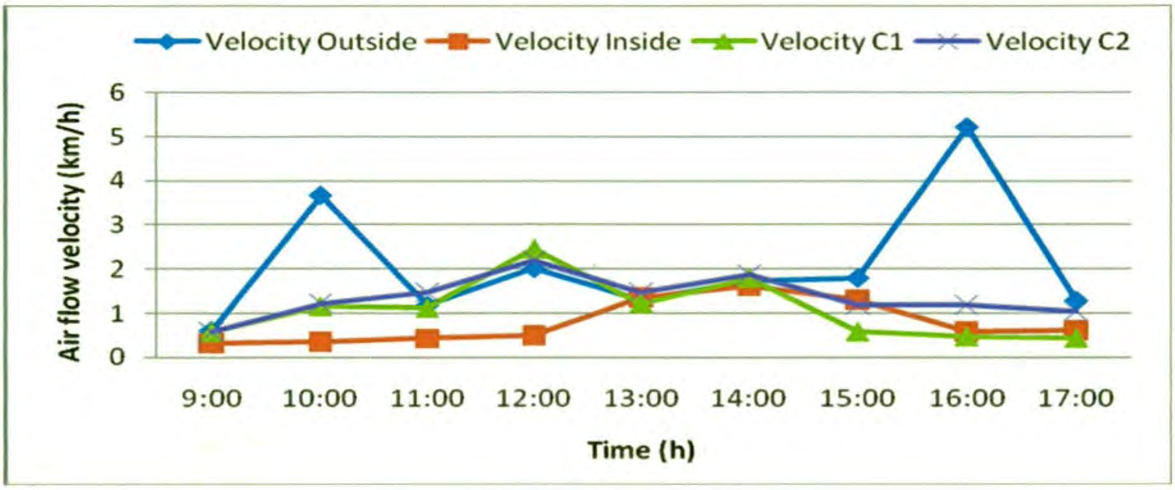

Fig 4.3: Variation of air flow velocity with time for no load fan operated test

Fig 4.3 shows the changes in air flow velocity. It Was observed that for No load fan operated test range of air flow velocity through first chimney was in between 0.432 to 2.448 km/h and range of air flow velocity through second chimney was 0.576 to 2.196 km/h, while range of air flow velocity outside and inside the dryer was 0.612 to 5.22 km/h and 0.288 to 4.716 respectively. Data of air flow variation is presented in Appendix-G.

As shown in Fig 4.4 the maximum relative humidity inside the tunnel during no load fan operated test was 39 per cent at 09.00 h, while minimum relative humidity was 24 per cent at 14:00 h Maximum ambient relative humidity was 39 per cent at 09.00 h while minimum ambient relative humidity was 33 per cent at 14:00 h. Data is presented in Appendix-G.

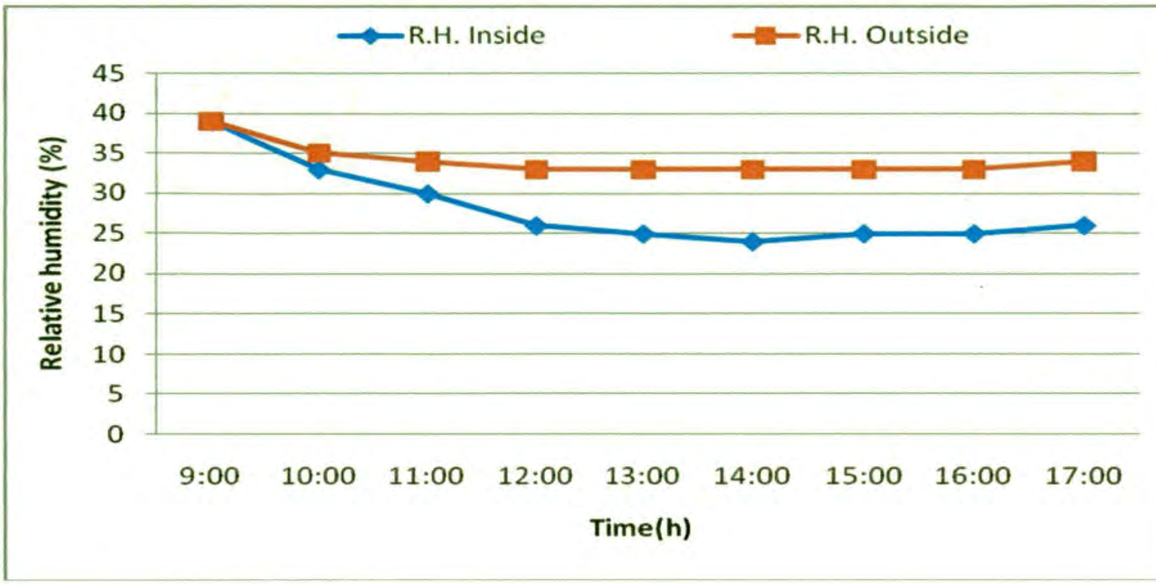

Fig 4.4: Variation of relative humidity inside and outside the solar tunnel dryer under no load fan operated condition.

4.4.4 No load without fan operated test.

It was observed that no load without fan operated test the minimum inside temperature was 44°C at 09.00 h in the month of April while maximum temperature attended inside the tunnel dryer was 70°C at 14:00 h Corresponding, minimum ambient temperature was 37.5°C at 09.00 h while maximum ambient temperature was 41.5°C at 14.00 h as shown in Fig 4.5.

It was recorded that no load without fan operated test there was increase in the temperature by 28.5°C at 14:00 h inside the solar tunnel dryer as compared to corresponding ambient temperature in the month of April 2010. As shown in Fig 4.5. Data is presented in Appendix-B.

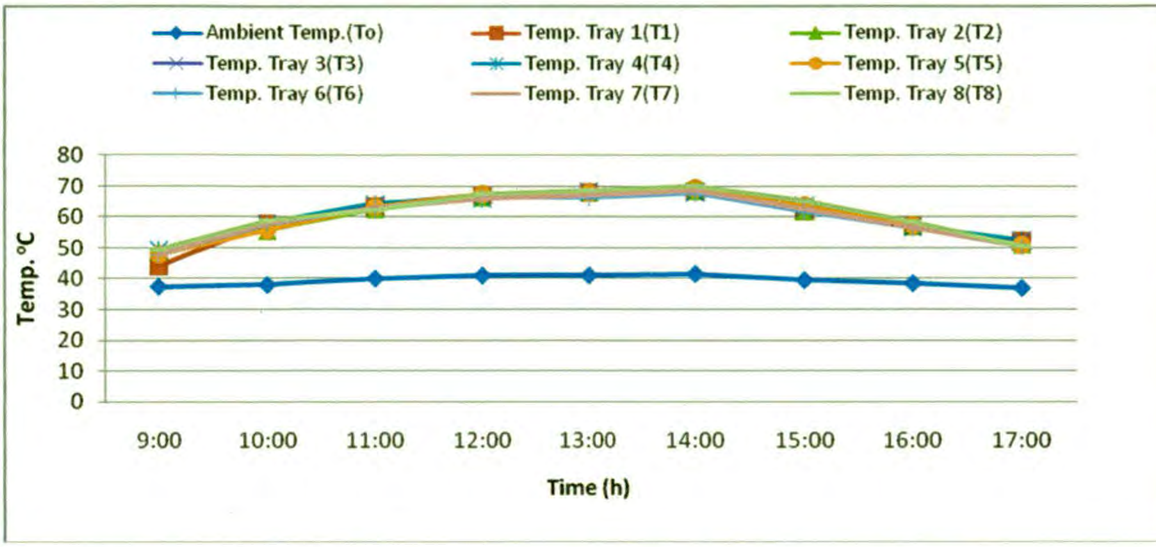

Fig 4.5: Variation of temperature with time inside and outside the solar tunnel dryer under no load test fan operated conduction.

It was recorded that the minimum and maximum solar insolation was 250 W/m^2 at 17:00 h and 760W/m^2 at 13:00 h respectively. As shown in Fig 4.6. Data is presented in Appendix-B.

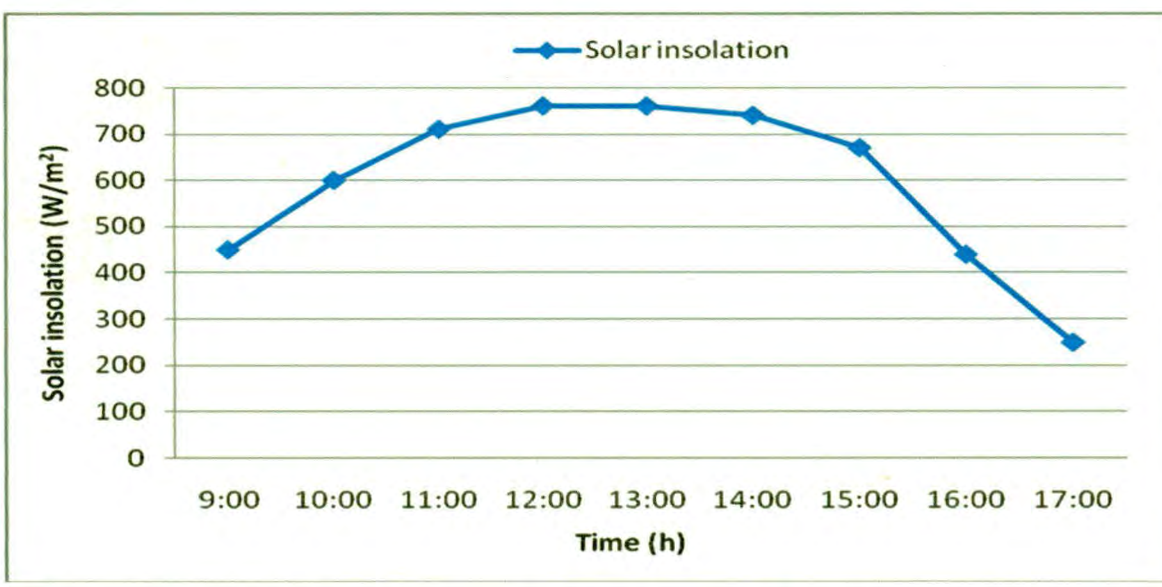

Fig 4.6: Variation of solar insolation with time for no load without fan operated test

It was observed that for No load without fan operated test range of air flow velocity through first chimney was in between 0.648 to 1.08 km/h and range of air flow velocity through second chimney was 0.432 to 1.224 km/h, while range of air flow velocity outside and inside the dryer was found to 1.152 to 6.732 km/h and 0.18 to 0.576 respectively (Fig 4.7). Data of air flow variation is presented in Appendix-B.

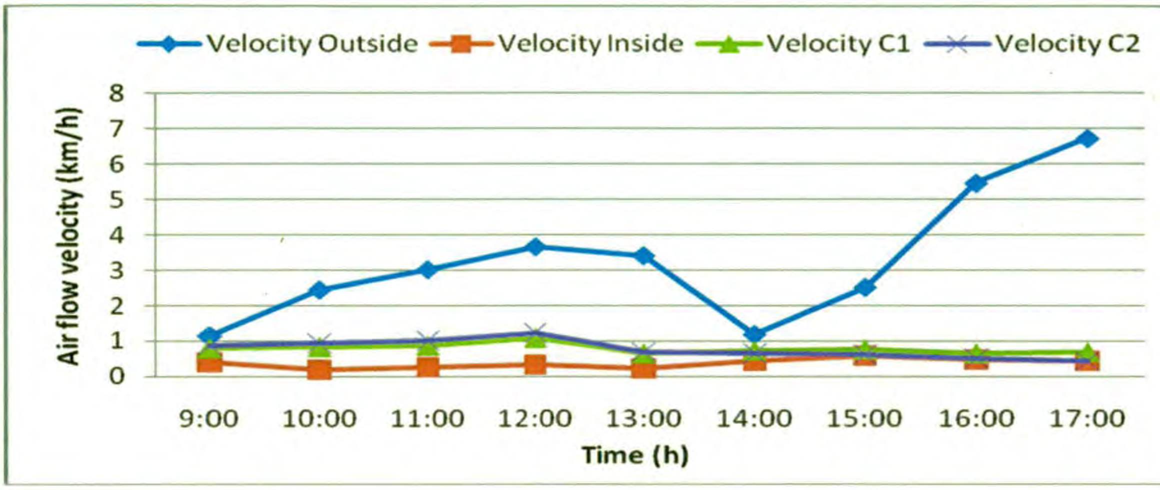

Fig 4.7: Variation of air flow velocity with time for no load without fan operated test.

As shown in Fig 4.8 the maximum relative humidity inside the tunnel during no load without fan operated was 38 per cent at 09.00 h, while minimum relative humidity was 16 per cent at 13:00 h Maximum ambient relative humidity in this month was 35 per cent at 09.00 h while minimum ambient relative humidity was 29 per cent at 14:00 h. Data is presented in Appendix-B.

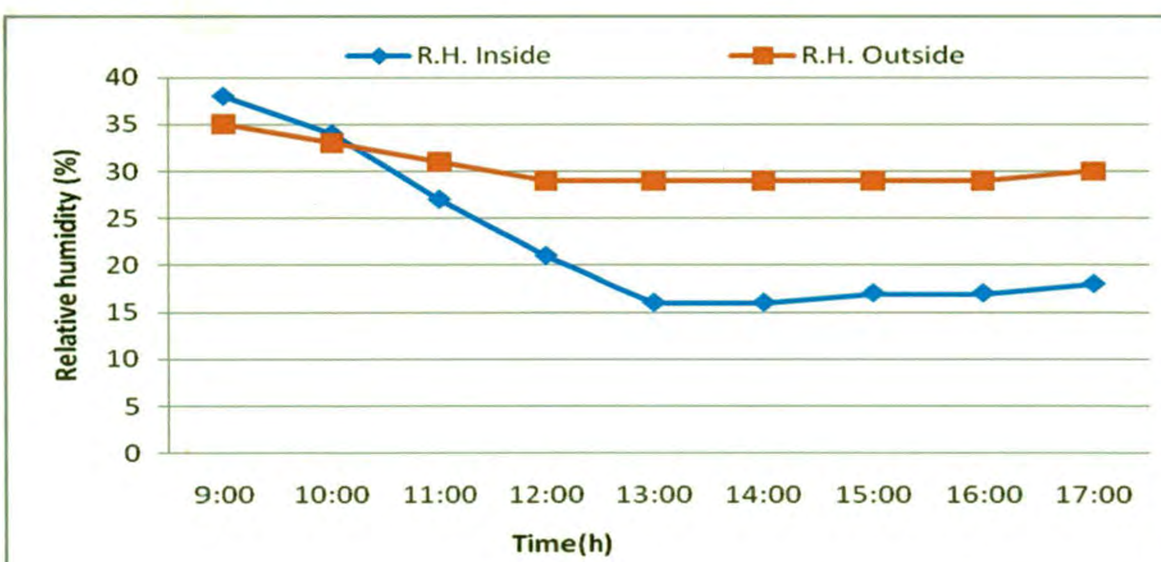

Fig 4.8: Variation of relative humidity inside and outside the solar tunnel dryer under no load without fan operated condition.

4.4.5 Load test of solar tunnel dryer (fan operated and without fan operated)

Load test of solar tunnel dryer (fan operated and without fan operated) was made for evaluating the performance of solar tunnel dryer in actual load condition. In load testing, 50 kg and 4 cm thick of red chilly were spread in eight trays. Each tray contain 6.250 kg of red chilly in solar tunnel dryer and sample of same quantity was kept open air sun drying for comparison purpose load test fan operated and without fan operated was done in the months of April and May for 4 consecutive days.

For evaluating the performance parameter like measuring solar insolation, ambient temperature, ambient relative humidity, air temperature and relative humidity inside the solar tunnel dryer are studied. Inside view of solar tunnel dryer is given in plate 4.3

In the first day fan operated drying test it was observed that the minimum inside temperature was 46°C at 17:00 h in the month of May while maximum temperature attended inside the tunnel dryer was 62.5°C at 11:00 h Corresponding, minimum ambient temperature was 36°C at 17:00 h while maximum ambient temperature was 42°C at 14:00 h Minimum and maximum Sun dried chilly bed temperature was 42.5°C and 57°C at 17:00 h and14:00 h respectively (Fig 4.9). Data is presented in Appendix-H.

It was recorded that the minimum and maximum solar insolation as 200 W/m^2 at 17:00 h and 760 W/m^2 at 14:00 h respectively (Fig 4.33).

Plate 4.1 : Red chilly pepper before drying in solar tunnel dryer

Plate 4.2 : Red chilly pepper after drying in solar tunnel dryer

Plate 4.3: Inside view of solar tunnel dryer under load condition

Plate 4.4 : Outside view of Solar tunnel dryer and Recording of observation.

Plate 4.5 : Open air sun drying of chilly

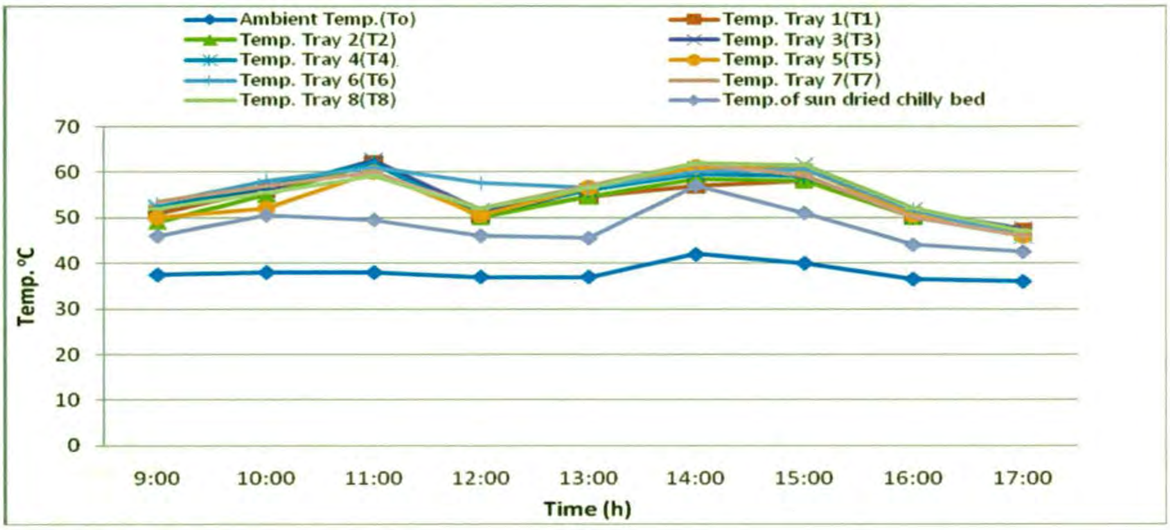

Fig 4.9: Variation of temperature with time at first day no load fan operated test.

Minimum and maximum outside relative humidity was 33 and 42 respectively. Minimum and maximum inside relative humidity was 24 and 32 respectively (Fig 4.10). Data is presented in Appendix-H.

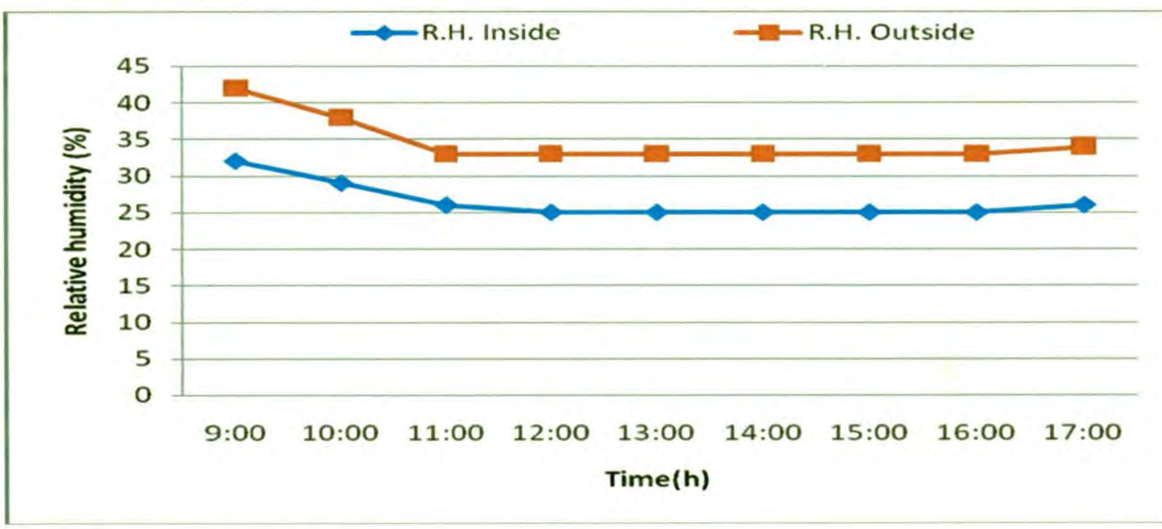

Fig 4.10: Variation of first day relative humidity inside and outside the solar tunnel dryer under load fan operated condition.

It was observed that for load fan operated first day test range of air flow velocity through first chimney was in between 0.18 to 0.936 km/h and range of air flow velocity through second chimney was 0.324 to 1.512 km/h, while range of air flow velocity outside the dryer has found to 0.26 to 14.864 km/h and range of air flow velocity inside centre of the dryer was found to 0.216 to 0.9 km/h (Fig 4.11). Data of air flow variation is presented in Appendix-H.

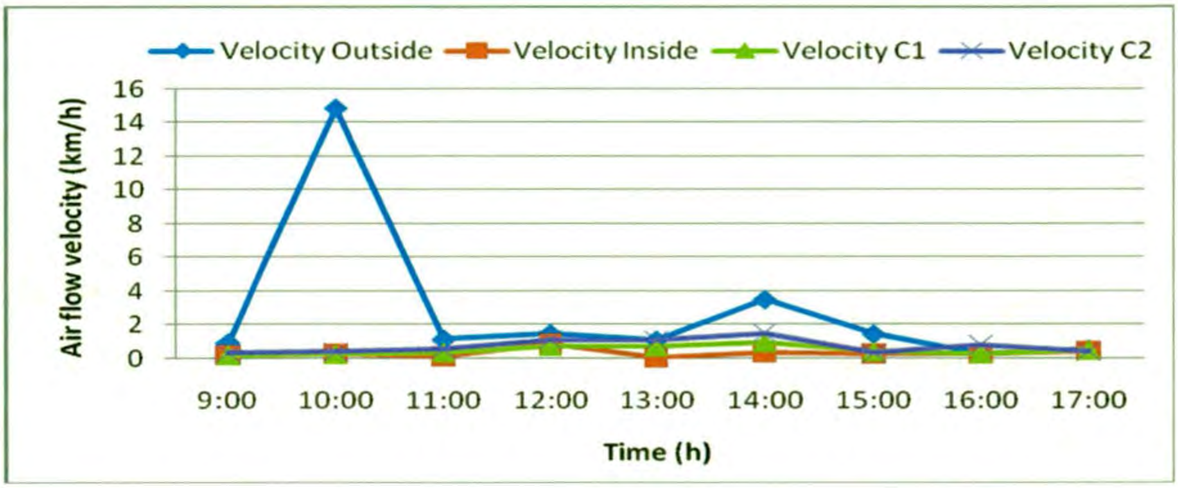

Fig 4.11: Variation of air flow velocity with time (fan operated first day Load test.)

First day without fan operated drying test was observed that the minimum inside temperature was 43°C at 09.00 h in the month of April while maximum temperature attended inside the tunnel dryer was 69°C at 14:00 h Corresponding, minimum ambient temperature was 36°C at 09.00 h while maximum ambient temperature was 41.5°C at 14:00 h Minimum and maximum chilly bed temperature was 40°C and 52.5°C at 17:00 h and 14:0 h respectively (Fig 4.12). Data is presented in Appendix-C.

It was recorded that the minimum and maximum solar insolation was 280 W/m^2 at 17:00 h and 860W/m^2 at 12:00 h respectively as shown in Fig 4.34. Data is presented in Appendix-C.

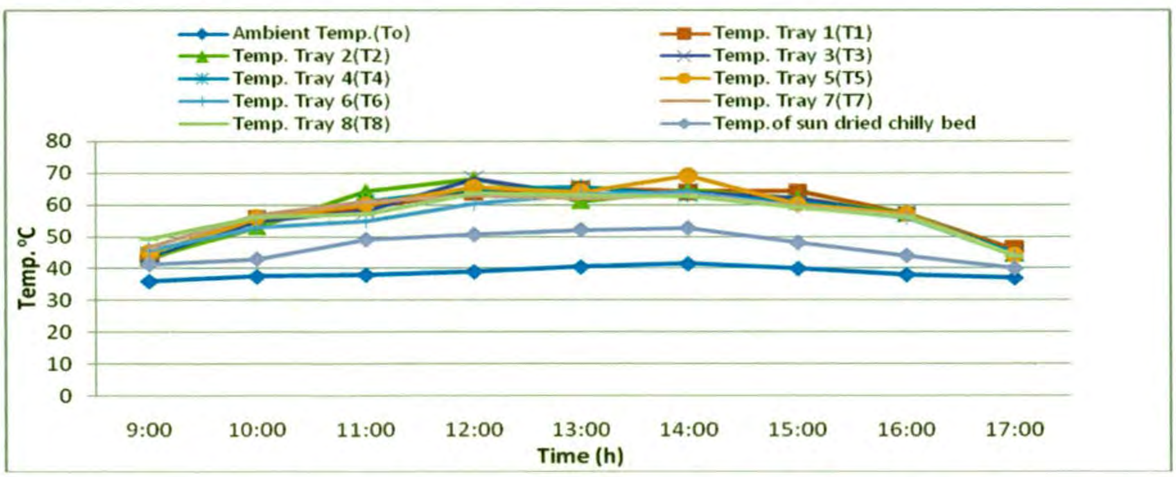

Fig 4.12: Variation of temperature with time at first day no load test without fan operated of drying of chilly.

Minimum and maximum outside relative humidity was 23 and 32 respectively. Minimum and maximum inside relative humidity was 19 and 27 respectively (Fig 4.13). Data is presented in Appendix-C.

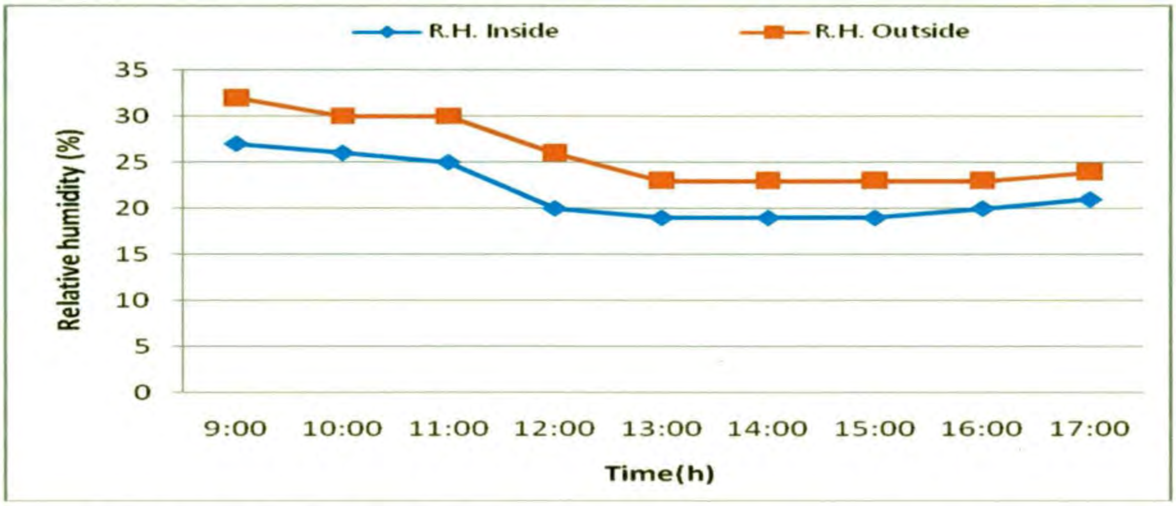

Fig 4.13: Variation of first day relative humidity inside and outside the solar tunnel dryer under load without fan operated condition.

It was observed that for load without fan operated first day test range of air flow velocity through first chimney was in between 0.468 to 1.008 km/h and range of air flow velocity through second chimney was 0.54 to 0.9 km/h, while range of air flow velocity outside the dryer has found to 1.512 to 5.436 km/h and range of air flow velocity inside dryer has found to 0.18 to 0.72 km/h (Fig 4.14). Data of air flow variation is presented in Appendix-C.

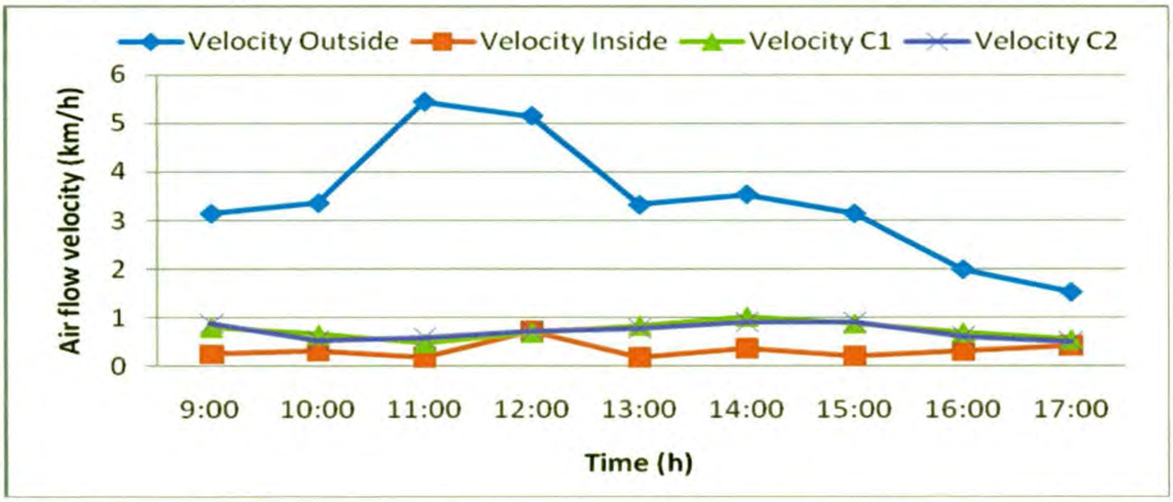

Fig 4.14: Variation of air flow velocity with time (without fan operated first day Load test.)

In the second day of fan operated drying test it was observed that the minimum inside temperature was 48°C at 17:00 h in the month of May while maximum temperature attended inside the tunnel dryer was 68°C at 12:00 h Corresponding, minimum ambient temperature was 38°C at 17:00 h while maximum ambient temperature was 42°C at 12:00 h

Minimum and maximum chilly bed temperature was 44°C and 57°C at 09.00 h and 13:00 h respectively (Fig 4.15). Data is presented in Appendix-I.

It was recorded that the minimum and maximum solar insolation was 200 W/m^2 at 17:00 h and 720 W/m^2 at 13:00 h respectively (Fig 4.33).

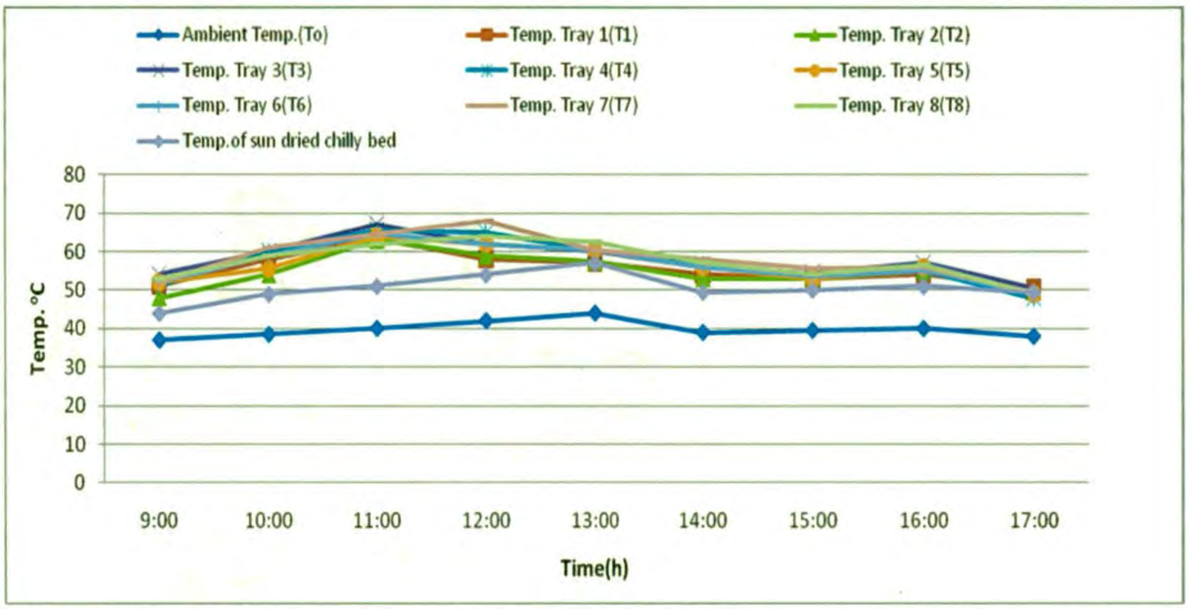

Fig 4.15: Variation of temperature with time on second day (no load fan operated test).

Minimum and maximum outside relative humidity was 35 and 41 respectively. Minimum and maximum inside relative humidity was 24 and 32 respectively (Fig 4.16). Data is presented in Appendix-I.

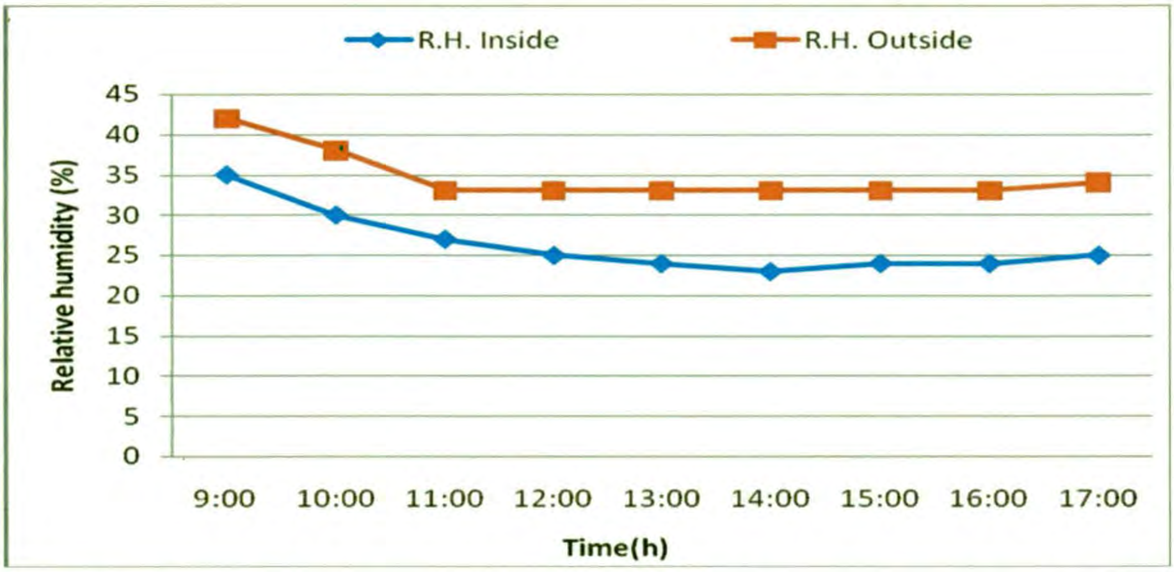

Fig 4.16: Variation of Second day relative humidity inside and outside the solar tunnel dryer under load fan operated condition.

It was observed that for load fan operated Second day test range of air flow velocity through first chimney was in between 0.252 to 4.5 km/h and range of air flow velocity through second chimney was 0.432 to 5.58 km/h, while range of air flow velocity outside the dryer has found to 1.872 to 12.672 km/h and range of air flow velocity inside centre of the dryer has found to 0.288 to 1.188 km/h (Fig 4.17). Data is presented in Appendix-I.

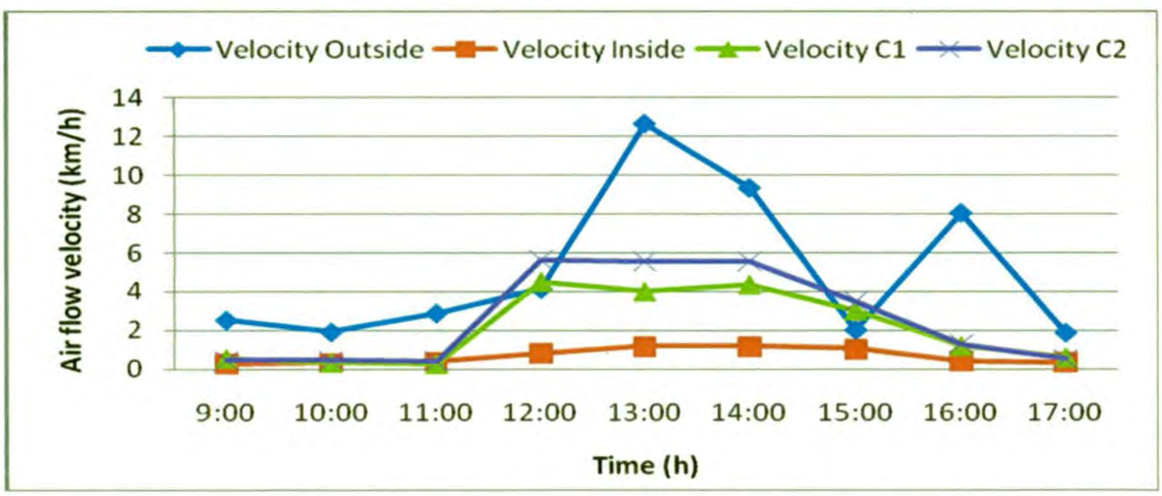

Fig 4.17: Variation of air flow velocity with time (fan operated Second day Load test.)

In the second day of without fan operated drying it was observed that the minimum inside temperature was 42°C at 17:00 h in the month of April while maximum temperature attended inside the tunnel dryer was 69.5°C at 12:00 h corresponding, minimum ambient temperature was 37°C at 17:00 h while maximum ambient temperature was 41°C at 12.00 h Minimum and maximum chilly bed temperature was 40.5°C and 56°C at 17:00 h and12:00 h respectively (Fig 4.18).

It was recorded that the minimum and maximum solar insolation was 200 W/m^2 at 17.00 h and 930 W/m^2 at 13:00 h respectively (Fig 4.34). Data is presented in Appendix-D.

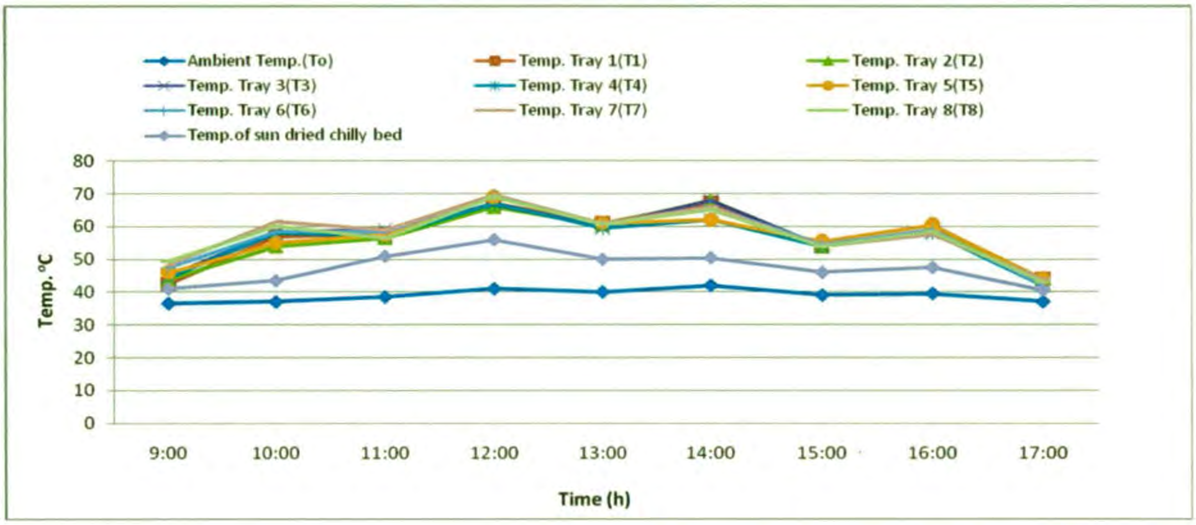

Fig 4.18: Variation of temperature with time at second day of without fan operated drying of chilly.

Minimum and maximum outside relative humidity was 29 and 34 respectively. Minimum and maximum inside relative humidity was 21 and 32 respectively (Fig 4.19). Data is presented in Appendix-D.

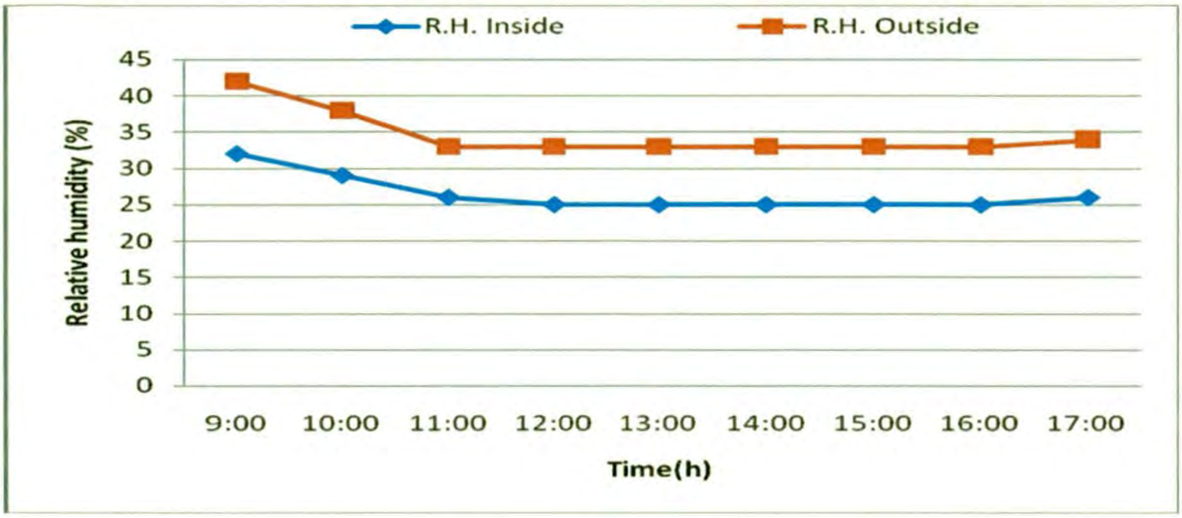

Fig 4.19: Variation of Second day relative humidity inside and outside the solar tunnel dryer under load without fan operated condition.

It was observed that for load without fan operated second day test range of air flow velocity through first chimney was in between 0.288 to 0.936 km/h and range of air flow velocity through second chimney was 0.252 to 1.08 km/h, while range of air flow velocity outside the dryer has found to 1.404 to 8.64 km/h and range of air flow velocity inside dryer has found to 0.288 to 0.54 km/h (Fig 4.20). Data is presented in Appendix-D.

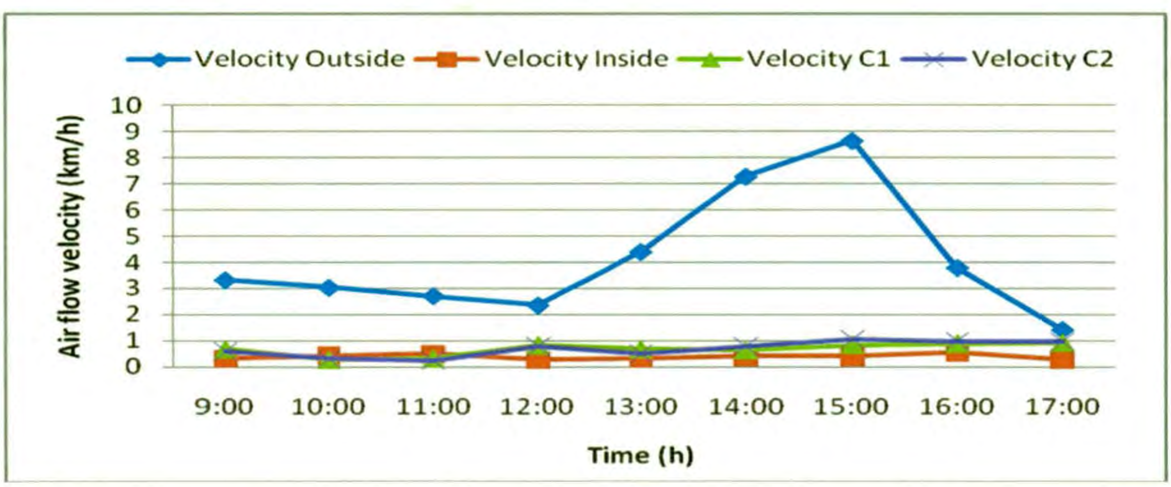

Fig 4.20: Variation of air flow velocity with time (without fan operated Second day Load test.)

In the third day of fan operated drying it was observed that the minimum inside temperature was 49.5°C at 17:00 h in the month of May while maximum temperature attended inside the tunnel dryer was 73°C at 12:00 h corresponding, minimum ambient temperature was 37.5°C at 17:00 h while maximum ambient temperature was 42.0°C at 12:00 h Minimum and maximum chilly bed temperature was 42.5°C and 56°C at 09.00 h and 13:00 h respectively (Fig 4.21). Data is presented in Appendix-J.

It was recorded that the minimum and maximum solar insolation was 180 W/m^2 at 17:00 h and 810 W/m^2 at 13:00 h respectively (Fig 4.33). Data is presented in Appendix-J.

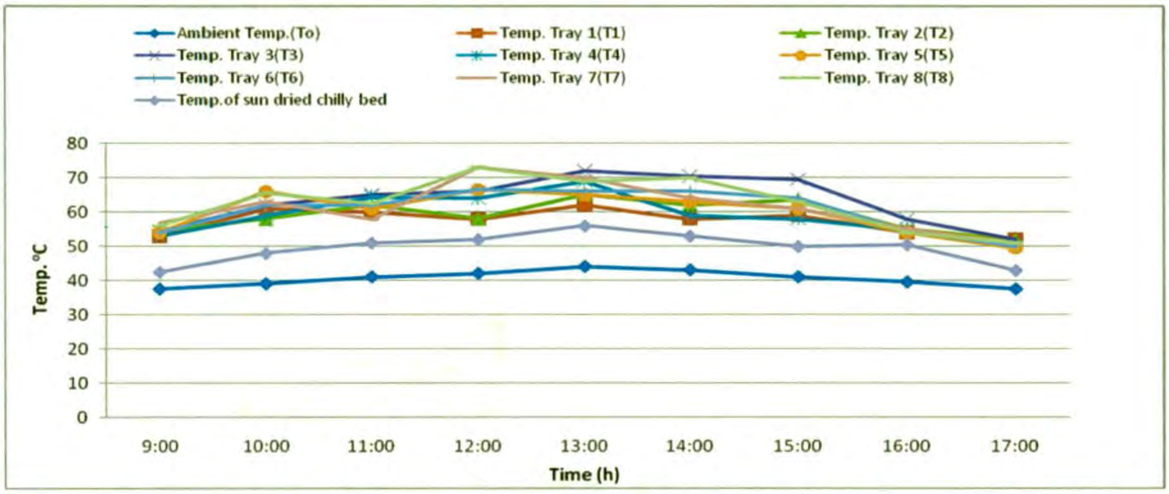

Fig 4.21: Variation of temperature with time at Third day of fan operated drying of chilly.

Minimum and maximum outside relative humidity was 33 and 42 respectively. Minimum and maximum inside relative humidity was 23 and 35 respectively (Fig 4.22). Data is presented in Appendix-J.

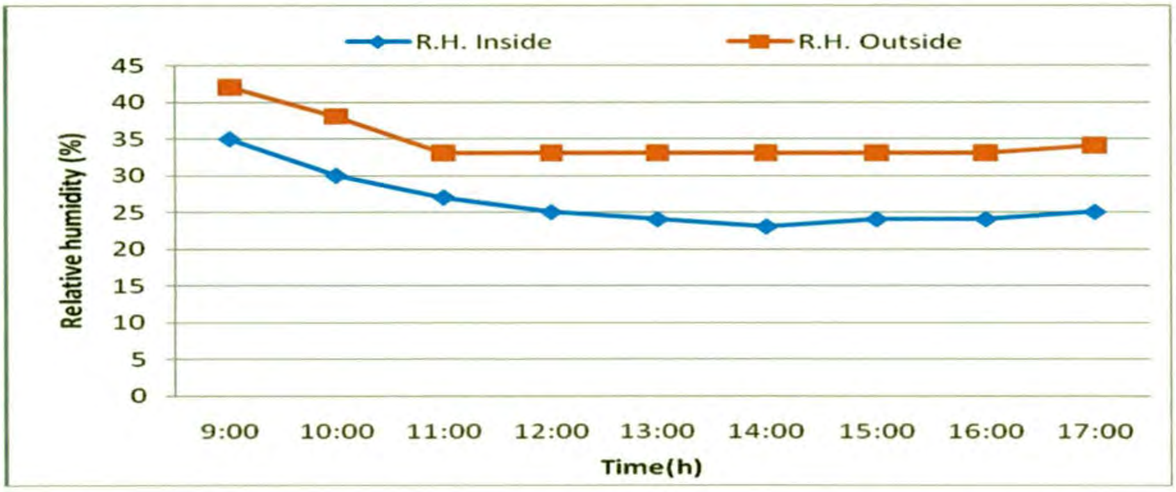

Fig 4.22: Variation of Third day relative humidity inside and outside the solar tunnel dryer under load fan operated condition.

It was observed that for load fan operated third day test range of air flow velocity through first chimney was in between 0.216 to 3.384 km/h and range of air flow velocity through second chimney was 0.216 to 5.076 km/h, while range of air flow velocity outside the dryer has found to 3.024 to 7.164 km/h and range of air flow velocity inside dryer has found to 0.18 to 2.376 km/h (Fig 4.23). Data of air flow variation is presented in Appendix-J.

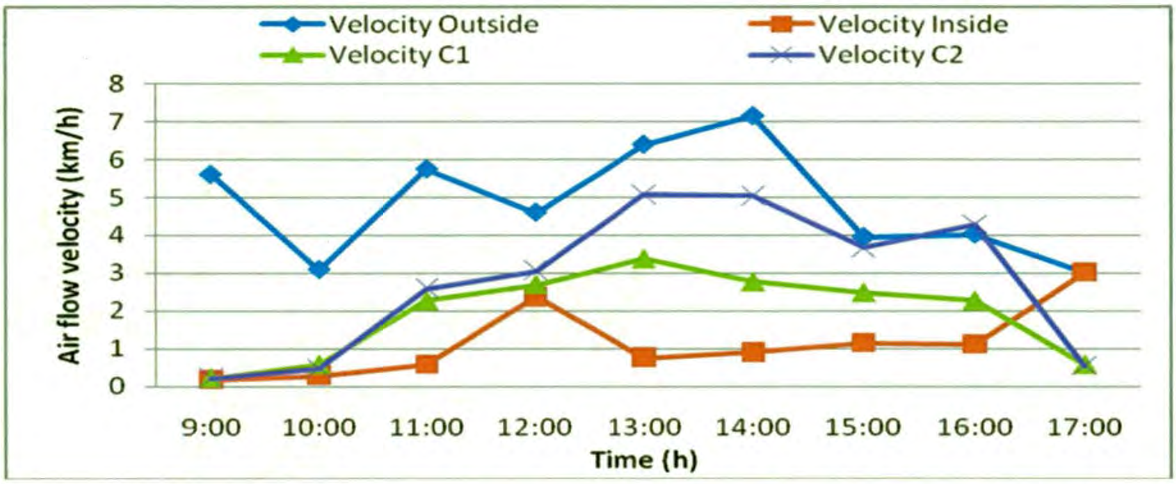

Fig 4.23: Variation of air flow velocity with time (fan operated Third day Load test.)

In the third day of without fan operated drying it was observed that the minimum inside temperature was 50.5°C at 09.00 h in the month of April while maximum temperature attended inside the tunnel dryer was 78.5°C at 14:00 h Corresponding, minimum ambient temperature was 36°C at 09.00 h while maximum ambient temperature was 42°C at 14:00 h Minimum and maximum chilly bed temperature was 41°C and 57°C at 09.00 h and 14:00 h respectively (Fig 4.24). Data is presented in Appendix-E.

It was recorded that the minimum and maximum solar insolation was 240 W/m^2 at 17:00 h and 910 W/m^2 at 14:00 h respectively (Fig 4.34). Data is presented in Appendix-E.

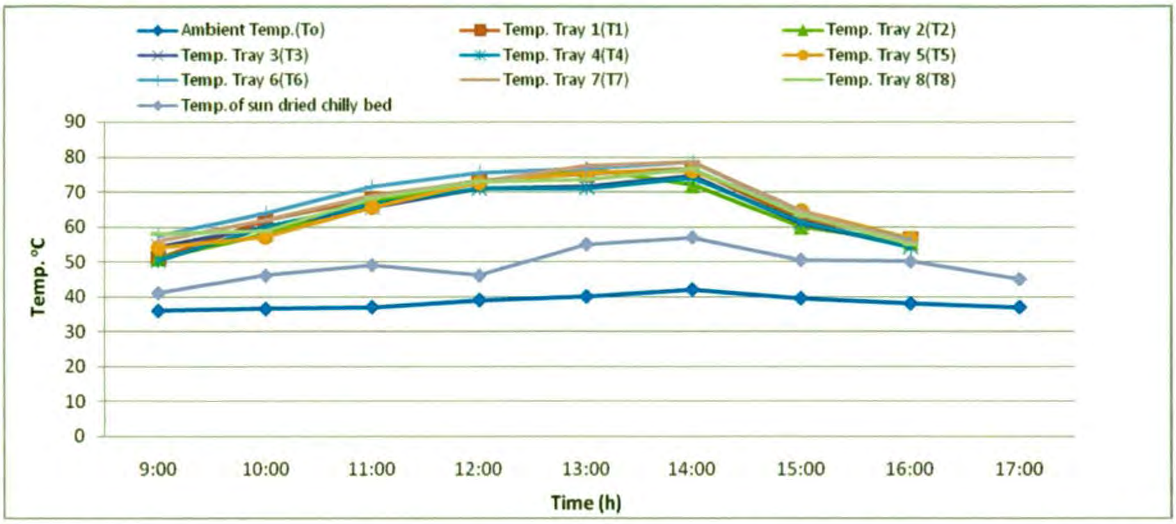

Fig 4.24: Variation of temperature with time at Third day of without fan operated drying of chilly.

Minimum and maximum outside relative humidity was 28 and 32 respectively. Minimum and maximum inside relative humidity was 20 and 27 respectively (Fig 4.25). Data is presented in Appendix-E.

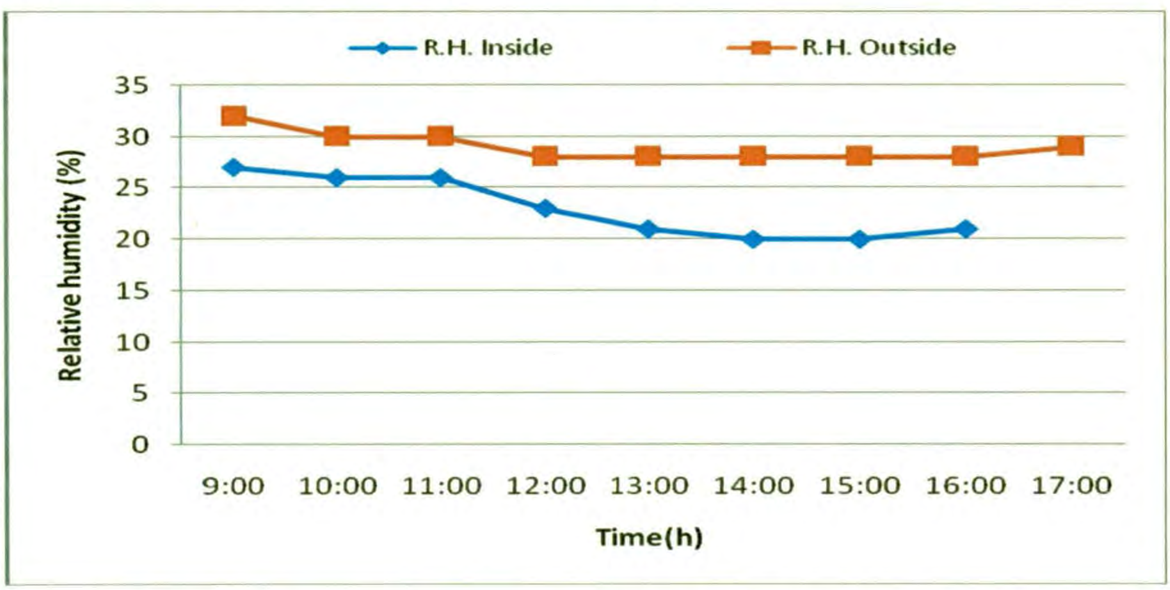

Fig 4.25: Variation of Third day relative humidity inside and outside the solar tunnel dryer under load without fan operated condition.

It was observed that for load without fan operated third day drying test range of air flow velocity through first chimney was in between 0.18 to 0.828 km/h and range of air flow velocity through second chimney was 0.252 to 0.864 km/h, while range of air flow velocity outside the dryer has found to 1.368 to

6.518 km/h and range of air flow velocity inside dryer was found to 0.144 to 0.612 km/h (Fig 4.26). Data of air flow variation is presented in Appendix-E.

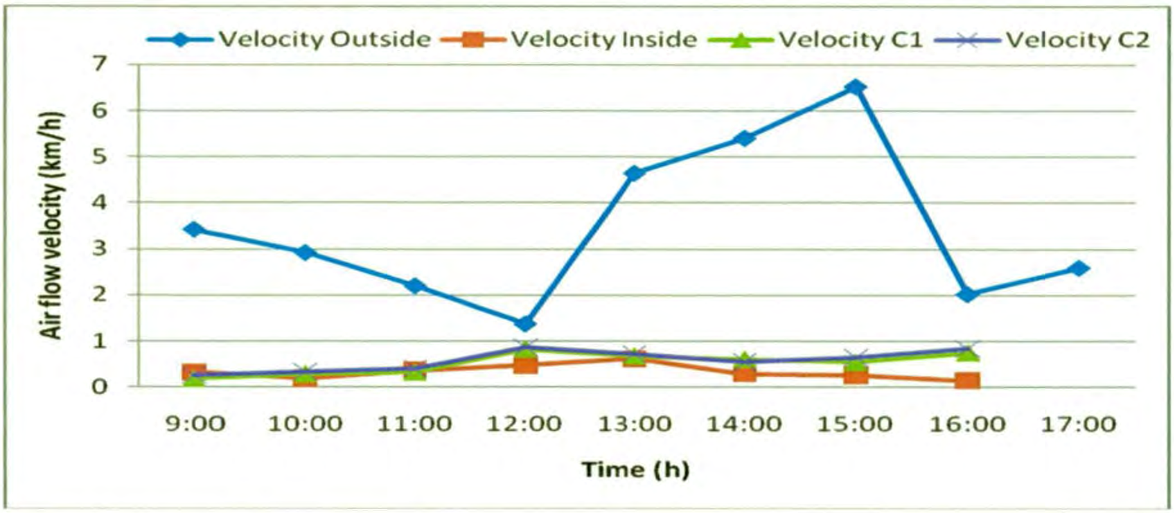

Fig 4.26: Variation of air flow velocity with time (without fan operated Third day Load test.)

On fourth day only sun drying chilly was for observation. Minimum and maximum chilly bed temperature was 44.5°C and 56°C at 9.00 h and 13.00 h respectively in the month of May Corresponding, minimum ambient temperature was 38°C at 09.00 h while maximum ambient temperature was 42°C at 13:00 h (Fig 4.27). Data is presented in Appendix-K.

It was recorded that the minimum and maximum solar insolation was 400 W/m^2 at 16:00 h and 810 W/m^2 at 13:00 h respectively (Fig 4.33). Data is presented in Appendix-K.

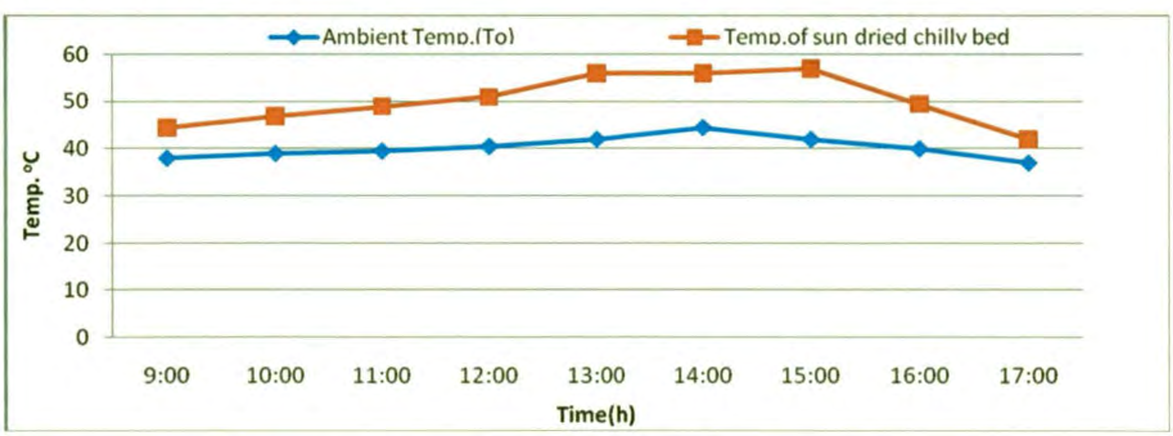

Fig 4.27: Variation of temperature with time at Fourth day of sun drying chilly.

Minimum and maximum outside relative humidity was 30 and 37 respectively (Fig 4.28). Data is presented in Appendix-K.

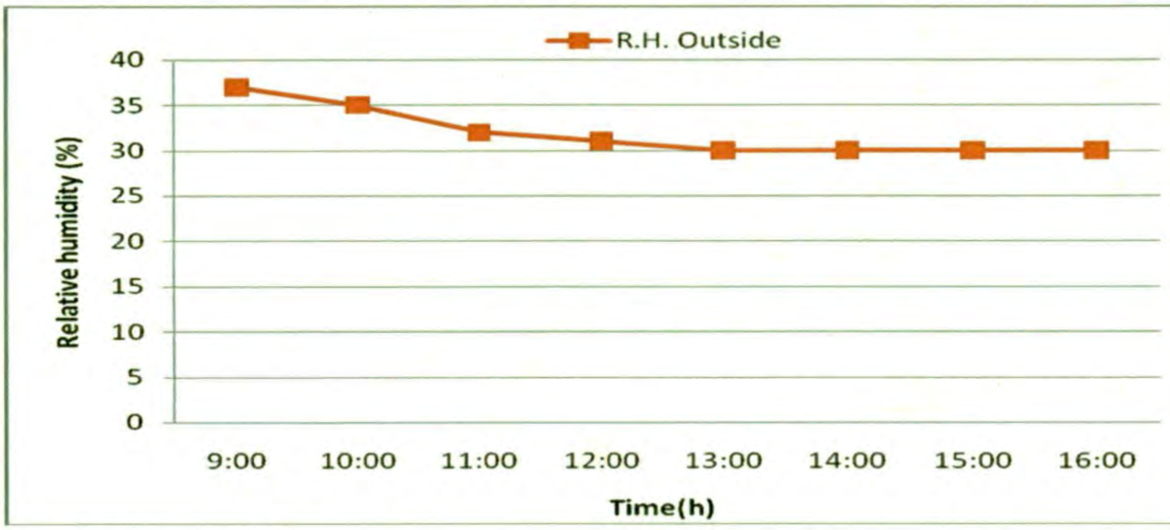

Fig 4.28: Variation of Fourth day relative humidity durning Sun drying chilly test.

It was observed that for fourth day range of air flow ambient velocity was found to 2.988 to 13.5 km/h (Fig 4.29). Data is presented in Appendix-K.

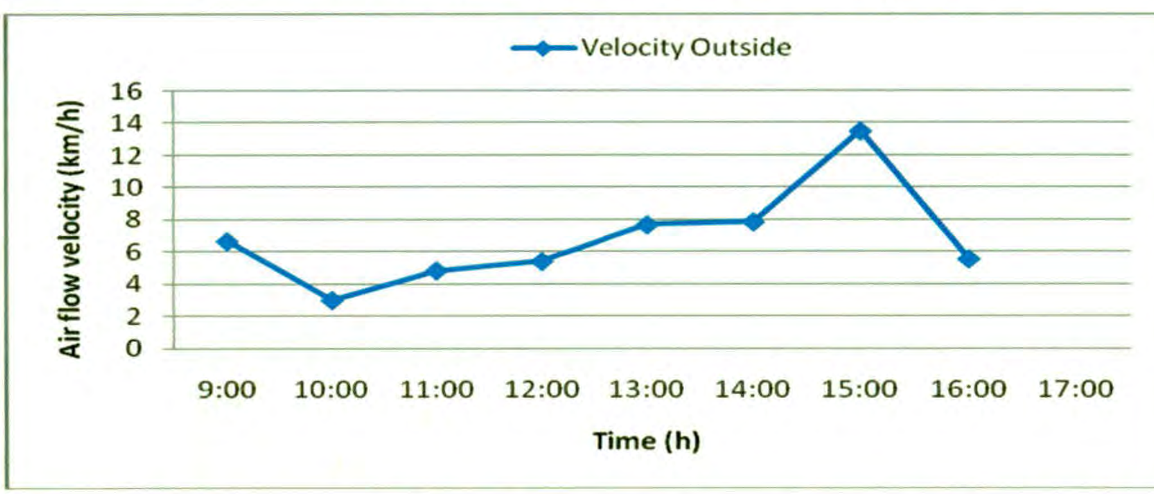

Fig 4.29: Variation of air flow velocity with time during Sun drying chilly test.

On fourth day only sun drying chilly was for observation. Minimum and maximum chilly bed temperature was 43°C and 56°C at 09.00 h and13:00 h month of April respectively corresponding, minimum ambient temperature was 37.5°C at 09.00 h while maximum ambient temperature was 41.5°C at 13:00 h (Fig 4.30). It was recorded that the minimum and maximum solar insolation was 510 W/m^2 at

09.00 h and 840 W/m^2 at 13:00 h respectively (Fig 4.34). Data is presented in Appendix-F.

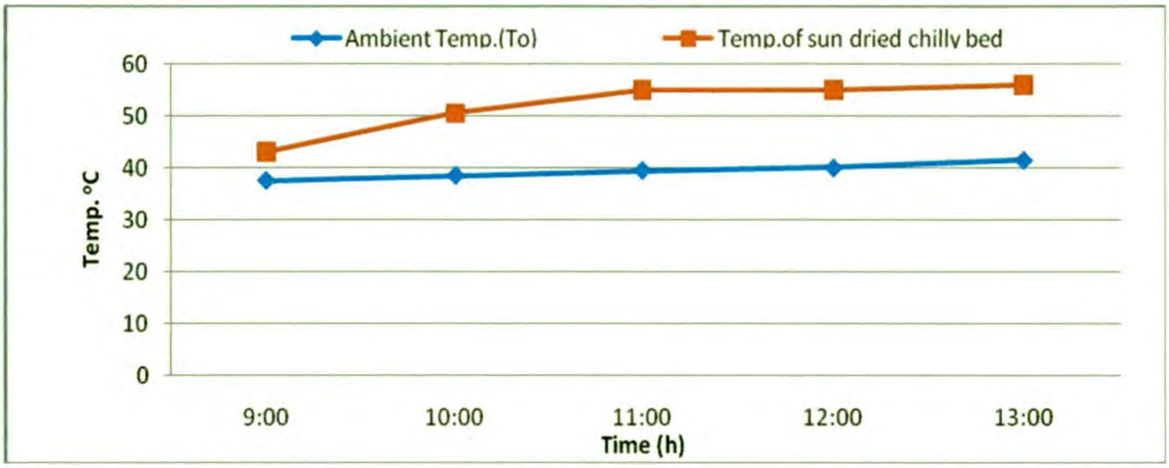

Fig 4.30: Variation of temperature with time at Fourth day sun drying chilly.

Minimum and maximum outside relative humidity was 31 and 39 respectively (Fig 4.31). Data is presented in Appendix-F.

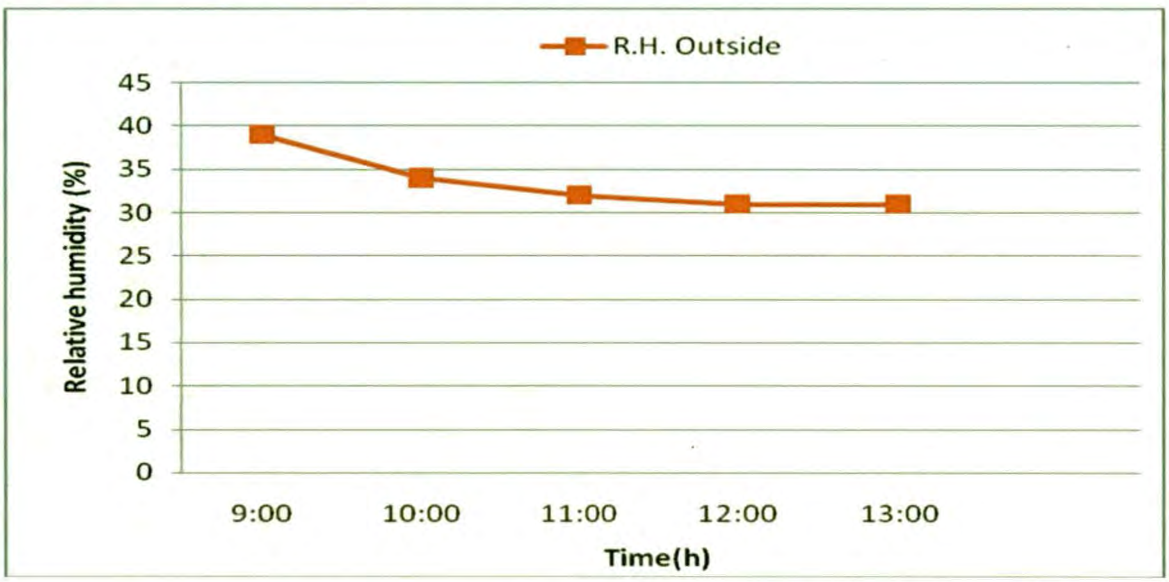

Fig 4.31: Variation of Fourth day relative humidity of sun drying chilly test.

It was observed that for fourth day range of air flow ambient velocity was found to 1.872 to 12.24 km/h (Fig 4.32). Data of air flow variation is presented in Appendix-F.

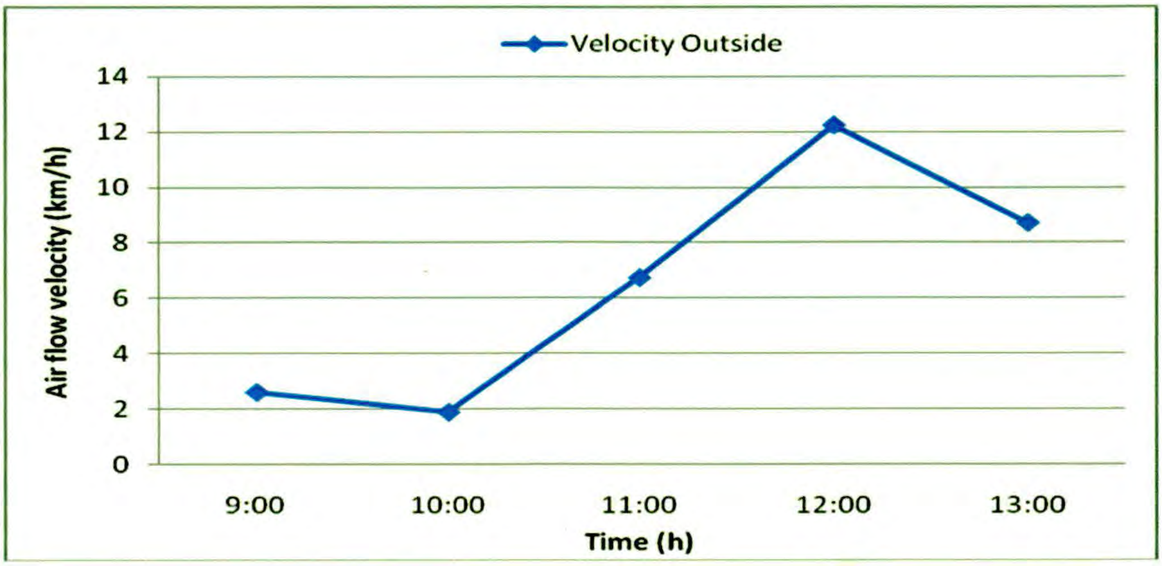

Fig 4.32: Variation of air flow velocity with time (fourth day sun drying chilly test.)

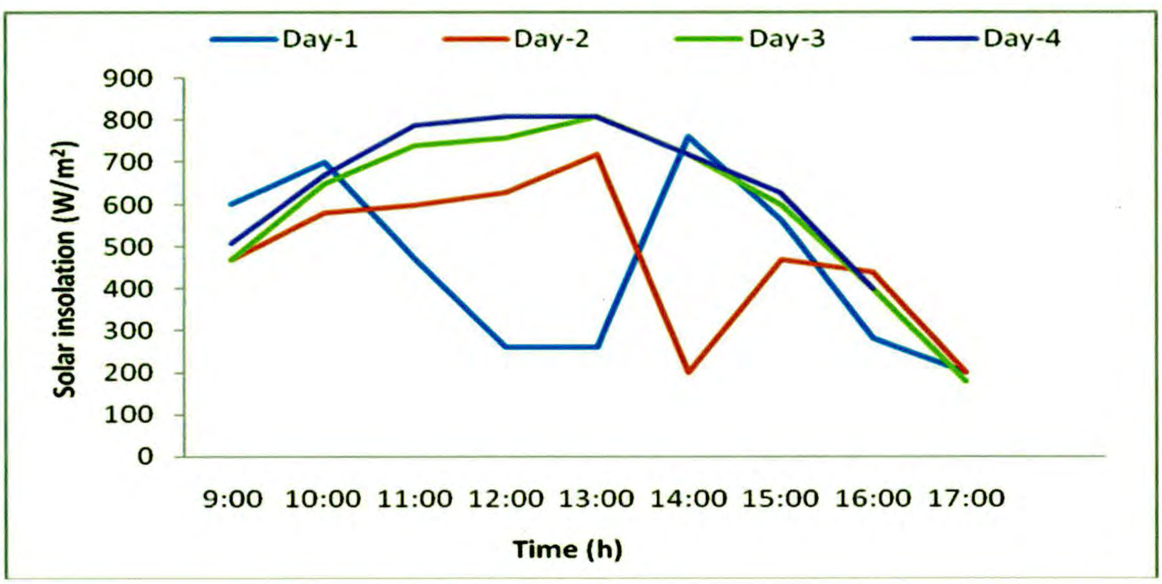

Fig 4.33: Variation of solar insolations with time (fan operated drying test.)

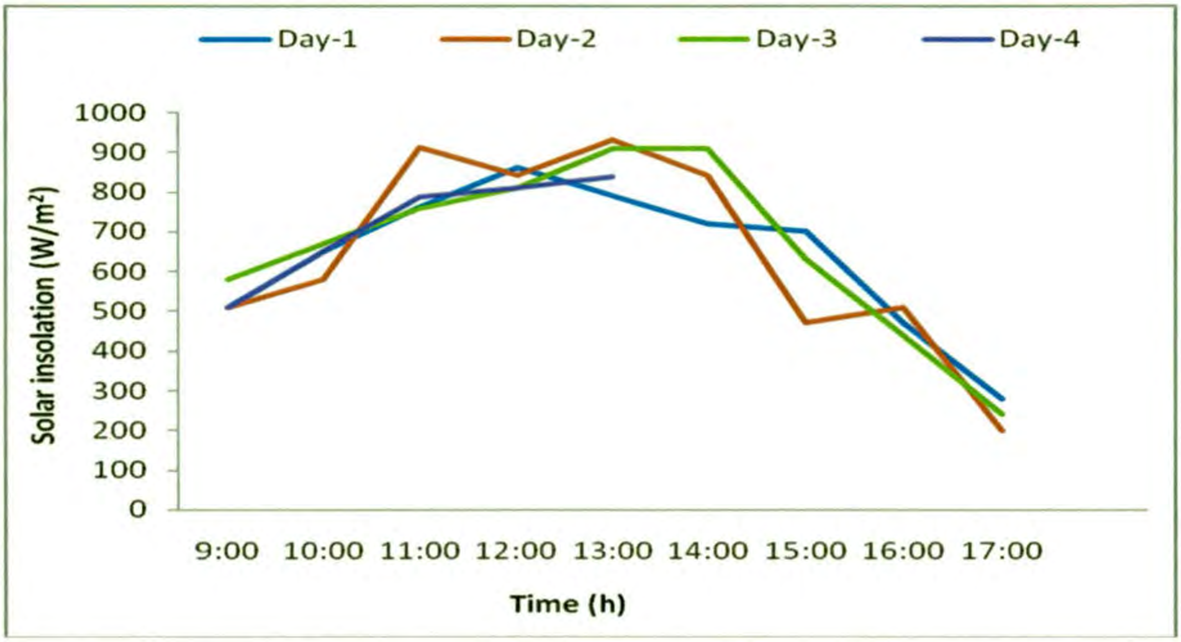

Fig 4.34: Variation of solar insolations with time (without fan operated drying test.)

From figure of relative humidity inside the solar tunnel dryer was less than the relative humidity in the open air sun drying outside the solar tunnel dryer. This is due to the fact that as insolation increases from 9 am onwards temperature inside the dryer increases rapidly which reduces the relative humidity comparing to the increase in temperature inside. There is a quick changes in temperature and relative humidity inside the dryer than outside. This may be due to the fact that the heat generated inside the tunnel entrapped in the dryer which do not escape out due to the transparent polythene sheet cover.

4.5 Moisture content

During load without fan operated test 25 h required for drying total amount of red chilly in the solar tunnel dryer from moisture content of 70.66 to 7.86 per cent (w.b.). During sun drying chilly test 31 h required for drying total amount of red chilly, from moisture content 71.12 to 7.72 per cent (w.b.). The load test without fan operated was conducted in the months of April (Fig 4.35). Data is presented in Appendix-L and M.

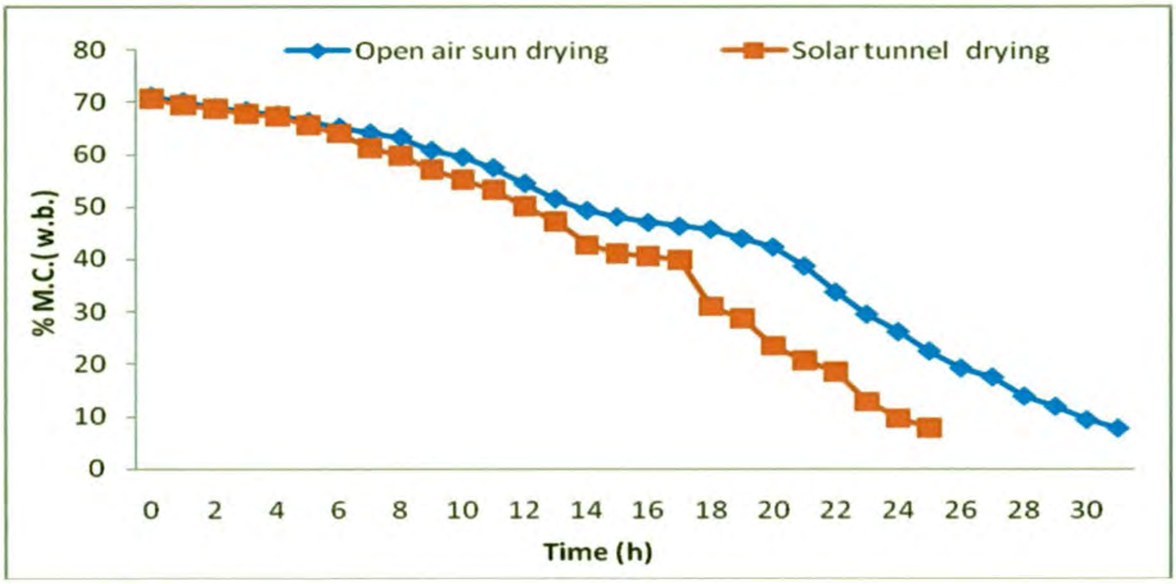

Fig. 4.35: Variation of Moisture evaporation with time without fan operated load test.

During fan operated load test 26 h required for drying total amount of red chilly in the solar tunnel dryer from moisture content of 75.26 to 7.70 per cent (w.b.). During sun drying chilly test 34 h required for drying total amount of red chilly, from moisture content of 74.61 to 7.54 per cent (w.b.). The load fan operated test was conducted in the months of May (Fig 4.36). Data is presented in Appendix-N and O.

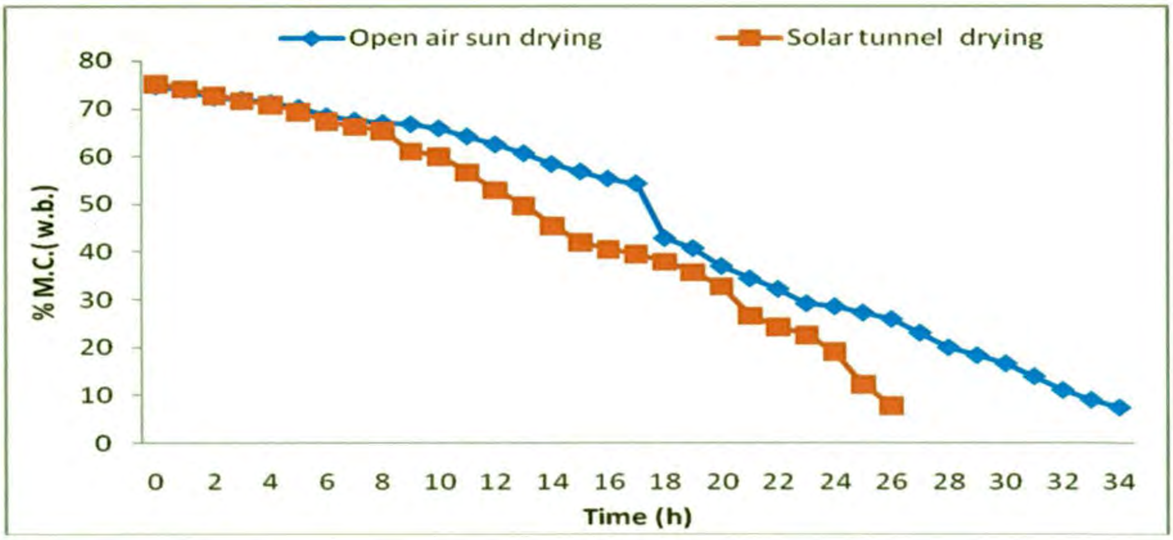

Fig. 4.36: Variation of Moisture evaporation with time fan operated load test.

4.6 Variation of drying rate and drying efficiency

From the data obtained during investigation it was observed that the constant rate period of drying was absent during the entire period of drying and the drying took place under the falling rate period in both the drying methods.

The drying rate for the red chilly was estimated from the difference in its moisture content in a given time interval and expressed as gm water evaporated per hour. It was observed that drying rate and drying efficiency of red chilly is decreases as moisture content of material is decreases. At starting time the drying rate was more. Reason is that more moisture is lost in less time and the free moisture available in chilly is less at later stages, which resulted in the lower drying rates at later stages. The drying rate of red chilly under different conditions is represented in Fig 4.37 and Fig 4.38 respectively and values are shown in Appendix-L M N and O.

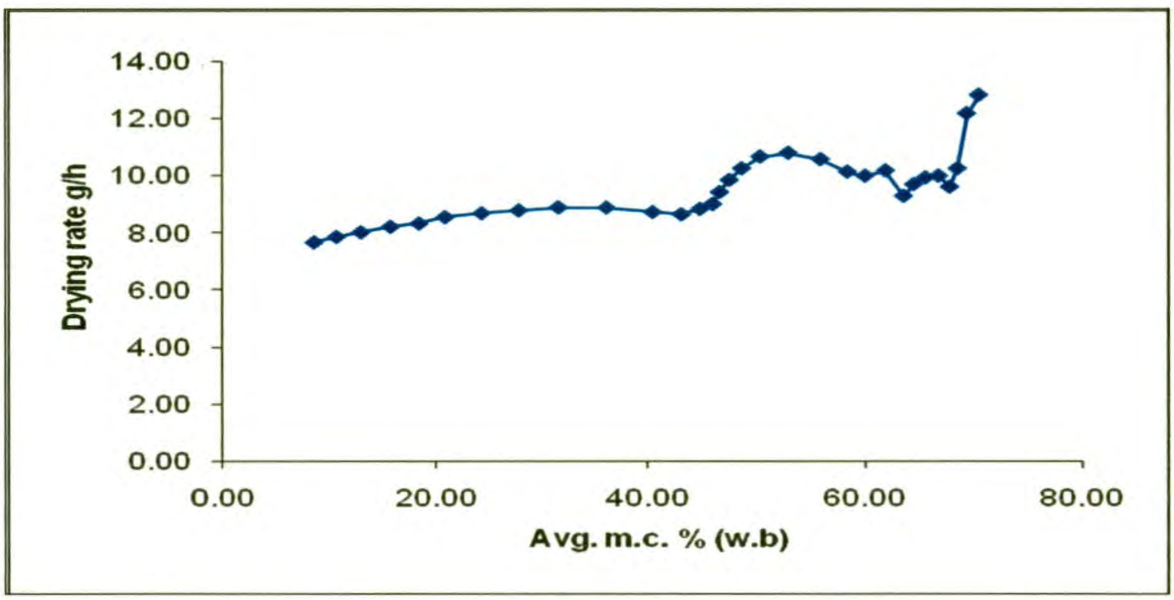

Fig. 4.37: Variation in drying rate with moisture content of open air Sun chilly drying (comparison with without fan operated test)

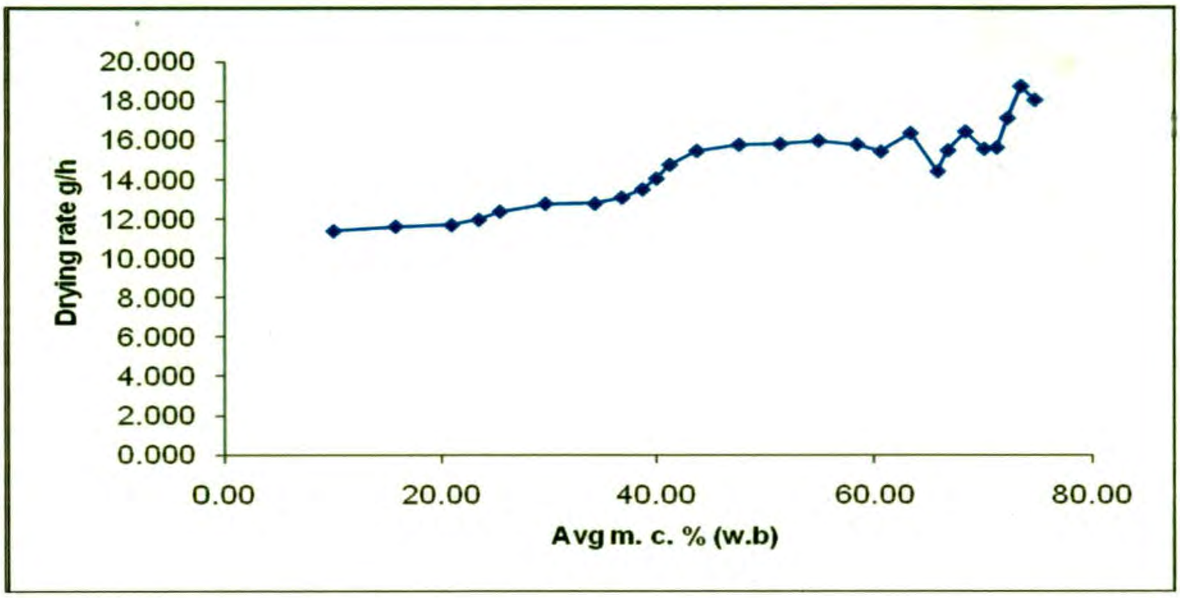

Fig. 4.38: Variation in drying rate with moisture content of fan operated solar tunnel chilly drying.

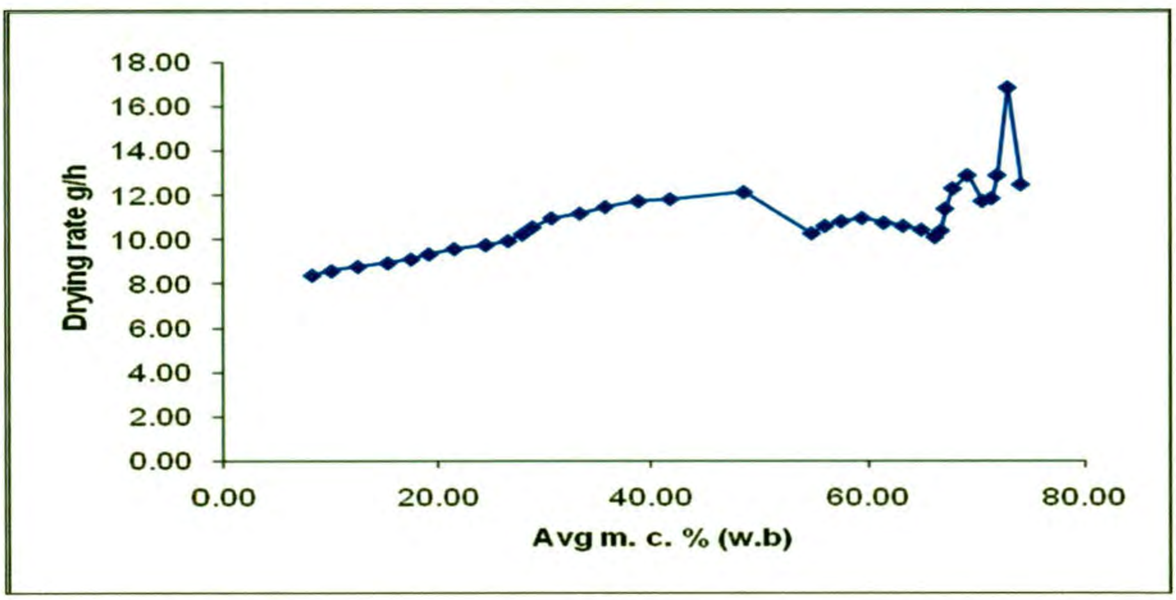

Fig. 4.39: Variation in drying rate with moisture content of open air Sun chilly Drying (comparison with fan operated test).

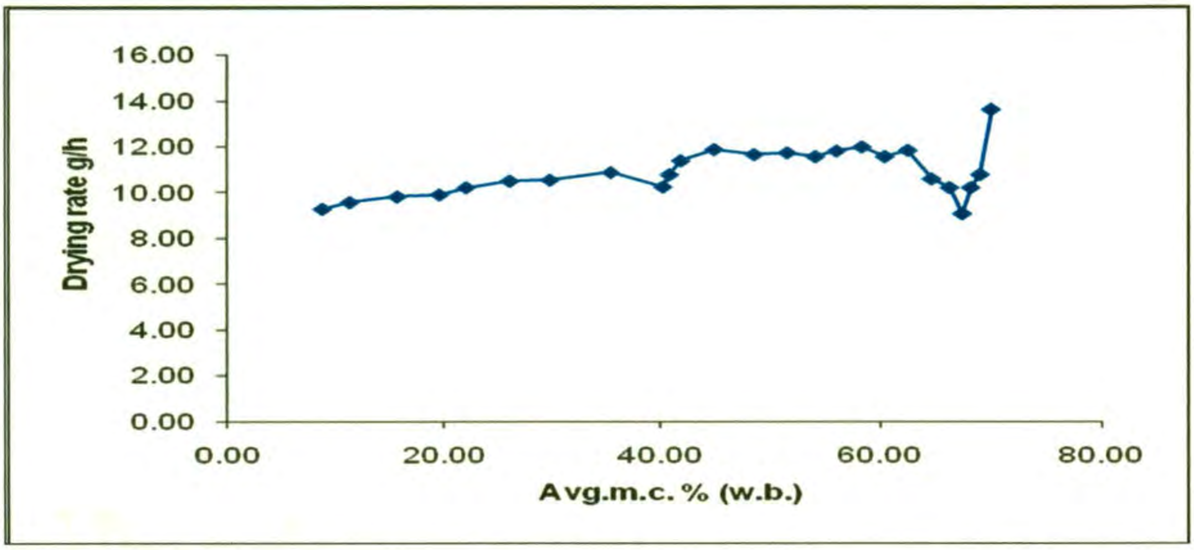

Fig. 4.40: Variation in drying rate with moisture content of without fan operated solar tunnel chilly drying.

4.6.1 Efficiency of solar tunnel dryer

Efficiency of solar tunnel dryer fan operated and without fan operated was calculated considering a capacity of 50 kg chilly required 3 days.

Table 4.4 Moisture evaporated average solar insolations and solar tunnel dryer efficiency without fan operated for chilly drying (Fig 4.41)

Days	Moisture evaporated per day (kg)	Average solar insolation (W/m^2)	Dryer efficiency, per cent
First day (April 24, 2010)	17.425	637.78	40.179
Second day (April 25, 2010)	11.603	643.34	26.523
Third day, (April 26, 2010)	6.587	661.12	14.653

Table 4.5 Moisture evaporated average solar insolations and solar tunnel dryer efficiency fan operated for chilly drying (Fig 4.42)

Days	Moisture evaporated per day (kg)	Average solar insolation (W/m^2)	Dryer efficiency, Per cent
First day (May 8, 2010)	17.638	454.44	57.078
Second day (May 9, 2010)	14.012	478.89	43.029
Third day (May 10, 2010)	8.075	592.23	20.052

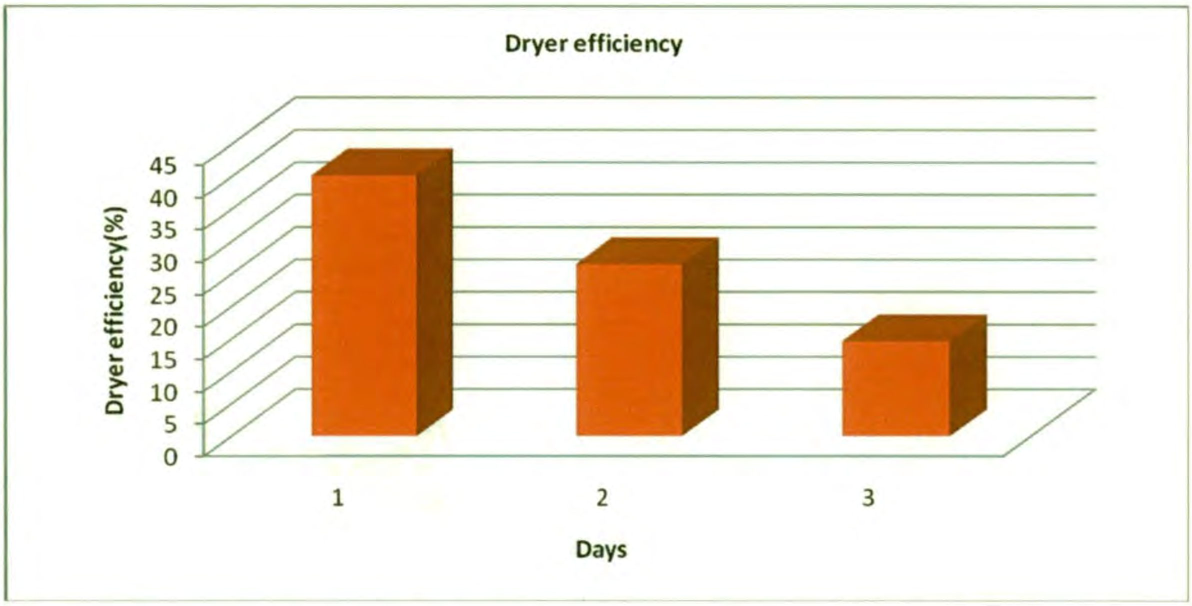

Fig 4.41: Efficiency of solar tunnel dryer each day of chilly drying without fan operated test.

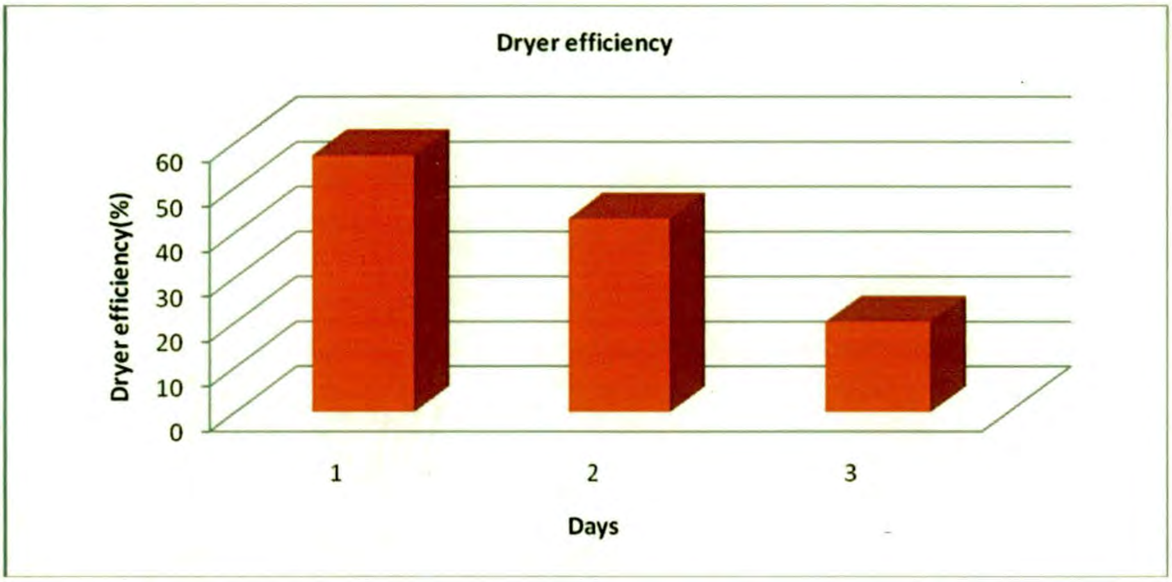

Fig 4.42: Efficiency of solar tunnel dryer each day of chilly drying fan operated test.

From Table 4.4 and 4.5 it was observed that dryer efficiency was directly proportional to moisture evaporation i.e. efficiency decreases with moisture evaporation.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSIONS

Most of agricultural products are dried at temperature range of 45–75^{0}C. Solar energy can be used to heat air up to this range of temperature needed for drying of most of agricultural products, efficiently and economically without compromising in quality of final product. There are many types and designs of solar dryers available for drying of agricultural commodity. The solar tunnel dryer is used mostly and more efficiently for drying agricultural and industrial products.

The study includes design and development of solar tunnel dryer of 50 kg capacity per batch of fresh red chilly at the C.A.E.T., M.A.U. Parbhani. The dryer consist of solar air collector cum drying chamber of size 5.182 m x 1.22 m. The dryer had rectangular base structure with hemispherical roof. The frame made up of hoops of M.S. square pipes, over which 200 micron UV stabilized polythene sheet is wrapped. One end of the frame consists of eight trays each of 122 cm x 9 cm size for loading and unloading the material. Two chimneys of 9.72 cm diameter and 30 cm height are installed for producing air draft in the dryer. The total cost of construction of solar tunnel dryer was Rs 36220/-.

The tests were conducted to know the performance of designed dryer in the month of April and May 2010. The tests were conducted from 9:00 to 17:00 h and the hourly data was recorded. The no load test (fan operated and without fan operated) was carried out to know the trend of various operating parameters with respect to time.

During no load fan operated test maximum temperature inside the solar tunnel dryer was 66.5^{0}C while minimum was 47^{0}C. The corresponding maximum and minimum ambient temperature was 40^{0}C and 37^{0}C respectively. It was observed that there was increment of 26.5^{0}C temperature inside the solar tunnel dryer as compared to ambient temperature. The average ambient solar insolation was 555.56 W/m^2. The maximum and minimum relative humidity inside the solar tunnel dryer was 39 per cent and 24 per cent respectively. The maximum and minimum relative humidity outside solar tunnel dryer was 39 per cent and 33 per cent respectively.

During no load without fan operated test maximum temperature inside the solar tunnel dryer was 70^0C while minimum was 44^0C. The corresponding maximum and minimum ambient temperature was 41.5^0C and 37.5^0C respectively. It was observed that there was increment of 28.5^0C temperature inside the solar tunnel dryer as compared to ambient temperature. The average ambient solar insolation was 597.78 W/m^2. The maximum and minimum relative humidity inside the solar tunnel dryer was 38 per cent and 16 per cent respectively. The maximum and minimum relative humidity outside solar tunnel dryer was 35 per cent and 29 respectively.

The load test (fan operated and without fan operated) of dryer was conducted for evaluating the performance at actual loaded condition. The performance of solar tunnel dryer carried out for drying red chilly. Two samples of fresh red chilly were kept for experiment. One inside the solar tunnel dryer; where as one sample was kept outside the solar tunnel dryer for open air sun drying.

During full load fan operated test maximum temperature inside the solar tunnel dryer was 73^0C while minimum was 48^0C. The corresponding maximum and minimum ambient temperature was 42^0C and 37^0C respectively. The air temperature rise inside the solar tunnel dryer over ambient air temperature was 31^0C. The maximum solar insolation inside the solar tunnel dryer was 810 W/m^2 and minimum was 180 W/m^2. The maximum and minimum relative humidity inside the solar tunnel dryer was 35 per cent and 23 per cent respectively. The maximum and minimum relative humidity outside solar tunnel dryer was 42 per cent and 33 per cent respectively.

During full load without fan operated test maximum temperature inside the solar tunnel dryer was 78.5^0C while minimum was 42^0C. The corresponding maximum and minimum ambient temperature was 42^0C and 37^0C respectively. The air temperature rise inside the solar tunnel dryer over ambient air temperature was 36.5^{0}C. The maximum solar insolation inside the solar tunnel dryer was 930 W/m^2 and minimum was 200 W/m^2. The maximum and minimum relative humidity inside the solar tunnel dryer was 32 per cent and 19 per cent respectively. The maximum and minimum relative humidity outside solar tunnel dryer was 34 per cent and 23 per cent respectively.

Fan operated load test the initial moisture content of red chilly was 75.26 per cent (w.b.), which is reduced up to 7.70 per cent. The total time required to reduce this moisture content was 26 h. Open air sun drying red chilly initial moisture content was 74.61 per cent (w.b.) which was reduced up to 7.54 per cent (w.b.) respectively. The total time required to reduce this moisture content was 34 h.

Without fan operated test the initial moisture content of red chilly was 70.66 per cent (w.b.), which was reduced up to 7.86 per cent. The total time required to reduce this moisture content was 25 h.

Open air sun drying initial moisture content of red chilly was 71.12 per cent (w.b.), which is reduced up to 7.72 per cent (w.b.) respectively. The total time required to reduce this moisture content was 31 h. The variations of moisture content were measured at interval of one hour.

The surface area, length, shape, bulk density, diameter, of the chilly decreased with the increase in drying time. The temperature and relative humidity had a major role on drying of chilly. As temperature increased relative humidity decreased and thereby the drying rate of chilly increased. Drying took place in the falling rate period.

Conclusions

The following major conclusions were drawn from the experimental studies of performance of solar tunnel dryer for drying red chilly.

1. During no load without fan operated test, the maximum and minimum temperature inside the solar tunnel dryer in the month of April was 70^{0}C and 44^{0}C respectively; while the corresponding maximum and minimum ambient temperature was 41.5^{0}C and 37.5^{0}C respectively. It was observed that there

was increment of 28.5^{0}C temperature inside the solar tunnel dryer as compared to ambient temperature.

2. The maximum and minimum solar insolation during no load without fan operated test was 760 W/m^2 and 250 W/m^2 respectively.
3. It was found that temperature attended inside the solar tunnel dryer was suitable for drying of red chilly.
4. During load without fan operated test, the initial moisture content of red chilly was 70.66 per cent (w.b.) and it was reduced to value of 7.86 per cent. The time required to reduce this moisture was 25 h. In open air sun drying red chilly it was 71.12 (w.b.) and it was reduced to value of 7.72 per cent. The time required to reduce this moisture was 31 h.
5. During load fan operated test, the initial moisture content of red chilly was 75.26 per cent (w.b.) and it was reduced to value of 7.70 per cent. The time required to reduce this moisture was 26 h. In open air sun drying red chilly it was 74.61 per cent (w.b.) and it was reduced to value of 7.54 per cent. The time required to reduce this moisture was 34 h.
6. The solar tunnel dryer is able to reduce the drying time and to increase the product quality in comparison to the sun drying
7. Dryness of red chilly and overall appearance of the red chilly at the end of drying process were found good.
8. It is estimated that total cost of solar tunnel dryer of 50 kg capacity was about Rs. 36,220/- including electrical component.
9. To attain maximum temperature in solar tunnel dryer the drying chamber of solar tunnel dryer need to be air tight and restricted air supply form bottom side of tunnel.

SUGGESTION FOR FUTURE WORK

1. The dryer should be tried for drying other products also.
2. The dryer should test another season also.
3. The efforts should be made to reduce the initial cost of dryer by using some other constructional material.
4. The dryer should be tested at different height form ground level.

ABSTRACT

ABSTRACT

The solar tunnel dryer of 50 kg capacity per batch is designed and developed at the C.A.E.T., M.A.U., Parbhani. The dryer had rectangular base structure of size 5.19 m x 1.22 m with hemispherical roof of maximum ceiling height 0.62 m. The frame made up of hoops of M.S. square pipes, over which 200 micron UV stabilized polythene sheet is wrapped. One end of the frame consists of Tray opening of 9 cm x 622 cm size for loading and unloading the material and free space movement. Two chimneys of 15 cm diameter and 30 cm height were installed for producing draft in the dryer.

The tests were conducted from 9:00 to 17:00 h in the month of April and May and hourly data was recorded. The performance of solar tunnel dryer was evaluated for two conditions viz. no load condition and full load condition with red chilly. These tests were carried out to know the trend of various operating parameters such as temperature, solar insolation, relative humidity and moisture content of red chilly inside and outside the solar tunnel dryer. During load without fan operated test 25 h required for drying total amount of red chilly, in the solar tunnel dryer form moisture content 70.66 to 7.86 per cent (w.b). During sun drying chilly test 31 h required for drying total amount of red chilly, form moisture content of 71.12 to 7.72 per cent (w.b).The load without fan operated test was conducted in months of April.

During fan operated load test 26 h required for drying total amount of red chilly, in the solar tunnel dryer form moisture content of 75.26 to 7.70 per cent (w.b). During sun drying chilly test 34 h required for drying total amount of red chilly, form moisture content of 74.61 to 7.54 per cent (w.b).The load fan operated test was conducted in month of May. The total cost of construction of solar tunnel dryer is Rs 36,220/-.

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APPENDICES

APPENDIX –A

Position of thermometer

Position	Number
Ambient temperature Thermometer	T(0)
Thermometer tray 1	T(1)
Thermometer tray 2	T(2)
Thermometer tray 3	T(3)
Thermometer tray 4	T(4)
Thermometer tray 5	T(5)
Thermometer tray 6	T(6)
Thermometer tray 7	T(7)
Thermometer tray 8	T(8)
sun dried chilly bed Thermometer 9	T(9)
Thermometer chimney 1	C1
Thermometer chimney 2	C2

APPENDIX –B

No Load test without fan

Date 22\4\2010

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)									R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1 (^{0}C)	Temp C_2 (^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside (km/h)
		T0	T1	T2	T3	T4	T5	T6	T7	T8								
9:00	450	37.5	44	48.5	49	49.5	48	48	48	49.5	38	35	45	41	0.792	0.864	1.152	0.396
10:00	600	38	58	55.5	58	58	56	58	58	59	34	33	54	56	0.828	0.936	2.448	0.18
11:00	710	40	63.5	62.5	64	64.5	63.5	63	63	62	27	31	54.5	55.5	0.864	1.008	3.024	0.252
12:00	760	41	67	66.5	67	66	67.5	66.5	66	67.5	21	29	57	57	1.08	1.224	3.672	0.324
13:00	760	41	68	68	68.5	68.5	68	66.5	67	68.5	16	29	58.5	58	0.648	0.684	3.42	0.216
14:00	740	41.5	68.5	68.5	68	68.5	69.5	68	68.5	70	16	29	55	55	0.72	0.648	1.188	0.432
15:00	670	39.5	62	62	62.5	64	64	62	62.5	65	17	29	55	56	0.756	0.612	2.52	0.576
16:00	440	38.5	57	57	56.5	57	57.5	56.5	56.5	58.5	17	29	49	49	0.648	0.504	5.472	0.468
17:00	250	37	52	51	52	52.5	51	50.5	50.5	50.5	18	30	45.5	46	0.684	0.432	6.732	0.432
Avg.	597.77	39.33	60	59.94	60.61	60.94	60.55	59.88	60	61.16	22.66	30.44	52.61	52.61	0.78	0.768	3.292	0.364

APPENDIX –C

Load test without fan

Date 24\4\2010 Day I

Time (h)	Solar insolation W\m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1(^{0}C)	Temp C_2(^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside Centre of tunnel dryer (km/h)	Weight loss of chilly g/h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9									solar dried	sun dried
9:00	510	36	43	43.5	44	44.5	45	46	47	49.5	41.4	27	32	49.5	50.5	0.792	0.864	3.132	0.252	300	270
10:00	650	37.5	56	53	55	56	56	53	57	56	43	26	30	53.5	53	0.648	0.54	3.348	0.324	288	260
11:00	760	38	59	64	58	61	60	55	61	57	49	25	30	56.5	50	0.468	0.576	5.436	0.18	281	251
12:00	860	39	64	68	68	65	65.5	60.5	63	63.5	50.5	20	26	56	54	0.684	0.72	5.148	0.72	273	246
13:00	790	40.5	65	61	63	65.5	64	63.5	62	63	52	19	23	54.5	53	0.828	0.756	3.312	0.18	268	240
14:00	720	41.5	64	64.5	64	63	69	64	63	62.5	52.5	19	23	52	55	1.008	0.9	3.528	0.36	255.0	241
15:00	700	40	64	62	62	60.5	60	59.5	59.5	59	48	19	23	50	57.5	0.864	0.9	3.132	0.216	244.0	223.5
16:00	470	38	57	57	56.5	57	57	56	56.5	56	44	20	23	49	50.5	0.684	0.612	1.98	0.324	227.0	217
17:00	280	37	46	44.5	44.5	44.5	44	44	44	44	40	21	24	41	43	0.54	0.504	1.512	0.432	218.5	212
Avg.	637.77	38.61	57.55	57.5	57.22	57.44	57.83	55.72	57	56.72	46.71	21.77	26	51.33	51.83	0.724	0.708	3.392	0.332		

Appendix –D

Load test without fan

Date 25\4\2010 Day II

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C$_1$(^{0}C)	Temp C$_2$(^{0}C)	Air Velocity C$_1$ (km/h)	Air Velocity C$_2$ (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside Centre of tunnel dryer (km/h)	Weight loss of chilly g/h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9									solar dried	sun dried
9:00	510	36.5	42.5	44	45	44.5	46	47.5	48.5	49.5	41	32	34	47	46.5	0.684	0.612	3.312	0.324	205	198.5
10:00	580	37	57	54	58.5	58	55	58.5	61.5	60	43.5	28	33	45.5	46	0.288	0.324	3.024	0.432	196	192
11:00	910	38.5	57.5	56.5	59	57	57.5	58.5	59	56.5	51	26	32	52	52.5	0.324	0.252	2.7	0.504	188	183
12:00	840	41	67	66	67	67	69	69.5	69.5	69	56	23	30	50.5	50.5	0.828	0.792	2.34	0.288	176	171
13:00	930	40	61	60.5	60	59.5	61	60.5	61	60.5	50	22	29	49.5	43	0.684	0.54	4.392	0.324	166.5	160.5
14:00	840	42.2	67	68	68	62	62	66	66	65	50.5	21	29	57	54	0.648	0.792	7.272	0.396	153.5	153.5
15:00	470	39	54	54	54	54	55.5	54.5	54	54	46	21	29	50	49	0.864	1.08	8.64	0.396	149.5	150
16:00	510	39.5	59	59	58.5	58	60.5	59	57.5	58.5	47.5	22	29	49	49.5	0.9	1.008	3.78	0.54	148	147
17:00	200	37	44	44	43	42	44	42	44	43	40.5	23	30	42	42.5	0.936	0.972	1.404	0.288	146.5	145
Avg.	643.33	38.96	56.55	56.22	57	55.77	56.72	57.33	57.88	57.33	47.33	24.22	30.55	49.166	48.16	0.684	0.708	4.096	0.388		

APPENDIX –E

Load test without fan

Date 26\4\2010 Day III

Time (h)	Solar insolation W\m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1(^{0}C)	Temp C_2(^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside Centre of tunnel dryer (km/h)	Weight loss of chilly g/h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9									solar dried	sun dried
9:00	580	36	51	51	54.5	50.5	54	57.5	56	58	41	27	32	49	50	0.18	0.252	3.42	0.324	127.5	143.5
10:00	670	36.5	62	58	60	60	57	64	62	59	46	26	30	53	53	0.288	0.324	2.916	0.18	123.5	139
11:00	760	37	68	67	65.5	66.5	65.5	71.5	69	68	49	26	30	54	54	0.324	0.396	2.196	0.36	120	135
12:00	810	39	73	72,5	71	71	72.5	75.5	73	73	46	23	28	55	55	0.828	0.864	1.368	0.468	111	127
13:00	910	40	75	76.5	71.5	71	75.5	76.5	77.5	73.5	55	21	28	60	61	0.684	0.72	4.644	0.612	108	117.5
14:00	910	42	76.5	72	74.5	74	76	78.5	78.5	76.5	57	20	28	56.5	57	0.612	0.54	5.4	0.288	101	110.5
15:00	630	39.5	62	60	61	61.5	64.5	64	64.5	63.5	50.5	20	28	56	56	0.504	0.648	6.518	0.252	97.5	105.5
16:00	440	38	56.5	55.5	54.5	54	56.5	56	55.5	55	50	21	28	49	50.5	0.756	0.828	2.016	0.144	95.5	100.5
17:00	240	37									45		29					2.592		-	96.5
Avg.	661.11	38.33	65.5	62.85	64.06	63.56	65.18	67.93	67	65.81	48.83	23	29	54.06	54.56	0.522	0.571	3.452	0.328		

APPENDIX – F

Sun drying of chilly for IVth Day

Date 27\4\2010

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)		R.H. Outside (per cent)	Air Velocity Outside (km/h)	Weight loss of chilly g/h sun dried
		T0	T9			
9:00	510	37.5	43	39	2.592	94.5
10:00	650	38.5	50.5	34	1.872	90.5
11:00	790	39.5	55	32	6.732	88.5
12:00	810	40	55	31	12.24	86.5
13:00	840	41.5	56	31	8.712	84.5
Avg.	720	39.4	51.9	33.4	6.4296	88.9

APPENDIX –G

No load test (fan operated)

Fan on time: 11.20 A.M.

Date 4\5\2010

Fan off time: 16.05 P.M.

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)									R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1(^{0}C)	Temp C_2(^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside (km/h)		
		T0	T1	T2	T3	T4	T5	T6	T7	T8								In front of fan	Centre of tunnel dryer	East side of dryer
9:00	560	37.5	48	50.5	52	53	52.5	52.5	54	53	39	39	44.5	45.5	0.576	0.576	0.612		0.324	
10:00	580	38	51	51.5	54	55	54	58.5	59	58	33	35	46.5	47.5	1.152	1.224	3.672		0.36	
11:00	720	40	58	60.5	61	61.5	63	62	66	62	30	34	53	55	1.116	1.476	1.188		0.432	
12:00	760	37.5	56	56	57	57	59	59.5	61.5	60	26	33	50	52	2.448	2.196	2.016	4.104	0.504	0.288
13:00	790	40	55	57	56.5	59.5	66.5	58	60	60	25	33	52	52.5	1.224	1.476	1.296	4.716	1.368	1.188
14:00	510	40.7	56	57	57.5	57	59.5	60.5	61	60	24	33	49.5	52	1.8	1.872	1.728	3.492	1.62	1.152
15:00	440	39.5	54.5	55	56	55	57	57	58	57	25	33	49	50	0.576	1.188	1.8	2.412	1.296	1.08
16:00	380	39	51	51.5	52	51.5	52	52.5	54	54	25	33	48	49	0.468	1.188	5.22	3.312	0.576	0.36
17:00	260	37	47	47	47.5	47.5	47.5	48	49	48.5	26	34	43	43.5	0.432	1.044	1.296		0.612	
Avg.	555.55	38.8	52.94	54	54.83	55.22	56.77	56.5	58.05	56.94	28.11	34.11	48.38	49.66	1.088	1.36	2.092	3.607	0.788	0.813

APPENDIX –H

Load test (fan operated)

Fan on time: 11.45 A.M.

Date 8\5\2010 Day I

Fan off time: 12.10 P.M.

Time (h)	Solar insolation W\m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1(^{0}C)	Temp C_2(^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside (km/h)			Weight loss of chilly g/h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9								In front of fan	Centre of tunnel dryer	East side of dryer	Solar tunnel dried	sun dried
9:00	600	37.5	51	49	52	52.5	50	53	53.5	52	46	32	42	46	47	0.18	0.324	0.936		0.216		291	315
10:00	700	38	56	55	56	57	52	58	57	55.5	50.5	29	38	50	50.5	0.252	0.396	14.868		0.288		278	305
11:00	470	38	62	62	62.5	62	60	61	60	59	49.5	26	33	49.5	52	0.36	0.54	1.152		0.108		264	288
12:00	260	37	50.5	50	51.5	50.5	50.5	57.5	52	52	46	25	33	46	46	0.72	1.152	1.476	4.932	0.9	0.9	254	284
13:00	260	37	54.5	54.5	56	56	56.5	56.5	57	56.5	45.5	24	33	46.5	47	0.684	1.08	1.08		0.036		246	277
14:00	760	42	57	58.5	60	59.5	61	60	62	62	57	24	33	53	54	0.936	1.512	3.492		0.36		235	268
15:00	560	40	58	58	61.5	59	60.5	60.5	59	61.5	51	24	33	51.5	51	0.396	0.324	1.44		0.288		220	253
16:00	280	36.5	50	50	51.5	50	50.5	51.5	50	52	44	25	33	45	43	0.288	0.792	0.26		0.288		213	246
17:00	200	36	47	46.5	47.5	46	46	46	46	47	42.5	26	34	44.5	44.5	0.468	0.432	0.54		0.468		208	242
Avg.	454.44	38	54	53.72	55.38	54.72	54.11	56	55.16	55.27	48	26.11	34.66	48	48.33	0.476	0.728	2.804	4.932	0.328	0.9		

APPENDIX –I

Load test (fan operated) Fan on time: 11.15 A.M.

Date 9\5\2010 Day II Fan off time: 15.15 P.M.

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C_1 (^{0}C)	Temp C_2 (^{0}C)	Air Velocity C_1 (km/h)	Air Velocity C_2 (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside (km/h)			Weight loss of chilly g/h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9								In front of fan	Centre of tunnel dryer	East side of dryer	solar dried	sun dried
9:00	470	37	51	48	54	51	52	52	52	53	44	32	41	46	46	0.54	0.468	2.52		0.288		185	240
10:00	580	38.5	58	54	60	60	55.5	59	61	59	49	28	40	50	50.5	0.324	0.468	1.908		0.324		180	234
11:00	600	40	63.5	63	67	65.5	64	64.5	64.5	62	51	25	40	54	54.5	0.252	0.432	2.88		0.396		166	223
12:00	630	42	58	59	62	65	62	62	68	64	54	24	38	53	52.5	4.5	5.652	4.14	8.172	0.828	0.792	153	213
13:00	720	44	57	57.5	60	60.5	60.5	60.5	60.5	62.5	57	24	35	54.5	53	3.996	5.58	12.672	8.784	1.188	0.576	143	203
14:00	200	39	54	53	56	56.5	56	56	58	57	49.5	24	35	46.5	47.5	4.356	5.58	9.36	9	1.188	0.864	132	192
15:00	470	39.5	53	53	54.5	54	53	53.5	55.5	54	50	25	35	46	47	3.024	3.492	2.016	4.356	1.044	0.432	124	185
16:00	440	40	54	55	57	55	56	55	56	56.5	51	25	35	55	55	1.188	1.332	8.064		0.432		121	179
17:00	200	38	50.5	49.5	50.5	48	49	49	9.5	49	49.5	26	36	48.5	48	0.576	0.54	1.872		0.36		119	175
Avg.	478.88	39.77	55.44	54.66	57.88	57.27	56.44	56.83	53.88	57.44	50.55	25.88	37.22	50.38	50.44	2.084	2.616	5.048	7.578	0.672	0.666		

APPENDIX –J

Load test (fan operated) Fan on time: 10.30 A.M.

Date 10\5\2010 Day III Fan off time: 16.10 P.M.

Time (h)	Solar insolation W\m^2	Temperature variation (^{0}C)										R.H. Inside (per cent)	R.H. Outside (per cent)	Temp C(^{0}C)$_1$	Temp C$_2$(^{0}C)	Air Velocity C$_1$ (km/h)	Air Velocity C$_2$ (km/h)	Air Velocity Outside (km/h)	Air Velocity Inside (km/h)			Weight loss of chilly g\h	
		T0	T1	T2	T3	T4	T5	T6	T7	T8	T9								In front of fan	Centre of tunnel dryer	East side of dryer	solar dried	sun dried
9:00	470	37.5	53	54.5	54.5	53	54	54	57	56	42.5	35	42	44.5	47.5	0.216	0.216	5.616		0.18		116	140
10:00	650	39	61	58	62	59	66	62	63	65.5	48	30	38	51.5	53	0.576	0.468	3.096		0.288		112	135
11:00	740	41	60	62	65	64.5	61	62	58	62.5	51	27	33	53	53.5	2.268	2.592	5.76	8.46	0.576	0.216	107	127
12:00	760	42	58	58	66	64	66.5	66.5	73	73	52	25	33	55	55.5	2.7	3.06	4.608	9.396	2.376	0.684	98	122
13:00	810	44	62	65	72	69	65	66	70	69	56	24	33	57	56.5	3.384	5.076	6.408	8.28	0.756	0.36	95	118
14:00	720	43	58	62	70.5	59	63	66	64	70	53	23	33	55.5	55	2.772	5.04	7.164	13.716	0.9	0.54	93	113
15:00	600	41	59	63.5	69.5	58	61	64	61	63	50	24	33	54.5	54.5	2.484	3.672	3.96	8.352	1.152	0.9	89	112
16:00	400	39.5	54	55	58	55	54	54.5	55	54	50.5	24	33	49	50	2.268	4.284	4.032	14.364	1.116	0.216	82	110
17:00	180	37.5	52	52	52	50	49.5	50	51	51	43	25	34	48	49	0.576	0.54	3.024		3.024		78	108
Avg.	592.22	40.5	57.44	58.88	63.27	59.05	60	60.55	61.33	62.66	49.55	26.33	34.66	52	52.72	1.916	2.772	4.852	10.428	1.152	0.486		

APPENDIX –K

Sun drying 0f chilly   Day IVth Day

Date 11\5\2010

Time (h)	Solar insolation W/m^2	Temperature variation (^{0}C)		R.H. Outside (per cent)	Air Velocity Outside (km/h)	Weight loss of chilly g/h sun dried
		T0	T9			
9:00	510	38	44.5	37	6.66	104
10:00	670	39	47	35	2.988	100
11:00	790	39.5	49	32	4.824	98
12:00	810	40.5	51	31	5.40	96
13:00	810	42	56	30	7.668	93
14:00	720	44.5	56	30	7.848	90
15:00	630	42	52	30	13.5	88
16:00	400	40	49.5	30	5.544	86.5
Avg.	667.5	40.68	50.62	31.87	6.804	

APPENDIX –L

Moisture reduction and time required in solar tunnel dryer without fan operated chilly drying test.
Initial moisture content (w.b.) =70.66 per cent

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample (g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
1	0	0.0	300.0	70.66	-	240.83	-	--
2	1	12.0	288.0	69.45	70.05	227.31	234.07	13.64
3	2	19.0	281.0	68.69	69.07	219.35	223.33	10.80
4	3	27.0	273.0	67.77	68.23	210.26	214.81	10.23
5	4	32.0	268.0	67.17	67.47	204.58	207.42	9.09
6	5	45.0	255.0	65.49	66.33	189.81	197.19	10.23
7	6	56.0	244.0	63.94	64.72	177.30	183.55	10.61
8	7	73.0	227.0	61.24	62.59	157.98	167.64	11.85
9	8	81.5	218.5	59.73	60.48	148.32	153.15	11.58
10	9	95.0	205.0	57.08	58.40	132.98	140.65	12.00
11	10	104.0	196.0	55.11	56.09	122.75	127.87	11.82
12	11	112.0	188.0	53.20	54.15	113.66	118.21	11.57
13	12	124.0	176.0	50.01	51.60	100.02	106.84	11.74
14	13	133.5	166.5	47.15	48.58	89.23	94.62	11.67
15	14	146.5	153.5	42.68	44.92	74.45	81.84	11.89
16	15	150.5	149.5	41.14	41.91	69.91	72.18	11.40
17	16	152.0	148.0	40.55	40.85	68.20	69.05	10.80
18	17	153.5	146.5	39.94	40.24	66.50	67.35	10.26
19	18	172.5	127.5	30.99	35.46	44.90	55.70	10.89
20	19	176.5	123.5	28.75	29.87	40.36	42.63	10.56
21	20	185.0	115.0	23.49	26.12	30.70	35.53	10.51
22	21	189.0	111.0	20.73	22.11	26.15	28.42	10.23
23	22	192.0	108.0	18.53	19.63	22.74	24.45	9.92
24	23	199.0	101.0	12.88	15.70	14.79	18.76	9.83
25	24	202.5	97.5	9.75	11.32	10.81	12.80	9.59
26	25	204.5	95.5	7.86	8.81	8.54	9.67	9.30

APPENDIX –M

Moisture reduction and time required for open air Sun drying of chilly. **Date: 24\4\2010**
Initial moisture content (w.b.) =71.12 per cent

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample (g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
1	0	0.0	270.0	71.12	-	246.26	-	--
2	1	10.0	260.0	70.01	70.56	233.44	239.85	12.82
3	2	19.0	251.0	68.93	69.47	221.89	227.66	12.18
4	3	24.0	246.0	68.30	68.62	215.48	218.69	10.26
5	4	30.0	240.0	67.51	67.91	207.79	211.63	9.62
6	5	39.0	231.0	66.24	66.88	196.24	202.02	10.00
7	6	46.5	223.5	65.11	65.68	186.63	191.44	9.94
8	7	53.0	217.0	64.07	64.59	178.29	182.46	9.71
9	8	58.0	212.0	63.22	63.64	171.88	175.08	9.30
10	9	71.5	198.5	60.72	61.97	154.57	163.22	10.19
11	10	78.0	192.0	59.39	60.05	146.23	150.40	10.00
12	11	87.0	183.0	57.39	58.39	134.69	140.46	10.14
13	12	99.0	171.0	54.40	55.90	119.30	126.99	10.58
14	13	109.5	160.5	51.42	52.91	105.83	112.57	10.80
15	14	116.5	153.5	49.20	50.31	96.86	101.34	10.67
16	15	120.0	150.0	48.02	48.61	92.37	94.61	10.26
17	16	123.0	147.0	46.96	47.49	88.52	90.44	9.86
18	17	125.0	145.0	46.22	46.59	85.95	87.24	9.43
19	18	126.5	143.5	45.66	45.94	84.03	84.99	9.01
20	19	131.0	139.0	43.90	44.78	78.26	81.15	8.84

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample (g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
21	20	135.0	135.0	42.24	43.07	73.13	75.70	8.66
22	21	143.0	127.0	38.60	40.42	62.87	68.00	8.73
23	22	152.5	117.5	33.64	36.12	50.69	56.78	8.89
24	23	159.5	110.5	29.43	31.54	41.71	46.20	8.89
25	24	164.5	105.5	26.09	27.76	35.30	38.50	8.79
26	25	169.5	100.5	22.41	24.25	28.89	32.09	8.69
27	26	173.5	96.5	19.20	20.80	23.76	26.32	8.56
28	27	175.5	94.5	17.49	18.34	21.19	22.47	8.34
29	28	179.5	90.5	13.84	15.66	16.06	18.63	8.22
30	29	181.5	88.5	11.89	12.87	13.50	14.78	8.03
31	30	184.0	86.0	9.33	10.61	10.29	11.89	7.87
32	31	185.5	84.5	7.72	8.53	8.37	9.33	7.67

APPENDIX –N

Moisture reduction and time required in solar tunnel dryer for chilly drying (fan operated test.)
Initial moisture content (w.b.) =75.26 per cent

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample(g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
1	0	0	291	75.26	-	304.20	-	--
2	1	13	278	74.10	74.68	286.15	295.18	18.057
3	2	27	264	72.73	73.42	266.70	276.42	18.752
4	3	37	254	71.66	72.19	252.81	259.76	17.131
5	4	45	246	70.73	71.20	241.70	247.25	15.626
6	5	56	235	69.36	70.05	226.42	234.06	15.557
7	6	71	220	67.28	68.32	205.58	216.00	16.437
8	7	78	213	66.20	66.74	195.86	200.72	15.478
9	8	83	208	65.39	65.79	188.92	192.39	14.411
10	9	106	185	61.08	63.24	156.97	172.94	16.360
11	10	111	180	60.00	60.54	150.02	153.50	15.418
12	11	125	166	56.63	58.32	130.58	140.30	15.784
13	12	138	153	52.95	54.79	112.52	121.55	15.974
14	13	148	143	49.65	51.30	98.63	105.57	15.813
15	14	159	132	45.46	47.56	83.35	90.99	15.775
16	15	167	124	41.94	43.70	72.24	77.79	15.464
17	16	170	121	40.50	41.22	68.07	70.15	14.758
18	17	172	119	39.50	40.00	65.29	66.68	14.054
19	18	175	116	37.94	38.72	61.13	63.21	13.504
20	19	179	112	35.72	36.83	55.57	58.35	13.086
21	20	184	107	32.72	34.22	48.62	52.10	12.779
22	21	193	98	26.54	29.63	36.12	42.37	12.766
23	22	196	95	24.22	25.38	31.96	34.04	12.375
24	23	198	93	22.59	23.40	29.18	30.57	11.958
25	24	202	89	19.11	20.85	23.62	26.40	11.691
26	25	209	82	12.20	15.66	13.90	18.76	11.612
27	26	213	78	7.70	9.95	8.34	11.12	11.379

APPENDIX –O

Moisture reduction and time required for open air Sun chilly drying **Date: 8\5\2010**

Initial moisture content (w.b.) =74.61 per cent

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample (g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
1	0	0	315	74.61	-	293.86	-	-
2	1	10	305	73.78	74.19	281.35	287.60	12.50
3	2	27	288	72.23	73.00	260.10	270.72	16.88
4	3	31	284	71.84	72.03	255.10	257.60	12.92
5	4	38	277	71.13	71.48	246.34	250.72	11.88
6	5	47	268	70.16	70.64	235.09	240.72	11.75
7	6	62	253	68.39	69.27	216.34	225.71	12.92
8	7	69	246	67.49	67.94	207.58	211.96	12.32
9	8	73	242	66.95	67.22	202.58	205.08	11.41
10	9	75	240	66.68	66.81	200.08	201.33	10.42
11	10	81	234	65.82	66.25	192.58	196.33	10.13
12	11	92	223	64.14	64.98	178.82	185.70	10.46
13	12	102	213	62.45	63.29	166.32	172.57	10.63
14	13	112	203	60.60	61.53	153.82	160.07	10.77
15	14	123	192	58.34	59.47	140.06	146.94	10.99
16	15	130	185	56.77	57.56	131.31	135.69	10.84
17	16	136	179	55.32	56.04	123.81	127.56	10.63
18	17	140	175	54.30	54.81	118.81	121.31	10.30
19	18	175	140	42.87	48.59	75.05	96.93	12.16
20	19	180	135	40.76	41.81	68.80	71.92	11.85
21	20	188	127	37.02	38.89	58.79	63.79	11.75
22	21	193	122	34.44	35.73	52.54	55.67	11.49
23	22	197	118	32.22	33.33	47.54	50.04	11.20

Sr. No.	Time (h.)	Loss of moisture (g)	Weight of sample (g)	% moisture (w. b.)	% Avg. m.c. (w.b.)	% moisture (d.b.)	% Avg. m.c. (d.b.)	Drying rate g/h
24	23	202	113	29.22	30.72	41.29	44.41	10.98
25	24	203	112	28.59	28.91	40.04	40.66	10.58
26	25	205	110	27.29	27.94	37.54	38.79	10.25
27	26	207	108	25.95	26.62	35.04	36.29	9.95
28	27	211	104	23.10	24.52	30.03	32.54	9.77
29	28	215	100	20.02	21.56	25.03	27.53	9.60
30	29	217	98	18.39	19.21	22.53	23.78	9.36
31	30	219	96	16.69	17.54	20.03	21.28	9.13
32	31	222	93	14.00	15.35	16.28	18.16	8.95
33	32	225	90	11.14	12.57	12.53	14.41	8.79
34	33	227	88	9.12	10.13	10.03	11.28	8.60
35	34	228.5	86.5	7.54	8.33	8.15	9.09	8.40

APPENDIX –P

Design calculation of solar tunnel dryer

Assumptions

The assumptions of certain parameters are made for design of solar tunnel dryer, which includes:

1	Weight of selected product taken for drying, kg	X = 50
2	Initial moisture content of selected product in per cent (w.b.)	m_1= 80 per cent
3	Final moisture content of selected product in per cent (w.b.)	m_2 = 8 per cent
4	Ambient air temperature (^{0}C)	T_1 = 33
5	Temperature inside the solar tunnel dryer (^{0}C)	T_2 = 55
6	Total drying time, h	t = 26
7	Specific heat of water , kcal/kg °C	C_p = 0.45
8	Specific heat of product , kcal/kg °C	C_d = 1.12
9	Specific heat of air (C_a), kJ/kg °C	= 1.005
10	Latent heat of vaporization of water, kcal/kg	λ = 540
11	Density of exit air (ρ_e), kg/ m^3	= 1.0539
12	Density of air at 0^{O}C (ρ_0), kg/ m^3	= 1.252
13	Gravity constant, m/s^2	= 9.8
14	Temperature of air at 0^{O}C(T_0), 0^O K	= 273
15	Overall thermal efficiency of solar tunnel dryer, per cent	η =30 per cent
	Global solar radiation for Parbhani region (k), Kcal/hr/m^2	= 750

Quantity of water to be removed

Amount of initial water content (M), kg $= \frac{(m_1 \times x)}{100}$

((80 x 50)/100 =40

Weight of bone dry product (M_d), kg $x - M$ = 50-40 =10

Initial moisture content (d.b.), per cent $= \frac{m_1}{(100 - m_1)} \times 100$

(80 / (100-80)) x 100

= 400 per cent

Final moisture content (d.b.), per cent $= \frac{m_2}{(100 - m_2)} \times 100$

(8 / (100-8) x 100

= 8.70 per cent

Weight of water to be removed (M_w), kg $= \frac{(m_1 - m_2)}{(100 - m_2)} \times x$

((80-8)/ (100-8)) x 50

= 39.14

Total energy required Q, kcal

Q = $M_d \times C_d \times (T_2 - T_1)$ + $M \times C_p \times (T_2 - T_1)$ + $M_w \times \lambda$

10x1.12 (55-33) + 40 x 0.45 x (55-33) + 39.14 x 540 = 21778 kcal

Energy required per hour Q_t, kcal/h

$Q_t = \frac{Q}{t}$ 21778 / 26 = 837.62 kcal/h

APPENDIX –Q

Specifications of hot air oven

Sl. No.	Parameter	Specification
1	Inner chamber	Stainless steel, size 455 mm (W)×605 mm (H) ×455 mm (D) (Approx.). The dimensions can vary within 2.5 cm on any side.
2	Outer chamber	Steel with white enamel
3	Number of shelves	3 (adjustable) stainless steel
4	Timer	5–120 minutes
5	Temperature	50°C to 250°C$\pm$1°C
6	Temperature control knob	Graduated in centigrade, digital indicator cum controller (electronic), switch to select high or low rates of heating. On/Off switch with pilot lamp indicator. Operable at 240V AC 1.3 kw 25 ampere .

Specifications of Mututoyo Digimatic Digital caliper

Sr. No.	Parameter	Specification
1	Resolution	0.01 mm
2	Precision	$\pm$ 0.02 mm (100/150/200 mm) $\pm$ 0.03 mm (300 mm)
3	Repeatability	0.01 mm
4	Alimentation	One pie
5	Temperature utilization	0^0C to 40^0C
6	Temperature stockage	-10^0C to 60^0C

Specifications of Anemometer

Sr. No.	Parameter	Specification
1	Make	Kanomak
2	Model	24-6"
3	Manufacture	Nichon, Kagaru Co. Ltd. Osaka Japan
4	Temperature	0^0C to 50^0C
5	Air velocity	1-50 m/s
6	Accuracy	± 2 %
6	Power source	12 V (DC)

Specifications of weight balance

Sr. No.	Parameter	Specification
1	Maximum weight	5 kg
2	Capacity	5 kg
3	Minimum	10 gm
4	ACC class III	e = 800 mg

Specifications of other weight balance

Sr. No.	Parameter	Specification
1	Maximum weight	30 kg
2	Capacity	30 kg
3	Minimum	10 gm
4	ACC class III	e = 59 mg

Specifications of Battery

Sr. No.	Parameter	Specification
1	Model	INVARED 500 +
2	Capacity	150 Ah
3	Dimension	(+ 3 mm) length 506 mm, width 202 mm,
		Height 273 mm
4	Weight (kg ± 5 %)	Dry = 34.90 kg
		Filled – 52.50 kg
5	Volume of electrolyte	2/40 liter/cell) (1.220 SPV)
6	Limiting current	Start (up to 3.364) – 1560
		Finish (up to 2.75 v) – 7.80
7	Constant potential	32.30
	Limiting current (Amps)	
8	Trackle current (current in (MA)	Min – 130 MA
		Max – 520 MA
	Solar panel	18 v 1.5 Amp.
	Solar charge controller 999	12 V 7.5 Amp current 27 V capacity

Specifications of solarimeter

Sr. No.	Parameter	Specification
1	Model	CEL make
2	Solar radiation	0 to 120 mW/cm2 , 0-100 langles

Specifications of hygrometer

Sr. No.	Parameter	Specification
1	Model	BARIGO make
2	Hygrometer	0 to 100 %

Specifications of mercury thermometer

Sr. No.	Parameter	Specification
1	Temperature range	0-110^{0}C

Specifications of DC fan

Sr. No.	Parameter	Specification
1	Type	Magnetic induction
2	Voltage	12 V
3	Current	6 Amp
4	RPM	2000
5	Diameter fan blade	22 cm
6	Solar charge controller	12 V, 7.5 AH.