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Experimental Investigation of Mixed Mode Forced Convection Solar Dryer for Turmeric (Curcuma Longa)

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Abstract **- This paper presents an experimental effort on forced convection mixed mode solar dryer for turmeric at Miraj, India (16.83°N 74.63°E). To study the effect of drying time on mixed mode type forced convection solar dryer, 15kg of good quality of boiled turmeric are loaded. It has been experimentally analyzed that drying time can be reduced up to 7 days as compared to a conventional method which requires 13 - 15 days. The experiment was conducted in February month in Miraj, Maharashtra having incident solar radiation and wind speed 5.12 W/m^2/day and 5 km/hr respectively. The drying experiment conducted with turmeric and it was found that the complete drying process could be attained with 47 hours (considering sunshine hr.) The effect of different air mass flow rate on moisture content, moisture ratio, drying rate, drying time and dryer efficiency has been evaluated for turmeric.**
Keywords**: Solar Dryer, Turmeric, Moisture content**

I. INTRODUCTION

India is the largest producer, consumer and the exporter of turmeric. It accounts for 80% of the world output. Other major producers are China, Myanmar, Nigeria, Bangladesh, Pakistan, Srilanka, Taiwan, Burma, Indonesia, Malaysia, Vietnam, Thailand and Central America etc. Global production is around 8 to 9 Lacks tones. Indian turmeric industry contributes about 78% of world production and 60% of the exports of Turmeric. Asian countries consume much of their own turmeric production nearly 90%.

TABLE I PRODUCTION OF TURMERIC IN WORLD

S. No.	Country	Percentage
1	India	78
2	China	8
3	Myanmar	4
4	Nigeria	3
5	Bangladesh	3
6	Others	4

From the above table, the major share is taken by India. It accounts for 78% of total World production followed by China (8%) Myanmar (4%), Nigeria and Bangladesh together (6%). Drying using the sun under the open sky for preserving food and agricultural crops has been practiced since ancient times. However, this process has many disadvantages, spoilt products due to rain, wind, moisture, and dust; loss of productivity due to birds and animals; deterioration in the harvested crops due to decomposition, insect attacks, and fungi, etc. Further, the process is labor-intensive, time-consuming and requires a large area for spreading the product out to dry. Artificial mechanical drying, a relatively recent development, is energy intensive and expensive, and ultimately increases the product cost. Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. A typical solar food dryer improves upon the traditional open-air sun system in five important ways.

It is faster. Foods can be dried for a shorter period of time. Solar food dryers enhance drying times in two ways. Firstly, the translucent, or transparent, glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Secondly, the flexibility of enlarging the solar collection area allows for the greater collection of the sun's energy.

It is more efficient. Since foodstuffs can be dried more quickly, less will be lost to spoilage immediately after harvest. This is especially true of products that require immediate drying of freshly harvested fruit with high moisture content.

It is hygienic. Since foodstuffs are dried in a controlled environment, they are less likely to be contaminated by pests and can be stored with less likelihood of the growth of toxic fungi.

It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain most of their nutritional value such as vitamin C. Since the solar energy is freely available and it is very cheap, it can be used instead of conventional fuels to dry products.

Drying equipment may be classified in several ways. The two most useful classifications are based on the method of transferring heat to the wet solids or the handling characteristics and physical properties of the wet material. In broad terms, they can be classified into two major groups namely

Passive solar energy drying systems (Conventionally termed natural circulation solar dryer systems) and Active solar energy drying systems (a Most type of which are often termed as hybrid solar dryer) Solar drying methods are usually classified to four categories according to the mechanism by which the energy, used to remove moisture, is transferred to the product:

1. Sun or natural dryers: The material to be dried is placed directly under hostile climate conditions like solar radiation, ambient air temperature, relative humidity and wind speed to achieve drying.
2. Direct solar dryers: In these dryers, the material to be dried is placed in an enclosure, with transparent covers or side panels. Heat is generated by absorption of solar radiation on the product itself as well as the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product and promotes the natural circulation of drying air.
3. Indirect solar dryers: In these dryers, air is first heated in a solar air heater and then ducted to the drying chamber.
4. Mixed-type solar dryers: The combined action of the solar radiation incident directly on the material to be dried and the air pre-heated in the solar air heater furnishes the energy required for the drying process.

Solar drying can be most successfully employed as a cost-effective drying technique. It has got several attractive features. For example, energy is available free of cost and can be harnessed in the site itself. Controlled drying is also possible by this method and it enhances the quality of the dried product. Solar drying systems must be properly designed in order to meet particular drying requirements of specific crops and to give satisfactory performance with respect to energy requirements.

In order to prevent this, some sort of auxiliary heating mechanisms should be incorporated with a solar dryer. Escalating prices of fossil fuels prevent the large-scale adoption of fossil fuel or electrical based dryer among small or marginal farmers. Hence it is essential to develop some mechanism that could be able to supply energy requirements during cloudy and non-solar hours. Thus the intermittent, variable and unpredictable nature of solar energy makes it necessary to incorporate a storage system with a solar dryer. The advantage of using storage system is that it stores excess energy and supplies when the collected amount is inadequate.

II. MARKET SURVEY

A. Processing Operations on Turmeric Crop

Processing of farm products leads to enhanced form-utility. Processing helps in the marketing of farm products by making them more edible, palatable and attractive. In addition, it adds to convenience in use, storage, and transit. It helps extend the availability of the product over a longer period of time. The government is encouraging the processing industry by providing tax exemptions on processed products, subsidies on packing costs, assured the supply of power and by the creation of 'Processing Parks' where all infrastructural requirements are provided by the government at a subsidized cost.

Fig. 1 Turmeric Processing

Turmeric, after harvest, undergoes the following processing operations:

1. Cleaning: Harvested turmeric rhizomes (75-80%) are cleaned by fresh water under pressure for removal of soil and other foreign matter.

2. Curing: Cleaned rhizomes are submerged in hot water in tins and boiled uniformly. Cured Rhizomes are then poured into a bamboo basket to drain the water and dried in yards. This process gives attractive color and characteristic aroma to turmeric. Boiling kills the growth of fresh rhizomes, eliminates the odor, reduces the time of drying, ensures even distribution of color and gives better quality product by gelatinization of starch in rhizomes.

3. Drying: Sun drying takes 12-15 days, till it b ecomes thoroughly hard and brittle, and can be broken with finger pressure with a m etallic sound. The moisture content of the dried turmeric is kept at 8%-10% for better storage. Artificial mechanical drying using cross-flow heated air dryers at 65 degrees centigrade is also used and found to provide best products, particularly for sliced turmeric, giving a brighter colored product than the sun-dried material.

4. Polishing: Polishing of rhizomes is done by rubbing with a hand under several folds of gunny cloth or using a polishing drum.

5. Coloring: To impart uniform bright yellow color to the turmeric, the polished rhizomes are treated with an emulsion or mixture of turmeric powder and alum under continuous shaking in a basket.

6. Grading: Grading refers to the process of 'sorting of products into different lots on the basis of similar quality'.

7. Milling: Usually, turmeric is milled on the home scale in flour mills. Milling is done in two stages; namely breaking into small pieces and powdering them to the desired fineness. 8. Packaging and Storage: Turmeric powder is packed in fiberboard drums, multiwall bags, and tin containers.

III. LITERATURE REVIEW

A lot of research work has been done by solar dryer researchers on design, development, and testing of solar dryers for different agricultural/non-agricultural products in different regions of the world.

El-Sebaiia [1] designed and fabricated an indirect-mode forced convection solar dryer. The thermal performance of the solar dryer under Tanta (latitude, 30° 47′ N and longitude, 31° E) prevailing weather conditions were experimentally investigated. The system consists of a double pass v-corrugated plate solar air heater connected to a d rying chamber. A blower was used to force the heated air into the drying chamber. Drying experiments were performed for thymus (initial moisture content 95% on wet basis) and mint (initial moisture content 85% on wet basis) at an initial temperature of 29 °C. The final moisture contents for thymus and mint were reached after 34 and 5 h, respectively. Fourteen mathematical models of thin layer drying were tested to specify the suitable model for describing the drying behavior 0f product.

Pangavhane [2] designed indirect type solar dryers functioning in natural convection mode. It is technically superior because all the important parameters have been taken into consideration while designing the collector and drying chamber. The initial cost of this dryer is quite high when compared to its capacity.

Changwat and Jain [3] studied solar cabinet drying of ginger and turmeric and compared the results with sun drying of the same. They found that not only the drying rate of ginger and turmeric was faster but also, their quality of the dried products was better than those dried in open air sun.

Prasad et al. [4] evaluated performance of hybrid drying of turmeric (Curcuma Zanga L.) at the village scale. They developed a direct type natural convection solar cum biomass dryer. The system was capable of generating an adequate and continuous flow of hot air temperature between 55 and 60°C. Turmeric rhizomes were successfully dried in developed system. Dried turmeric rhizomes obtained under solar biomass drying by two different treatments that are water boiling and slicing were similar with respect to physical appearance, texture, and color with significant variation in the volatile oil. They observed that eight-kilogram fuel wood was burned and 12.6 kg of water was removed to dry fifteen kilograms of fresh rhizome to 9% moisture. The dryer overall thermal efficiency was (28.5%).

Mital and Jose *et al.* [5] the colossal advantage of solar tunnel drying is the reduction of extended drying time into half or more. Fast drying in solar tunnel drying is due to the standard conditions provided in the dryer. A Huge quantity of moisture evaporated during the initial period of drying readily flows away from the additional heat obtained through the reflection of insolation incident on the white colored tunnel area (Esper and Muhlbauer,). It is also revealed from the study that drying period cannot be reduced considerably by conventional drying methods.

Avesahemad Husainy [6] designed and develops forced convection solar dryer for grapes with thermal energy storage by using paraffin wax. In this work indirect cum mixed mode forced convection solar grape dryer with thermal energy storage has been developed and tested experimentally. The grapes with pretreatment have been dried with a developed solar dryer. The designed dryer was integrated with a Phase Change Material to extend the use of dryer in the evening/night hours. The effect of air mass flow rate on moisture content, moisture ratio, drying rate, drying time and dryer efficiency have been evaluated for grapes. At the same time effect of thermal energy storage on drying time on grapes also evaluated with and without incorporation of thermal energy storage with variation in mass flow rate of air.

Avesahemad Husainy and Omkar S. Karangale [7] Hygienic drinkable water is a basic necessity for man along with food and air. Fresh water is also required for agricultural and industrial purposes. Most water sources are contaminated by industrial waste, sewage and agricultural runoff. The higher growth rate in world population and industries resulted water in a large acceleration of demand for fresh water. The natural source can meet a l imited demand and this leads to acute shortage of fresh water. Hence, there is an issue to essentially treat the salt and contaminated into purified water. There are several methods to convert impure water into potable water for drinking, but out of them thermal method is economically viable. In this paper experimentation were carried out on two different setups of double slope single basin solar still with and without thermal energy storage by phase change material.

IV. DESIGN, MECHANISM AND FABRICATION

The developed solar dryer consist of the different components of flat plate collector based solar air heater, dryer cabinet and blower. On the basis of the criteria mentioned, the design of the individual component was prepared and corresponding parameter (i.e. relative dimensions and material for solar flat plate collector, dryer cabinet) were calculated. The procedure of design and calculations for each component is mentioned below

The overall project is designed for drying of 15 k g of turmeric. Taking into consideration the drying area required for 12 kg of turmeric the drying chamber is designed. Then from the calculations carried out the total energy required for drying is calculated based on the desired final and initial moisture content of turmeric.

The energy required to dry the turmeric is the function of the moisture content to be removed. So, the testing report of the wet (raw) turmeric and the market purchased dried turmeric were taken from the labs for moisture contents. The reports resulted in the initial and the final moisture as 84% and 12.59% respectively. Using this data obtained the energy calculations were done.

A. Capacity of solar Dryer

Capacity of solar Dryer 12kg. Considering amount of moisture content: 8 4% for wet turmeric 15 % for dried turmeric

Amount of moisture to be removed from given quantity of turmeric to be dried

1. Amount of moisture (m_w) $=\frac{mp(mi-mf)}{(100-mf)}$

Here, M_p = mass of product
M_i= Initial moisture
M_f= Final moisture
M_p=12kg
M_i=84%
M_f=15%

$$M_w=\frac{mp(mi-mf)}{(100-mf)}$$
=12(84-15)/100-15
M_w=9.7411

Amount of heat required to evaporate water =

$Q = m_w \times h_{fg}$

hfg=latent heat of evaporation in kJ/kg of water

$h_{fg\,w}$ = 4186 (597-0.56 $\times T_p$) = 2.44MJ/kg

Tp-initial temperature of the product

Amount of heat required to evaporate water = $Q = m_w \times h_{fg}$= 23.7945MJ

Assume 10 % loss of heat in drying chamber

Amount of heat required to be supply = 23.7945MJ× 1.1 = 26.1740 ≈27MJ

Amount of heat required to be supply = 27MJ

Total energy to be supplied for drying of turmeric = 27MJ. Final relative humidity/equilibrium relative humidity, ERH(%) was calculated.
a_w= 1-exp(-exp (0.914+0.5639InM)
Where,
$M=M_f/100-M_f$
=15/100-15
=0.1764kg
a_w = 1-exp (-exp (0.914+0.5639InM)
= 1-exp (-exp (0.914+0.5639In0.1764)
= 0.6069
ERH= a_w×100
= 0.6069×100
= 60.69%
Total collector Area required

Assuming the efficiency of collector (η) = 24%

(Generally, the efficiency of flat plate collector is 22% to 28%.But by Using Reflector Surfaces the Flat Plate Collector Efficiency can be enhanced up to 30%)

Intensity of radiation (I) = 800 W/m^2

According to Solar Radiation Hand Book data by Solar Energy Centre, MNRE Indian Metrological Department it gives the 25.12MJm^{-2} per day.

Assuming efficiency of flat plate collector to be 24%

Energy retracted from FPC= η×25.12 ×Area (per day)

Energy required from FPC per day = 27/6
= 4.5MJ

Therefore Energy required from FPC per day = η×25.12 ×Area

4.5 = 0.24×25.12×Area

Area=0.74642 $m^2 \approx 0.8\ m^2$

The Flat Plate collector area required for supplying the essential heat energy is $0.8m^2$.

We are designed solar turmeric dryer for 15 kg capacity. Firstly the initial moisture content and nutritional values of turmeric were calculated by laboratory testing of the sample of the turmeric before starting experimental procedure and the information was used for various purposes. The experimental procedure was started by loading of turmeric on the trays of the drier cabinet. After loading 12 kg of fresh boiled turmeric complete sealing of cabinet was done so that there no any air leakage. Then the blower was connected to the setup and the flow was adjusted as per calculation. The temperatures at various sections of the dryer were taken from digital temperature indicator at regular intervals of time of 1 hr. up to six days. At the same time, solar radiations were measured with a s olar power meter. This procedure was continued for six days until required good quality turmeric were obtained. The sample of turmeric was tested in the laboratory.Test methodology has been planned and executed in order to find the drying time in the developed solar dryer. The effect of mass flow rate of air on moisture content, moisture loss, drying rate, drying time and dryer efficiency has to be evaluated and accordingly test has been executed.

1. Experimentation has been carried out for drying of turmeric from the initial moisture content of 84 % to final moisture content up to 13% for a variable mass flow rate of air.
2. Mass flow rate of air kept for the individual set of experimentation as 0.005127954 kg/sec and 0.006879873 kg/sec though dryer cabinet and
3. With a selected mass flow rate of air, time to time reduction in weight of the sample turmeric, flat plate collector air inlet, outlet temperature, dryer cabinet exit temperature, the intensity of solar radiation is noted till final moisture content reduced to 13 %.

V. PERFORMANCE

A. Drying Time with Moisture Ratio

The study of variation in the moisture ratio on the dry basis is done by plotting the graph of moisture content calculated on dry basis versus time. The moisture variation is calculated for the considered mass flow rates, it also gives an idea of the effect of mass flow rate on drying rate. The comparison study is done by plotting the moisture content on dry basis for the flow rates M1=0.006879873kg/sec, M2=0.005127954kg/sec. Vs the drying time. The same comparison study is carried out with turmeric. The graph easily interprets the effect of the flow rate on the drying time.

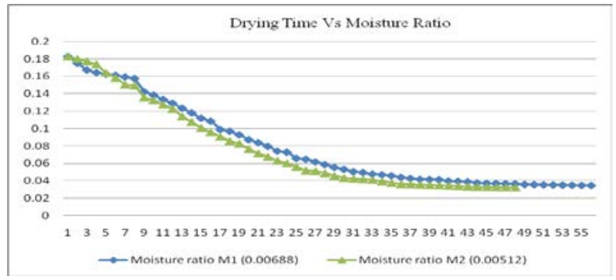


Fig. 2 Drying Time Vs Moisture Ratio

B. Drying Time with moisture content:

The study of variation in the moisture content on the dry basis is done by plotting the graph of moisture content calculated on dry basis versus time. The moisture variation is calculated for the considered mass flow rates, it also gives an idea of the effect of mass flow rate on drying rate. The comparison study is done by plotting the moisture content on dry basis for the flow ratesM1=0.006879873kg/sec, M2=0.005127954kg/sec. Vs the drying time. The same comparison study is carried out with turmeric. The graph easily interprets the effect of the flow rate on the drying

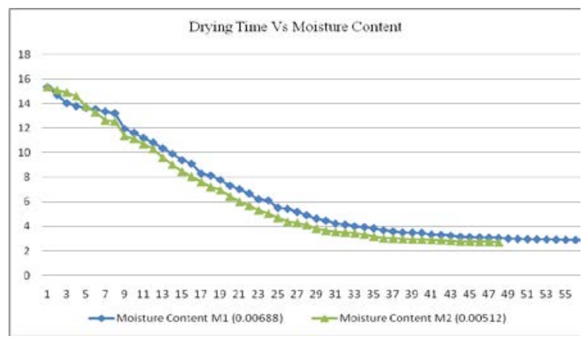


Fig. 3 Drying Time Vs Moisture Content

C. Drying Time with Mass Flow Rate

The drying time for different mass flow rates is analyzed in the below graph 5.13 From the analysis of the below graph, the drying period increases from nearly 198000 sec for mass air flow rate of 0.006879873kg/sec approximately 169200 for mass air flow rate of 0.005127954kg/sec. So, for turmeric with the increase in the mass flow rate of the air from 006879873kg/sec, 0.005127954kg/sec. the drying time increases by 8 hours.

TABLE II DRYING TIME FOR AVAILABLE MASS FLOW RATE

Mass flow Rate (Kg/s)	Drying Time (sec)
0.00688	198000
0.005120	169200

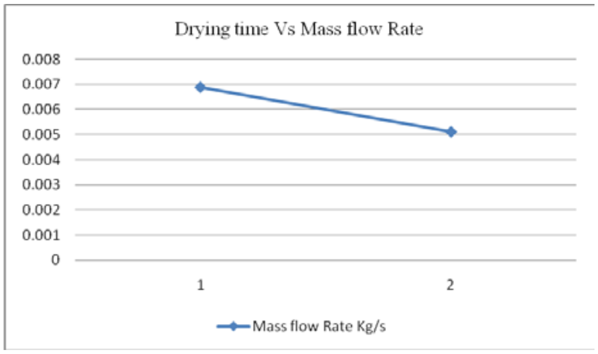


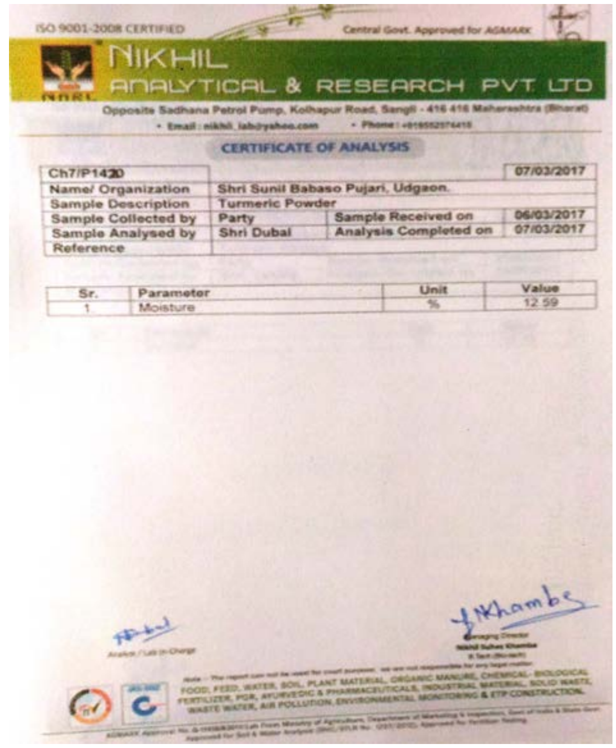
Fig. 4 Drying Time vs. Mass Flow Rate

VI. CONCLUSION

Fig. 5 Experimental Set up

In this experimentation work, mixed mode forced convection solar turmeric dryer has been developed and tested experimentally. The turmeric has been dried in the mixed mode solar dryer. The effect of different air mass flow rate on moisture content, moisture ratio, drying rate, drying time and dryer efficiency has been evaluated for turmeric. The following conclusions have arrived from the experimental work,

1. Dried turmeric production is possible with mixed mode forced convection solar dryer in much shorter time. An indirect type of solar dryer with forced air circulation can be used to produce superior quality turmeric acceptable in the international market.
2. The drying experiment conducted with turmeric and it was found that the complete drying process could be attained with 47 hours (considering sunshine hr.), which is very less compared with open sun drying.
3. With increase in mass flow rate of air the outlet air temperature of collector is going to decrease which reduces the drying temperature required and thus increases drying time
4. After all this work put forward extension of renewable energy based drying technology in the field of turmeric drying so that small-scale farmers can be economically benefited.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CERTIFICATE OF ANALYSIS

Ch7/P1420			07/03/2017
Name/ Organization	Shri Sunil Babaso Pujari, Udgaon.		
Sample Description	Turmeric Powder		
Sample Collected by	Party	Sample Received on	06/03/2017
Sample Analysed by	Shri Dubal	Analysis Completed on	07/03/2017
Reference			

Sr.	Parameter	Unit	Value
1	Moisture	%	12.59

Fig. 6 Laboratory Testing Report

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