Development of Electrically Heated Dryer for Turmeric

Thesis submitted to
Dr. Rajendra Prasad Central Agricultural University
in partial fulfillment of the requirements for the award of the degree of

Master of Technology in Agricultural Engineering
(Processing and Food Engineering)

By

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CERTIFICATE-I

Date - 31.08.2020

This is to certify that the thesis entitled **"Development of electrically heated dryer for turmeric"** submitted to Dr. Rajendra Prasad Central Agricultural University, Pusa in partial fulfillment of the requirement for the degree of **Master of Technology - Agricultural Engineering (Processing and Food Engineering)** embodied the results of the bonafide research work carried out by **Mr. Diwakar Tiwari** (MT/PFE/497/2018-19) under my guidance and supervision. The thesis has not been previously submitted for the award of Degree or Diploma of any University or Institute.

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This is to certify that the thesis entitled **"Development of electrically heated dryer for turmeric"** submitted by **Mr. Diwakar Tiwari,** (MT/PFE/497/2018-19) to Dr. Rajendra Prasad Central Agricultural University, Pusa in partial fulfillment of the requirement for the degree of **Master of Technology - Agricultural Engineering (Processing and Food Engineering)** was examined and approved on **23.10.2020**.

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Place : Pusa (DIWAKAR TIWARI)
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ABSTRACT

An electrically heated dryer was designed and fabricated for turmeric drying for 25 kg capacity with five drying trays. The fabricated dryer has the dimensions of drying chamber as 102 × 53 × 57 cm, tray-100 × 50 × 5 cm and stand-102 × 53 × 70 cm. The procured turmeric lot was thoroughly cleaned, washed and trimmed to get rhizomes which were boiled and tempered in laboratory autoclave for total 220 minutes. After determining initial moisture content (82.19 % w.b.), turmeric rhizomes were evenly spread on five drying trays (5 kg in each tray) and were put inside the preheated dryer. The data were recorded for weight reduction in samples from each tray at prefixed time interval. Other observations included the inlet and outlet temperature of drying air, dryer temperature and RH at bottom tray 1 and top tray 5, ambient temperature and RH, air velocity and energy consumed during entire period of experiment. Drying was continued till three consecutive weights were recorded as almost same indicating the samples had reached at their equilibrium in different trays. Weight reduction data was used to calculate moisture content in wet and dry basis and drying rate. The performance of the dryer was evaluated on the basis of moisture reduction, drying rate, time taken for drying, heat utilization factor and dryer efficiency. Some important physical properties like size, shape, surface area & volume, bulk density, true density, porosity were also determined for fresh, boiled and dried turmeric rhizomes. The turmeric rhizomes were dried from initial moisture content of 82.19 % (w.b.) to final moisture content in the range of 8.22% in 1980 minutes, 10.07% in 2280 minutes, 12.96% in 2580 minutes,13.98% in 2820 minutes, 15.68% in 3120 minutes for tray 1, tray 2, tray3 ,tray4 and tray 5 respectively. Overall drying rate during the process varied from 0.172×10^{-3} to 0.086×10^{-3} kgW /kg.dm.h. The dryer had an average HUF of 0.842 during turmeric drying with drying efficiency of 33.483%. The total moisture content reduction (from initial to final moisture content) was found 73.97, 72.12, 69.23, 68.20 and 66.51(%w.b.) in tray1, tray2, tray3, tray4 and tray5 in 1980, 2280, 2580, 2820, and 3120 minutes respectively. During full load condition, the average temperature in the drying chamber was 56.45°C, which is near to the optimum temperature required for drying of turmeric rhizomes. It can be concluded that the developed system is suitable for drying of 25 kg/batch turmeric for the farming community with good quality.

Key words : Electrically heated dryer, dryer performance, weight reduction, moisture reduction, drying rate, time taken for drying, heat utilization factor, dryer efficiency, physical properties, drying air temperature & RH

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol / Abbreviation	Meaning
%	Per cent
°	Degree
°C	Degree Celsius
Avg.	Average
C. longa	Curcuma longa
CAE	College of Agricultural Engineering
cc	Cubic centimeter
Cfm	Cubic feet per minute
cm	centimeter
d.b.	Dry basis
DrRPCAU	Dr. Rajendra Prasad Central Agricultural University
et al.	And others
g	gram
GI	Galvanized Iron
GW	Gigawatt
h	Hour
HUF	Heat Utilization Factor
ICAR	Indian Council of Agricultural Research
IMC	Initial Moisture Content
Kcal	Kilocalorie
Kg	Kilogram
Kg/ha	Kilogram per hectare
Kg/m^3	Kilogram per cubic meter
kg/s	Kilogram per second
kgW/kg.dm.h.	Kilogram water per kilogram drymatter hour
KJ	Kilojoule
Kj/kg°C	Kilojoule per kilogram degree celcius
kWh	kilowatt hour
m	Meter
M.C.	Moisture Content
m/s	Meter per second
m^2	square meter
mg	milligram
min	minute
MJ	Megajoule

mm	millimeter
mm^2	Square millimeter
MS	Mild steel
MT	Million tonnes
MW	megawatt
ME	Master of Engineering
M. Sc.	Master of Science
MPUAT	Maharana Pratap University of Agriculture & Technology
N	Newton
PC	Personal Computer
PHT	Post Harvest Technology
PVC	Poly vinyl chloride
RH	Relative humidity
rpm	Revolutions per minute
S.D.	Standard Deviation
TCA	Tirhut College of Agriculture
U.S.A.	United States of America
w.b.	Wet basis
Wt.	weight

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CHAPTER - I

INTRODUCTION

Turmeric is a spice derived from the rhizomes of *Curcuma longa*, which is a member of the ginger family Zingiberaceae. Turmeric is the most ancient medicinal spice, traditionally ubiquitous and held sacred. The history of turmeric is entwined with the history of Indian culture and also with the socio-religious practices of the country. It was popular even in Vedic times because of its unique properties of colour, flavour and also its importance as medicine in Ayurveda, besides its use as a cosmetic and significance in religious ceremonies and auspicious occasions.

In medieval Europe, turmeric was known as Indian Saffron, since it was widely used as an alternative to the far more expensive saffron spice. The plant is an herbaceous perennial, 60-90 cm high, with a short stem and tufted leaf. The root or rhizome has a tough brown skin and bright orange flesh. In fresh state, the rootstock has an aromatic and spicy fragrance, which on drying gives way to a more medicinal aroma. The bright yellow colour of turmeric comes mainly from polyphenolic pigments known as curcuminoids.

India is to be the home of turmeric. It accounts for 80 per cent of the world output and 60 per cent of world exports. Indian turmeric is considered the best in the world market because of its high curcumin content. India is the largest producer and exporter of turmeric with an annual production of about 931480 tons from 245790 hectares of area with yield of 3790 kg/ha during the year 2018-19 (Anonymous 2019). The main turmeric growing states are Telangana, Andhra Pradesh, Maharashtra, Orissa, Tamilnadu, Karnataka, and West Bengal. Recently, Bihar has started the cultivation of turmeric on a large scale. According to National Horticultural Board, Bihar produced about 2830 tonnes of turmeric during 2017-2018.

The commonly cultivated varieties are Suvarna, Suguna, Sudarsana, IISR Prabha, IISR Pratibha. The Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar has also developed two varieties – Rajendra Soniya – I and Rajendra Soniya – II. At the time of harvesting, turmeric like all other agricultural commodities, invariably contains high moisture that must be brought down to the desired level at which attack of micro-organisms would be minimized. At the same time, the retention of quality attributes should also be at the maximum. Turmeric contains up to 5 per cent essential oils (Ganpati et al. 2011) and up to 5 per cent curcumin (Tainter et al.1994).

Post harvest processing of turmeric, generally practiced in rural level, consists of two important processes i.e. curing and drying. The curing operation is carried with traditional bhatti (oven) which is an inefficient process. The curing of turmeric with traditional methods requires more time and energy. The rhizomes are then spread on the floor for open sun drying. In India, the average solar radiation available is 500 KW/m^2 for 250-300 days in a year with approximately 8-10 full sunshine hours. Finally, the dried rhizomes are milled or ground with hand operated *chakki*. During this process, the quality of the product deteriorates. Farmers sell turmeric in fresh form. The cost of raw product is comparatively very less as compared to value added product, so value addition at low cost is an alternative to increase income of farmers.

At commercial level, the post harvest processing of turmeric involves many unit operations such as washing, cleaning, curing, drying, polishing, size reduction and packaging. Curing is the most important pre-treatment in which cleaned rhizomes are boiled in water; sometimes in addition with 0.1 per cent sodium bicarbonate to retain its original colour until the rhizomes are cooked. Cooked rhizomes are cooled first and then dried using commercially available dryers like, tray dryer, cabinet dryer etc. After drying these become hard and solid. Completely dried turmeric holds 8 per cent moisture content. By the polishing process, the colour of turmeric becomes bright or shining. Finally the rhizomes are transformed into powder by using grinder and then packaging is done.

Many farmers in rural India face loss or deterioration of crop both qualitatively and quantitatively after harvesting it. This problem is prevalent mainly due to not performing proper post-harvest operations on the produce. One such ill-performed operation is drying. The drying of agricultural produce after harvesting reduces its moisture content considerably, thereby decreasing the risk of fungal and microbial contamination.

Sun drying offers a cheap method of drying but often results to inferior quality of products due to its dependence on weather conditions and vulnerability to the attack of dust, dirt, rains, insects, pests and micro-organism. For large-scale production, there are various known limitations of sun drying as damage to the crops by animals, birds and rodents, degradation in quality due to direct exposure to solar radiation, dew or rain, contamination by dirt, dust or debris. In addition, this system is labour and time intensive, as crops have to be covered at night and during bad weather and have to be protected from attack by domestic animals. There is also a chance of insect infestation and growth of microorganism due to non-uniform drying. Open sun drying requires large floor area and dependent on availability of solar energy.

In traditional method, turmeric is dried under open sun by spreading it on ground or in places that are otherwise unclean, or cow dung smeared floors. Farmers often dry harvested turmeric rhizomes to final moisture content in the range of 15-35%, depending upon the weather conditions. Uneven and non uniform drying promote microbes, especially fungus, to start growth immediately. Pruthi (1993) and Jose and Joy (2005) reported that traditional drying method could result in the loss of volatile oil up (to 25%) by evaporation, and in the destruction of some light sensitive oil constituents.

Most of the farmers depend upon the weather to dry their produce which results to ineffective drying when it is cloudy or during winter season. On the other hand, conventional fuel operated dryers are costly for rural farmers. As a solution to the mentioned issues, a project was planned for developing a tray dryer for drying turmeric rhizomes by electrical energy. Therefore the attempt has been made to develop a modern technique for drying turmeric with the following objectives

1. To develop the electrically heated dryer for turmeric.
2. To evaluate the performance of developed dryer.

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CHAPTER - II

REVIEW OF LITERATURE

This chapter deals with the review of the research work carried out in relation to the objectives of the proposed study. An extensive review of research literature has been made to facilitate devising an appropriate methodology towards accomplishing the entire research objectives. A brief review on the topics – Turmeric and its processing, Electrically heated dryer, and Engineering properties of turmeric is presented under the different heads.

2.1 Turmeric and its processing

Turmeric has very good nutritive and medicinal values. The nutritive ingredients of turmeric are given in **Table 2.1**.

Table: 2.1 Nutritive ingredients in raw turmeric

S. No.	Constituent	Quantity per 100 g
1	Water, g	6.0
2	Protein, g	8.5
3	Fat, g	8.9
4	Carbohydrate, g	69.9
5	Ash, g	6.8
6	Calcium, g	0.2
7	Phosphorous, mg	260
8	Sodium, mg	30
9	Potassium, mg	2000
10	Iron, g	47.5
11	Thiamine, mg	0.09
12	Riboflavin, mg	0.19
13	Niacin, mg	4.8
14	Ascorbic acid, mg	50
15	Food energy, Kcal	390

(Source : Sasikumar, 2001)

Kumar (1995) designed, developed and tested solar cabinet dryer for turmeric**.** The dryer was tested for local variety of turmeric at no load and loaded conditions at three different bed thicknesses i.e, 30, 45 and 60 mm along with sun drying. Maximum drying period in solar dryers was found to be 35 hours for 30 mm bed thickness (82.50 to 10.70% moisture content, w.b.), 42 hours for 45 mm bed thickness, (62.05 to 10.53% moisture content, w.b.) and 52.5 hours for 60 mm bed thickness (83.21 to 11.02% moisture content, w.b.), while sun-drying took 56, 70 and 84 hours for 30, 45, and 60 mm bed thicknesses, respectively for the same percentage of moisture reduction. The bulk density of freshly harvested turmeric was approx. 1.75 times that of dried turmeric. The colour of the dried turmeric was found to be changed differently as per bed thickness. Volumetric shrinking of turmeric was observed to be around 77.5%. Drying efficiency was found to be 81.87 percent.

Kumar (1997) studied drying characteristics of turmeric assisted with waste fired dryer. The drying characteristics of turmeric were studied with the waste fired dryer in two batches consisting of 60 and 30 mm bed thicknesses along with sun drying. Waste fired dryer was found to be suitable for drying turmeric. Maximum drying period for turmeric was found to be 14 hours for 60mm bed thickness (76.11 to 12.09 % m. c., w.b.), 11 hours for 30 mm bed thickness (76.11 to 12.12 % m. c., w.b.), and 10 to 6 days for different bed thicknesses under sun-drying. The bulk density of freshly harvested turmeric was approximately 1.85 times less than that of dried turmeric was found to be changed differently as per bed thickness. Volumetric shrinking of turmeric was observed to be around 46 percent. Drying of turmeric in 60mm bed thickness was found to be beneficial involving minimum cost of drying (Rs. 0.95/Kg and Rs. 12.21/h). Sun drying took very long time (82.5 percent more) as compared to mechanical drying.

Sinha (2001) developed an improved low cost boiler for curing about 525 kg turmeric rhizomes as well as fingers per day for value addition in turmeric processing by enhancing the quality of traditional curing turmeric. The curing characteristics were also evaluated at different curing temperature (80, 90 and 100^{o}C), different water- rhizomes/fingers ratio (0.750:1, 1:1 and 1.250:1) and different curing times (10,20,30,40,50 and 60 minutes). The actual curing time was evaluated for turmeric rhizomes and fingers as 50 min. and 40 min. based on the final moisture content, hardness and visual observations. The hardness and moisture content of turmeric rhizomes were found to be 6 kg force and 75.31 percent (w.b.) respectively after 50 minutes of cooking at 100^{o}C. The moisture content and hardness of turmeric fingers after 40 minutes of cooking at 100^{o}C temperature were found to be 76.21 percent (w.b.) and 3.4 kg force, respectively.

Varshney et al. (2004) conducted study of post harvest technology of turmeric. A study on the effect of pretreatment and drying method on turmeric quality revealed that curing of turmeric rhizomes at 0.75 kg/cm^2 pressure and drying in solar cabinet dryer at 74^{0}C gave satisfactory quality of turmeric rhizomes in terms of volatile oil, curcumin and oleoresin content.

Gunasekar et al. (2006) conducted study of solar drying for post harvest curing of turmeric. The effect of drying methods (direct sun drying and drying in solar dryer) on the key biochemical constituents such as curcumin, volatile oil, oleoresin and total protein of boiled turmeric (var: Erode) was studied. The quality of the turmeric rhizomes as influenced by the biochemical constituents varied at various levels of moisture content. The study indicated that the boiling and drying intensified the curcumin content, while the volatile oil, oleoresin and total protein content progressively decreased as the moisture content decreased. The results also revealed that the solar drying is better than direct sun drying as it achieved.

Pal et al. (2008) conducted study of farm level turmeric processing equipment. The improved curing unit required 50 min for curing a batch of 100 kg rhizomes with two labours. The improved method of curing took less time and fuel consumption was also found to be less compared to the traditional method of curing due to the lid covering. The overall performance was satisfactory and comfortable to the worker due to provision of easy unloading system by means of wooden handle.

Jose and Joy (2009) conducted drying experiments by adopting three methods solar tunnel drying, conventional drying and commercial drying for turmeric. 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.

Sanchavat (2012) studied performance and economic evaluation of biomass and solar energy system for turmeric. The results indicate that boiling and drying intensified the colour and curcumin content. The results also revealed that the solar drying is better than direct sun drying as it achieved the desired moisture content and essential quality in 42 hour (6 days) compared to 56 hour (8 days) in sun drying, thus saving considerable time (14 hours).

Lakshmi *et al.* (2017) studied the performance of a mixed mode forced convection solar dryer integrated with paraffin wax based thermal energy storage for drying the sliced black turmeric (*curcuma caesia*). Thin layer drying kinetics of sliced black turmeric dried in a solar dryer has been compared with the open sun drying. Two 200 g samples of black turmeric were chosen and one was placed in the solar dryer and another was placed in the open sun. The samples were dried from initial moisture content of 73.4 % (w.b.) to 8.5 % (w.b.) in 18.5 h in the solar dryer and the sample took 46.5 h in open sun drying. The overall solar air heater efficiency and the overall solar dryer efficiency were found to be 25.6% and 12.0%, respectively.

Shaikh *et al.* (2017) carried out performance analysis of forced convection solar dryer for turmeric. In this project work, the forced convection solar dryer for turmeric was designed, developed and successfully tested experimentally. The boiled turmeric rhizomes have been dried with the forced convection solar dryer. The effect of drying time, air mass flow rate, solar intensity, drying time has been evaluated. Following conclusions have been arrived from the experimental investigation carried out in the present work of solar turmeric dryer. The drying experiment conducted with boiled rhizomes and it is found that the complete drying cycle could be attained within 48 sunshine hours for forced convection, which is very less compared with open sun drying. Dried turmeric production is possible with developed solar dryer in much shorter time with better quality.

2.2 Electrically heated dryer

Gyanwali *et al.* (2014) studied on electric dryer for cash crops drying as an end-use promotion of micro hydro power in Nepal & its comparative analysis with biomass based drying system. Electric dryers serve farmers as an efficient, environment friendly and proper technology with high performance for quality product drying than other types of conventional dryers. For performance testing and comparison with biomass based drying system, an electric dryer was designed. Two different performance testing was carried out with 25 kg of fresh ginger as input which was dried for 4.5 hours. The first test was 30% efficient consuming 40 kWh of electric power with output of 5.4 kg of dried ginger. When leakage of the hot and dry air from dryer was minimized in the second test, dryer was 37% efficient. Later on, electric dryer system was compared with biomass based dryer system which shows that the drying rate of electric dryer is stable and constant, also the required temperature in this system can be maintained as per requirement like 60^0C in case of ginger drying. Temperature profile of drying air in biomass based system was unstable and inconsistent with periodical variation like a sinusoidal curve. The efficiency of the electrical dryer was much higher compared to biomass based system which lies between 10 to 13% depending upon feedstock input for gasifier.

Poornima *et al.* (2019) carried out study on effect of superheated steam drying on quality characteristics of turmeric rhizomes. Turmeric rhizomes were dried in a superheated steam dryer and analysed for its quality characteristics. The experiments were conducted under different temperatures (130, 140 and 150^{o}C); time (1.5, 2 and 2.5 h) and feed volume (60, 70 and 80 %) combinations. The experimental results showed that the moisture content decreased significantly ($P<0.05$) with an increase in temperature and time. Increase in feed volume percentage significantly reduced the moisture evaporation rate without affecting quality parameters. The curcumin content was varied from 3.65-4.65 % and it was significantly influenced by temperature and time. The rhizomes dried at 130°C for 1.5 h showed highest oleoresin (11.7%) and essential oil content (4.0 %). Turmeric drying at 142.19°C temperature, 1.7 h time and 66.60 % of feed volume was considered to be the optimized condition for drying of turmeric rhizomes.

2.3 Engineering Properties of Turmeric

Mishra (2015) studied the engineering properties of local grown turmeric variety. The engineering properties of turmeric rhizomes were determined as a function of moisture content. The average length, width and thickness of turmeric were 42.77, 10.85 and 9.51 mm respectively at 12.4% moisture content (d b). The volume, surface area and angle of repose were observed as 2.76 cm^3, 7925.33 mm^2 and 33° respectively. The bulk density, true density, porosity and terminal velocity of turmeric rhizomes were observed as 622.33 kg/m^3, 1253.93 kg/m^3, 50.37% and 7.22 m/s respectively. The mean value of peak compressive force for rhizomes to fail was 172.15 N at the corresponding displacement of 1.00 mm. Studies on rewetted turmeric rhizome showed that bulk density decreased from 622.33 to 602.66 kg/m^3 and true density increased linearly from 1253.93 to 1279.53 kg/m^3, porosity from 50.37 to 52.90%, terminal velocity from 7.12 to 10.85 m/s and angle of repose from 33 to 45.5 degree in the moisture range 12.40 to 21.85% (d b). The static co-efficient of friction also increased linearly on four metal surfaces, namely, mild steel (0.51 to 0.66), galvanized iron (0.47 to 0.64), aluminum (0.40 to 0.56) and stainless steel (0.37 to 0.54) with increase in moisture range from 12.40 to 21.85% (db).

Poornima *et.al* (2019) compared the physical properties of turmeric rhizomes on IISR-Alleppey variety. Boiling and drying are the essential steps followed in processing of turmeric rhizomes. Superheated steam was employed for boiling and subsequent drying of rhizomes in a superheated steam dryer. Overall dimensions namely length, width and thickness of the rhizomes, significantly ($p<0.05$) increased with boiling whereas significantly decreased with drying process. Bulk density of the fresh, boiled and dried rhizomes were found to be 530.9, 510.1 and 640.8 kg/m^3. Boiling process showed 10% increase in volume of the boiled rhizomes and 30% decrease in volume under drying process when compared to fresh rhizomes. Porosity of the rhizomes increased from 54.11 to 55.18 under boiling and decreased to 47.04 under drying process.

Shubhashini *et al.* (2015) determined physical properties of turmeric rhizomes at different moisture contents such as 8, 12 and 16 per cent *viz*., size, bulk density, true density, and porosity, by using standard procedures. It was found that the physical dimensions of turmeric rhizomes were increased with increasing the moisture content. They found that the average length, breadth and thickness increased from 48.6±0.38 mm to51.3±0.43 mm, 8.4±0.04 mm to 10±0.10 mm and 8.3±0.09 to 10±0.10 mm, respectively increased in moisture content from 8 to 10 per cent. The bulk density increased from 643.7±0.008 to 650.4±0.410 kg/m^3 with increasing moisture content from 8 to 10 per cent. The true density increased from 1288.7±0.015 to 1334.5±0.020 kg/m^3 with increasing moisture content from 8 to 10 per cent. Porosity increased from 66.2±0.002 to 68.5±0.003 per cent with increasing moisture content from 8 to 10 per cent. Angle of repose increased from 42.5±0.01 to 44.2±0.006^o with increasing moisture content from 8 to 10 per cent. Coefficient of fiction increased for mild steel surface from 0.232±0.001 to 0.271±0.006.

Kumar (2016) studied on engineering properties of turmeric rhizomes. The sample was divided into three grades (I: 30–40 mm, II: 40–50 mm and III: 50–60 mm) according to its major dimension to study physical properties. Geometric properties viz., length, breath, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, sphericity, aspect ratio, unit volume, surface area and shape factor were determined and found to be in the range of 30.18-48.54 mm, 9.72-10.62 mm, 5.12-6.38 mm, 14.72-22.84 mm, 12.72-14.64 mm, 23.21-26.54 mm, 17.54-21.32 mm, 0.24-0.38, 0.18-0.32, 1591-2904 mm3, 772-1268 mm2 and 1.61-1.74 for Grade I, II and III respectively. The gravimetric and frictional properties such as bulk density, true density, porosity and angle of repose were 264-348 kg/m3, 1340- 1358 kg/m3, 72.51-78.90 % and 35.57-37.90°, respectively. Also, coefficient of friction with three different surfaces namely aluminum sheet, mild steel sheet and plywood sheet were found to be in the range 0.68-0.80, 0.85-0.96, 0.82-0.88, respectively.

Choudhary and Garg (**2017)** studied the engineering properties of turmeric rhizomes as potential for developing processing machine. The engineering properties of turmeric rhizomes moisture range of 9.9 to 17.64 % dry basis. The study was conducted to investigate the physical and frictional properties of turmeric rhizomes namely; axial dimensions, geometric mean diameter, surface area, volume surface area, sphericity, bulk density, true density, porosity and angle of repose and coefficient of static friction were determined using standard methods. The result obtained from the study revealed mean length, width, thickness, geometric diameter, surface area, sphericity and seed volume ranged from 4.45±0.20 - 4.53±0.28 cm, 1.28±0.18 - 1.40±0.20 cm, 1.18±0.12 - 1.25±0.26 cm, 1.86±0.17 - 1.99±0.22cm 10.93±0.26 - 12.48±0.17 cm2, 41.90±0.01- 44.11±0.03 and 116.53±2.74 - 144.17±3.96 cm^3 respectively.

CHAPTER - III

MATERIALS AND METHODS

This chapter deals with the material and methodology adopted for design, development and performance evaluation of an electrically heated dryer for primary processing of turmeric. The material and experimental techniques used for studying the performance of an electrically heated dryer for drying of turmeric has been discussed.

3.1 Design of electrically heated dryer

The present research was initiated with the design and development of an electrically heated dryer. The dryer is designed consisting of drying chamber and electric heater.

The initial design assumptions made for electrically heated dryer are given below in Table 3.1.

Table 3.1 Initial design assumptions

S. N.	Design parameters	Values
1.	Type of drying product	Pre-treated Turmeric
2.	Initial moisture content (M_i), %	82%(wb)
3.	Final moisture content (M_f), %	08%(wb)
4.	Weight of material (W_g), kg	25 kg
5.	Location	CAE, Pusa, Bihar
6.	Ambient air temperature (T_a), ºC	30ºC
7.	Ambient air relative humidity (Rh_a), %	76 %
8.	Specific heat of water (C_w), kJ kg^{-1} C^{-1}	4.18 kJ kg^{-1} C^{-1}
9.	Specific heat of ambient air (C_a), kJ kg^{-1} C^{-1}	1.005 kJ kg^{-1} C^{-1}
10.	pecific heat of turmeric (C_p), kJ kg^{-1} C^{-1}	0.837 kJ kg^{-1} C^{-1}
11.	Average drying hours, h	48 h
12.	Drying air temperature (T_h), ºC	60ºC
13.	Exhaust air temperature (T_e), ºC	45ºC
14.	Latent heat of vaporization of water (λ), $kJkg^{-1}$	2260 $kJkg^{-1}$
15.	Efficiency of dryer (η), %	35%
16.	Density of exit air (ρ_e), kg m^{-3}	1.09 kg m^{-3}
17.	Height of chimney (H), cm	10.0 cm

The stepwise design calculations of electrically heated dryer are given as below.

i. Total quantity of water in the product, M_{tw} has been calculated by using following formula

$$M_{tw}=W_t\times M_i/100 \qquad \text{……... (3.1)}$$

Where, M_{tw}= Total mass of water in the product, kg

W_t= Mass of the wet product, kg

M_i= Initial moisture content of the product, (% w.b.)

M_{tw}= 25×0.82= 20.5 kg

ii. Bone dry weight of the product, W_{bd}. It is the dry weight remained after complete removal of moisture from the product, it is calculated by using following formula

$$W_{bd}=W_t - M_{tw} \qquad \text{……... (3.2)}$$

Where, W_{bd}=Bone dry weight of product, kg

W_t= Mass of the wet product, kg

M_{tw}= Total mass of the water in the product, kg

W_{bd}=25-20.5 = 4.5 kg

Hence final weight of product at 8% moisture

$W_f=W_{bd}\times100/(100-8)$ =5.375kg

iii. Mass of the water to be removed during drying, $M_{w.}$ Mass of the water to be removed to bring down the moisture content of product is calculated with the help of following formula.

$$M_w=W_t-W_f \qquad \text{……... (3.3)}$$

Where, W_f = Final weight of product after drying, (% wb.)

W_t= Weight of the wet product, kg

M_w=25-5.375=19.625 kg

iv. Total energy required for drying, Q_n

$$Q_n= W_{bd}C_p\times(T_d-T_a) + M_{tw}C_w(T_d-T_a) + M_w\times\lambda \qquad \text{……... (3.4)}$$

Where, Q_n = Total quantity of energy required for drying, kJ

W_{bd}= Mass of the bone dry product, kg

C_p&C_w= Specific heat of product and water, kJ/kg °C.

T_d = Drying air temperature, °C

T_a= Ambient air temperature, °C

M_w =Mass of the water to be removed during drying, kg

λ = Latent heat of vaporization of water, kJ/kg

Q_n =4.5×0.837× (60-30) +20.5×4.185× (60-30) +19.625×2260

=52141.77 kJ (for 48 hrs) = 1086.287kJ/h

v. Electric heater capacity

Heater capacity for ideal drying= Total energy required for drying of turmeric

=1086.287/3600 sec

=0.302kw

But for practical purpose assuming dryer efficiency only 25%

Total heater capacity= 0.302/0..25

= 1.208 kw

So electric heater having power of 1.5 kw should be selected.

vi. Blower capacity

The amount of energy supplied by air during drying must be

=Amount of energy required for drying of turmeric

So required amount of air ($M_{a)}$ for drying can be calculated by using following formula

$M_aC_{Pa}\Delta t=6517.72$ or $M_a = 6517.72 / C_{Pa}\Delta t$

Where, Ma= Mass of air required for drying, ($kg.h^{-1}$)

Cpa= specific heat ofair (1.005 kj/kg)

Δt = temperature difference of air between dryer inlet and outlet

We assume dryer outlet temperature = 45^oC

M_a= 6517.72/ 1.009 × (60 – 45)

= 430.639 kg of dry air per hour

So mass flow rate of air, M_{air} =430.639 / (60×60) = 0.119kg/sec

Now volumetric flow rate of air, V= M/ρ

= (0.119kg/sec) / (1 kg/m^3) [ρ=1 kg/m^3 for air]

=0.119 m^3/sec

So air blower having volumetric capacity 0.119 m^3/sec should be selected that is

= 0.119 * 3.280843

= 0.3904 cubic feet per second

= 0.3904 * 60 = 23.62 cfm,

Therefore blower capacity = 23.62 CFM

vii. Dimensions of trays: Considering the loading of turmeric rhizomes as $10kg/m^2$, the total drying area required for 25 kg turmeric was 2.5 m^2.Considering 5 trays require 0.5 $m^2$for each tray. So the size of each tray was kept as 100 cm × 50 cm with core height of 5 cm.

3.2 Fabrication of electrically heated dryer

A steady stream of hot air from electric heater flows into the drying chamber circulating through and over the turmeric results in continuous and efficient drying. There was no direct exposure of the turmeric to the environment; turmeric drying was more hygienic as there was no secondary contamination of the products through rain, dust, insects, rodents or birds. The products were dried by hot air only in the drying chamber. Fabrication of the designed electrically heated dryer system was carried out in following manner.

a) Dying Chamber

The drying chamber was fabricated as per the conceptualized design. The frame was fabricated with MS angle of 2 mm thickness. From the base to the ceiling of the drying chamber, side rails were provided for stacking five trays evenly at distances of 5cm apart. The entire unit was enclosed in a galvanized iron sheet box and insulated with thermo-coal sheet. The size of the finished drying chamber was 102 × 53 × 57 cm. For loading and unloading of the trays in the drying chamber a door was also provided with locking arrangement. The door was lined with sealing thermo-coal sheet to make it airtight. The inside view of drying chamber is shown in **Plate 3.1.**

Plate 3.1 Inside view of drying chamber

b) Trays

Each drying tray (**Plate 3.2**) was fabricated as per the dimensions: 100 × 50 × 5 cm with 276 perforations/holes of 10 mm diameter throughout the area of tray (4.33 % of total tray area). Five similar trays were fabricated with food grade perforated aluminum sheet of 2 mm thickness. Each tray carries about 5 kg of the material to be dried.

Plate 3.2 Drying trays

c) Drying air inlets

Drying air inlet of 4.8 cm was provided at the bottom of the drying chamber to pass the hot air into it. This air inlet was connected to electric heater through 78 cm PVC pipe.

d) Exhaust air chimney

The exhaust air chimney was fabricated in cylindrical shape with cross sectional diameter of 17 cm and a height of 9.5 cm. It was fabricated with G. I. sheet of 2 mm thickness.

e) Drying chamber stand

The stand for drying chamber was fabricated using 2 mm thick MS angle with size of 102 × 53 × 70 cm. Four heavy duty wheels were provided for easy movement of drying chamber.

The complete line diagram with all dimensions is shown in **Fig. 3.1.**

3.3 Experimental procedure

3.3.1 Procurement of Turmeric Rhizomes

Turmeric rhizomes were procured from TCA, Dholi and brought to the Department of Processing and Food Engineering, CAE, DrRPCAU, Pusa, Bihar to carry out the experiments. The turmeric rhizomes without protruding fingers were taken and cleaned to remove the foreign materials and washed with clean water to remove dirt adhering to the rhizomes before the start of the experiment. The initial moisture content of the rhizomes was determined by using hot air oven method at the temperature of 102±2^{o}C for 24 hours.

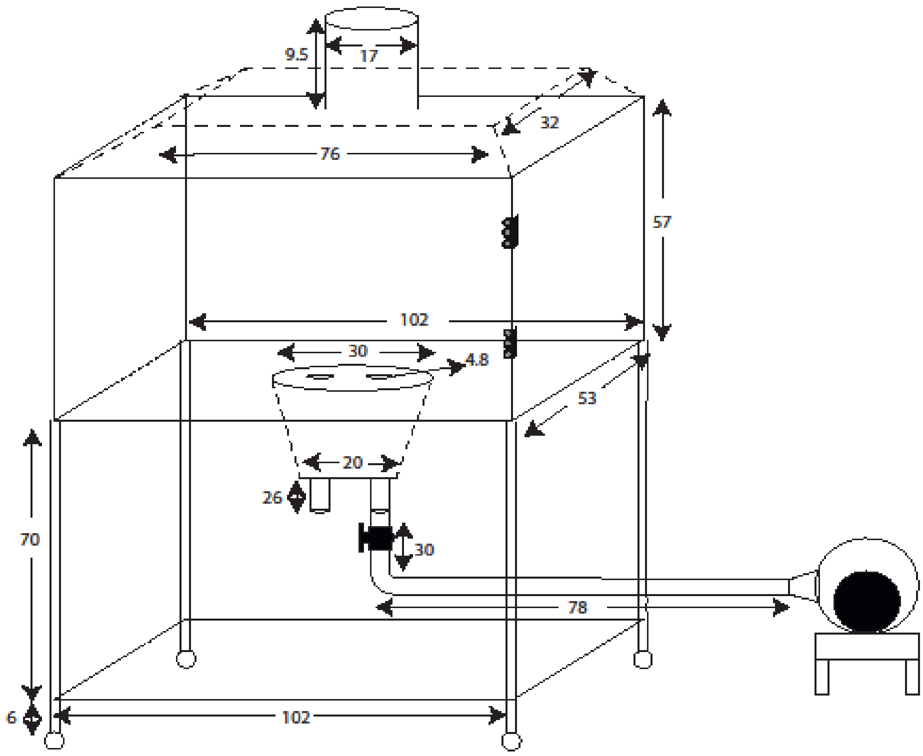


Fig. 3.1 Line diagram of turmeric dryer

3.3.2 Boiling of turmeric

Boiling is one of the most important post-harvest operations to be performed before drying which essentially involves cooking of fresh rhizomes in water until soft before drying. Boiling destroys the vitality of fresh rhizomes, avoids the raw odour, reduces the drying time and yield uniformly coloured product.

In our experiment, laboratory autoclave was used for boiling of turmeric rhizomes. Firstly 20 litres water was added in autoclave for 25 kg turmeric and heated for 35 minutes, then turmeric was added into this pre heated water and rhizomes boiled up to 80 minutes. At last boiled rhizomes were tempered for 105 minutes. So the total time for boiling was 220 minutes. Boiling process is shown in **Plate 3.3** below –

Plate 3.3 Boiling process of turmeric

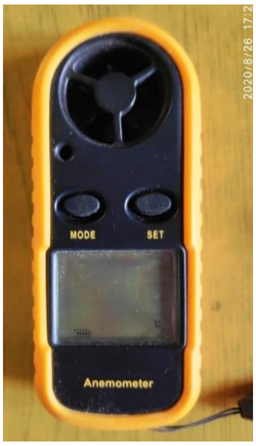
3.3.3 Drying of turmeric

Firstly the initial moisture content of boiled turmeric was determined. The Dryer was run empty for about 30 min in order to establish steady state conditions. The experimental procedure was started by loading of cured turmeric on the trays of the drier cabinet. After loading 25 kg of fresh boiled and cured turmeric in five trays, complete sealing of cabinet was done so that there is no any air leakage. Then the blower was connected to the setup and the flow was adjusted as per calculation. The sampling procedure was adopted for taking observations of reducing weight of turmeric during drying in each tray at fixed time intervals. The sample weights were taken on an electronic top pan digital balance (WENSER make, 300 g / .01 g). The temperatures and relative humidity at various sections of the dryer were taken with the help of data logger and digital temperature/RHmeters at regular intervals of time up to six days along with observation of air flow rate at entrance and exit, ambient temperature and RH. Drying was continued till three consecutive near constant weights were recorded from each tray. At the same time, electric energy was also measured with an energy meter.Voltage variac was used to supply constant voltage to heater-blower for maintaining required air inlet temperature. The complete experimental setup is shown in **Plate 3.4** and instruments used in **Plate 3.5**.

Plate 3.4 (a) Complete view of experimental setup

Plate 3.4 (b) Complete view of experimental setup with trays

Datalogger



Anemometer

Temp./RH meters

Energymeter

Voltage Variac

Digital Balance

Plate 3.5 Various instrument used in experimentation

3.4 Performance evaluation of dryer

The dryer's performance has been evaluated on the basis of following parameters during the full load test:

3.4.1 Moisture content and drying rate

The calculation of moisture contents (w. b. & d. b.) and drying rate was done as follows with the help of time and sample weight data for different trays presented under Appendix B1 to B5 –

A = Elapsed drying time (min)

B = Average elapsed time (min) = $\frac{A_n + A_{n+1}}{2}$, where n = 1, 2, 3, 4 ……

C = Sample weight (g)

D = Moisture removal (g) = Initial sample wt. − Sample wt. at any time

= $C_1 - C_n$, where n = 2, 3, 4, 5 ……..

Bone dry material in sample (W_{bd}) [FIXED VALUE]

$$= \frac{100}{100 + I.M.C.(\%d.b.)} \times Initial\ sample\ weight$$

E = Moisture present in the sample at any time = Sample wt. at any time – Bone dry material (Fixed) = C_n - W_{bd} , Where n = 1,2,3,4………

F = Moisture content at any time (% w.b.)

$$= \left\{ 1 - \frac{Initial\ sample\ wt.}{Weight\ at\ any\ time} (1 - I.M.C.\ w.b.\ in\ \ fraction) \right\} \times 100$$

G = Average moisture content (% w.b.) = $\frac{F_n + F_{n+1}}{2}$, where n = 1, 2, 3, 4 ……

H = Moisture content at any time (% d. b.) = $\frac{F_t}{100 - F_t} \times 100$, where t = 1, 2, 3, 4, ……

I = Average moisture content (% d.b.) = $\frac{H_n + H_{n+1}}{2}$, where n = 1, 2, 3, 4 ……

J = Drying rate (kg water / kg.dm.h) × 10^{-3} = $\frac{Moisture\ removal \times 60}{Elapsed\ time \times Bone\ dry\ material\ in\ sample}$

$$= \frac{D_n \times 60}{A_n \times W_{bd}}$$, where n = 2, 3, 4, 5, ……..

3.4.2 Heat utilization factor

The heat utilization factor (HUF) of the developed system was determined as per the following equation. It is a decimal value that indicates the amount of heat lost without being utilized for the intended purpose. The H.U.F. in the ideal condition is 1, against which this system was compared.

$$HUF = \frac{Tdi - Tc}{Tdi - Ta} \qquad \text{……... (3.5)}$$

Where,

T_{di} = Dryer cabinet inlet temperature, °C

T_c = Temperature of exhaust air, °C

T_a= Ambient air temperature, °C

3.4.3 Drying efficiency

The drying efficiency is the ratio of energy used for drying to the energy supplied by the electric heater. It is determined by the following equation:

$$\eta_d = \left(\frac{Q_w}{Q_g}\right) \times 100 \qquad \text{……... (3.6)}$$

$$Q_w = W_{bd}C_p \times (T_d - T_a) + M_{tw}C_w\,(T_d - T_a) + M_w \times \lambda \qquad \text{……... (3.7)}$$

Where, Q_w = Total quantity of energy required for drying, kJ

W_{bd}= Mass of the bone dry product, kg = 4.640

C_p&C_w= Specific heat of product and water, kJ/kg °C. = 0.837 & 4.185

T_d = Drying air temperature, °C = 56.45

T_a= Ambient air temperature, °C = 31.94

M_w =Mass of the water removed during drying, kg = 20.36

λ = Latent heat of vaporization of water, kJ/kg = 2260

So Q_w =4.64×0.837× (56.45-31.94) +20.54×4.185× (56.45-31.94) +20.36×2260

= 95.1889968 + 2106.87715 + 46013.60

= 48215.6661 kJ

Q_g = Energy supplied by heater = 40 kwh = 40×3600 = 144000 kJ

3.5 Determination of physical properties

The knowledge of physical properties plays an important role in the design of the drying equipment and hence these properties were studied for freshly harvested, boiled and dried turmeric rhizomes. The standard methods to determine the physical properties of the samples such as size, shape, bulk density, true density and porosity were adopted and the details are given below:

3.5.1 Size

The axial dimensions; major, intermediate and minor diameters which are also referred as length-l, width-a and thickness-b respectively were measured using a Vernier Calliper. 20 pieces each were randomly selected from the bulk to determine the size of the turmeric rhizomes. By measuring length, width and thickness; geometric mean, arithmetic mean, square mean and equivalent mean diameter were calculated by the following formulas.

$$\text{Arithmatic Mean diameter (AMD)} = \frac{l+a+b}{3} \qquad \text{……... (3.8)}$$

$$\text{Geometric Mean Diameter (GMD)} = \sqrt[3]{l\,a\,b} \qquad \text{……... (3.9)}$$

$$\text{Square Mean Diameter} = \sqrt{l\,a + a\,b + b\,l} \qquad \text{……... (3.10)}$$

$$\text{Equivalent Mean Diameter (EMD)} = \frac{AMD + GMD + SMD}{3} \qquad \text{……... (3.11)}$$

3.5.2 Surface Area and Volume

The surface area (S) and volume (V) of turmeric rhizomes were calculated by the relationship given below (Jain and Bal, 1997).

$$S = \frac{\pi B\ l^2}{2l - B} \quad \text{Where } B = \sqrt{a\,b} \qquad \textbf{……... (3.12)}$$

$$V = 0.25\left[\frac{\pi}{6} l\,(a+b)^{2}\right] \qquad \textbf{……... (3.13)}$$

3.5.3 Shape

Shape can be expressed in terms of sphericity (S) and was calculated by the formula given below (Mohsenin, 1986).

$$S = \sqrt[3]{\frac{l\,a\,b}{l}} \qquad \text{Where l, a and b - length, breadth and thickness, mm} \qquad \textbf{……... (3.14)}$$

3.5.4 Bulk Density

Bulk density is the ratio of mass and volume of the object and was determined by weighing the mass of the bulk samples filled in a glass beaker of known volume of 1000 cc.

3.5.5 True density

The true density of turmeric rhizomes was measured by platform scale method (Mohsenin, 1986). In this method, the turmeric rhizomes were weighed using a weighing balance of 0.1 g accuracy in air and immerse the sample in container which is completely filled with water. The amount of water absorbed by the sample was considered as negligible. The mass of displaced water gives the true density of the sample and was calculated using the following formula

$$\text{True Volume } (m^3) = \frac{\text{Mass of displaced water (kg)}}{\text{Density of water (kg/m}^3)} \qquad \textbf{……... (3.15)}$$

By knowing the mass of the turmeric rhizomes in air and the true volume, the true density was calculated as follows:

$$\rho_t = \frac{W_a}{V_t} \qquad \text{Where, } \rho_t \text{ - true density of turmeric rhizomes, kg/m}^3 \qquad \textbf{……... (3.16)}$$

W_a - mass of turmeric rhizomes in air, kg

V_t - true volume of turmeric rhizomes, m^3

3.5.6 Porosity

The porosity (ε) of the turmeric rhizomes was calculated using bulk density and true density with the formula given below (Mohsenin 1986) :

$$\varepsilon = \frac{\rho_b}{\rho_t} \qquad \text{Where, } \rho_b \text{ – bulk density, kg /m}^3 \quad \rho_t \text{– true density, kg /m}^3 \ \textbf{... (3.17)}$$

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CHAPTER - IV
RESULTS AND DISCUSSION

This chapter deals with the results of performance evaluation of the developed dryer for turmeric drying, physical properties of fresh/boiled/dried turmeric and some supporting relevant data.

4.1 Design and development of electrically heated dryer

The complete design and fabrication details have been mentioned in chapter III. For the electrical dryer, the air was heated while flowing through spiral type electrical heaters that had a heating capacity of 1.5 kW. The air flow rate was obtained from a centrifugal fan driven by 2900 rpm electric motor. The air which enters the electric heater in such a way is going to come in contact with hot electric coil. As the temperature of the coil is greater than that of the temperature of the air the heat transfer is going to take place from hot electric coil to the cold air. This process of heat transfer is going to increase the temperature of the air. The property of air is such that when the temperature of the air increases, the density of the air is going to decrease and thus the weight of the air is also going to decrease. Thus the lighter air is going to rise to the higher levels. The electric heater is placed at stand to the ground level and other end of the heater is connected to the drying chamber, the hot air is thus going to enter the drying chamber. The hot air which is less dense is going to rise through the drying chamber as it enters the drying chamber. Five trays are placed in the drying chamber; these trays are provided with holes which allow the air to pass from the bottom side of the tray to the top side of the tray. Material to be dried has been placed on these trays. The hot air in the drying chamber is going to come in contact with the material surface thus allowing the moisture content in the material to evaporate. As the water is evaporated from the material, the material is going to be dried i.e. it is going to lose the water present in it. Thus the air from the atmosphere is going to take away the moisture from the material and is going to dry it. The drying operation is carried out throughout the day without any interruption. The drying of material takes place without any pollution and without any loss.

4.2 Performance of electrically heated dryer

The performance of designed system was evaluated under full load conditions for turmeric drying. Experiment was carried out as per the methodology described under chapter III. Full load performance of system was evaluated by loading the dryer with 25 kg of turmeric with 82.19 % w. b. initial moisture content. The drying process was carried out for 3120 minutes by using electric energy during which electric heater of 1.5kw power was used for drying. In the developed dryer, the turmeric rhizomes were dried in 3120 minutes (52 hrs) in comparison to 74 hours in open-sun drying as reported by Arun *et al.*, 2014. This shows that electric dryer ensures quicker drying of the products than the open sun drying method with better quality and hygiene.

4.2.1 Drying characteristics of turmeric

The drying characteristics of turmeric rhizomes dried in electric dryer were studied in terms of moisture content reduction and drying rate. The experiment was conducted for drying of 25 Kg cured turmeric and observations were recorded. Drying data calculations were made and tables were constructed as per methodology explained under chapter III. All drying tables are presented in **Appendices B1 to B5** for each tray separately.

4.2.1.1 Moisture content reduction

For comparison of drying process in each tray, the moisture content (% d. b.) data were extracted from each table and are summarised in **Table 4.1** with drying time. The reduction of moisture content with time is presented in **Fig. 4.1**. It can be observed that moisture content of turmeric reduced with time in a linear fashion. Decrease of moisture content in the initial period where the non-bound moisture was removed and after that the bound moisture was removed until reaching the final moisture content followed an exponential trend in terms of time. The turmeric rhizomes were dried from initial moisture content of 82.19 % (w.b.) to final moisture content in the range of 8.22 – 15.68 % (w.b.) in 1980 - 3120 minutes in different trays. **Table 4.2** gives summary of drying for each tray at a glance. It is quite clear from data that the location of trays in the drying chamber plays an important role. The drying in the bottom most tray 1 was faster and the drying in top most tray 5 was slower. Different moisture contents were achieved at the end of drying in different timings. It was observed that when the drying was completed in bottom tray 1 in 1980 minutes with final moisture content of 8.22 % w.b., it was continued in all other trays reaching the M. C. levels of 21.38, 57.41, 52.71, 53.54 % w.b. respectively in trays 2, 3, 4, 5 at that time level (1980 min). This is due to the slow heat transfer rate from drying air to the turmeric in upper trays.

Table 4.1 Moisture content reduction with time in different trays during drying

Time (min)	Moisture content (% dry basis)					Time (min)	Moisture content (% dry basis)				
	Tray 1	Tray 2	Tray 3	Tray 4	Tray 5		Tray 1	Tray 2	Tray 3	Tray 4	Tray 5
0	461.482	461.482	461.482	461.482	461.482	1380	62.7214	133.604	230.056	291.156	255.466
15	457.186	459.367	460.121	460.683	461.016	1440	53.5221	116.366	238.938	282.944	235.877
30	452.669	457.811	459.19	459.302	460.016	1500	45.0941	103.859	234.855	276.623	219.952
45	448.647	455.011	458.904	458.14	459.217	1560	38.8144	93.6532	228.48	272.771	206.093
60	444.02	452.21	455.752	456.686	457.818	1620	34.683	83.2612	219.169	245.74	193.634
75	439.558	449.597	453.747	455.088	455.885	1680	26.4203	71.5001	215.015	215.729	177.643
90	434.27	445.988	451.741	453.271	454.686	1740	16.9456	61.108	203.268	188.262	162.318
105	428.321	443.25	449.95	452.327	453.687	1800	13.8609	51.4005	191.736	162.611	146.594
120	422.537	439.889	448.231	450.728	452.088	1860	9.89475	45.1155	170.463	142.992	136.466
150	411.906	434.164	444.149	447.313	450.489	1920	9.06848	34.7856	144.749	126.642	123.474
180	402.486	428.626	440.496	444.624	448.623	1980	8.95831	27.1938	134.793	111.455	113.879
210	392.461	421.719	436.914	440.991	446.024	2040		23.7091	108.577	96.5588	104.484
240	383.812	415.994	433.046	437.866	444.225	2100		16.864	98.1197	82.0258	94.1568
300	364.037	403.237	424.523	431.399	438.429	2160		11.8235	75.7005	72.9427	87.8271
360	345.804	390.294	415.784	424.423	434.031	2220		11.3879	55.1436	64.9495	81.0975
420	338.147	376.977	406.473	417.157	429.101	2280		11.2013	41.6778	57.8283	73.7683
480	306.418	363.1	398.809	411.271	425.369	2340			31.3635	52.9598	68.438
540	293.418	354.637	393.509	407.638	423.371	2400			25.7766	47.5826	61.5752
600	270.723	341.943	385.271	401.098	418.707	2460			17.0382	45.1846	56.7113
660	248.799	325.825	376.103	392.305	413.843	2520			15.3191	43.368	52.1139
720	225.773	310.082	366.29	383.731	408.113	2580			14.8894	33.3402	48.6492
780	200.489	289.982	354.687	373.34	401.45	2640				24.4751	46.0507
840	175.591	270.318	340.72	363.385	392.721	2700				19.3886	42.053
900	152.29	249.472	326.824	350.305	383.46	2760				17.136	38.988
960	130.862	230.679	313.287	338.533	375.331	2820				16.264	35.2568
1020	112.408	211.948	299.463	326.907	366.403	2880					29.2602
1080	100.675	196.205	283.561	321.094	353.943	2940					24.9959
1140	90.0986	185.999	271.456	314.99	337.952	3000					19.6656
1200	84.3698	168.327	256.486	311.066	321.228	3060					19.1326
1260	77.1536	159.179	246.172	305.18	302.905	3120					18.5996
1320	70.268	148.227	242.806	299.367	280.651						

Table 4.2 Summary of drying results at a glance

Particulars	Tray1	Tray2	Tray3	Tray4	Tray5
Initial moisture content (% wb)	82.19	82.19	82.19	82.19	82.19
Final moisture content (% wb)	8.22	10.07	12.96	13.99	15.68
Total moisture reduction (% wb)	73.97	72.12	69.23	68.20	66.51
Total time taken (in minutes)	1980	2280	2580	2820	3120
Moisture content in 1980 minutes (% wb)	8.22	21.38	57.41	52.71	53.24

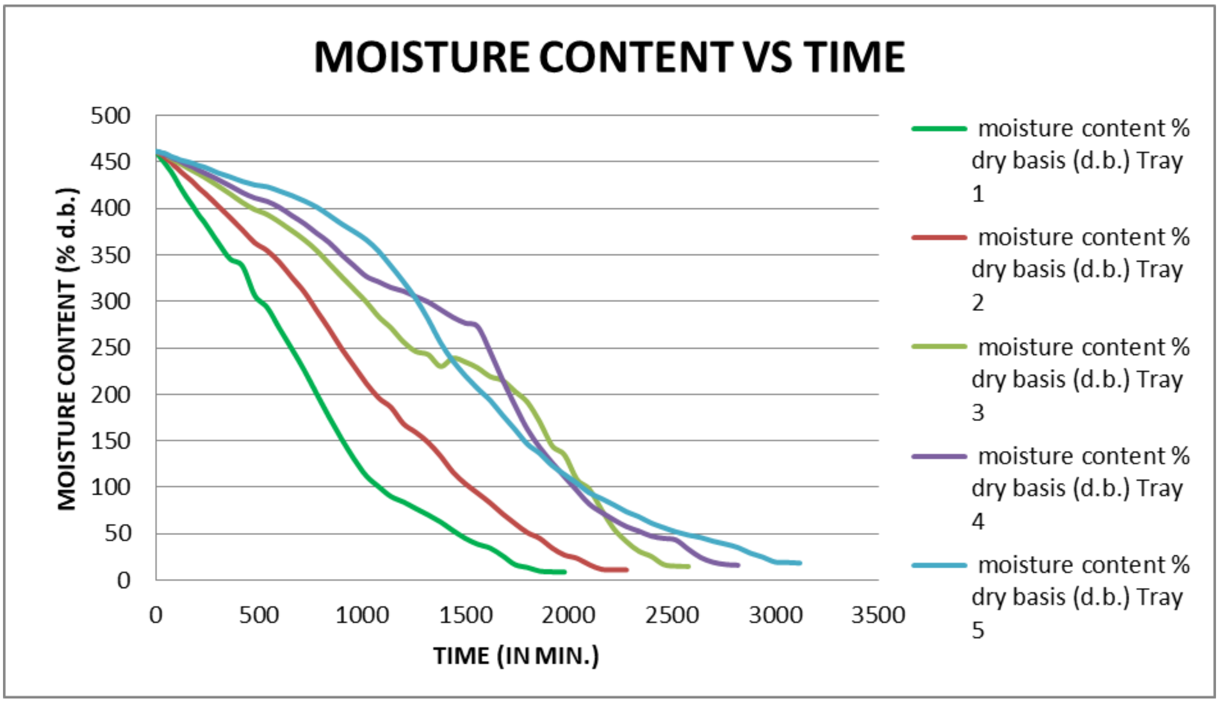

Fig 4.1 Moisture content reduction with time in different trays

4.2.1.2 Drying rate

The drying rate was calculated for each tray which is presented in Appndices B1 to B5. It was expressed as kg of water evaporated per kg dry matter per hour. Drying rates along with average moisture contents on dry basis have been extracted from appendices and are presented under **Table 4.3**. Data from this table were used to plot different drying curves as indicated in **Fig. 4.2**. From Fig 4.8 it can be observed that overall drying rate during the process varied from 0.172 $\times 10^{-3}$ to 0.086 $\times$ 10^{-3} kgW/kg.dm.h. The Fig 4.8 also indicates that during initial hours, moisture removal rate was higher, after which the drying rate decreased rapidly. During last hours of drying very negligible amount of water was removed, this shows that product almost had reached its equilibrium moisture content. During the first stage – the constant drying rate period – the surface water on the material is removed. In the second phase – the falling drying rate period – internal diffusion of the water to the surface of the material takes place (Gigler, 2000).

Table 4.3 Average M. C. and drying rates in different trays during drying

S. N.	Tray 1		Tray 2		Tray 3		Tray 4		Tray 5	
	Avg. M.C.	Drying Rate	Avg. M.C.	Drying Rate	Avg. M.C.	Drying Rate	Avg. M.C.	Drying Rate	Avg. M.C.	Drying Rate
	% d.b.	KgW /Kg.dm.h × 10^{-3}	% d.b.	KgW / Kg.dm.h × 10^{-3}	% d.b.	KgW / Kg.dm.h × 10^{-3}	% d.b.	KgW / Kg.dm.h × 10^{-3}	% d.b.	KgW / Kg.dm.h × 10^{-3}
1	459.334	0.1719	460.424	0.08463	460.802	0.05444	461.083	0.03198	461.249	0.01867
2	454.927	0.17631	458.589	0.07343	459.656	0.04585	459.993	0.0436	460.516	0.02933
3	450.658	0.17117	456.411	0.08629	459.047	0.03438	458.721	0.04457	459.617	0.03022
4	446.334	0.17466	453.61	0.09272	457.328	0.05731	457.413	0.04797	458.517	0.03667
5	441.789	0.17543	450.904	0.09508	454.749	0.06189	455.887	0.05116	456.852	0.0448
6	436.914	0.18145	447.792	0.1033	452.744	0.06495	454.179	0.05475	455.286	0.04533
7	431.296	0.18953	444.619	0.10419	450.846	0.0659	452.799	0.05233	454.186	0.04457
8	425.429	0.19477	441.569	0.10797	449.091	0.06626	451.527	0.05378	452.887	0.047
9	417.221	0.19835	437.027	0.10927	446.19	0.06934	449.02	0.05669	451.288	0.044
10	407.196	0.19669	431.395	0.10952	442.322	0.06996	445.968	0.0562	449.556	0.04289
11	397.473	0.19725	425.172	0.11361	438.705	0.0702	442.807	0.05855	447.324	0.04419
12	388.137	0.19421	418.856	0.11372	434.98	0.0711	439.428	0.05905	445.125	0.04317
13	373.925	0.19493	409.615	0.11649	428.785	0.07393	434.633	0.06017	441.327	0.04613
14	354.92	0.19284	396.765	0.11865	420.154	0.07617	427.911	0.06177	436.23	0.04578
15	341.975	0.17623	383.635	0.12072	411.129	0.07859	420.79	0.06333	431.566	0.04629
16	322.282	0.19387	370.038	0.12298	402.641	0.07835	414.214	0.06277	427.235	0.04517
17	299.918	0.18678	358.869	0.11872	396.159	0.07553	409.454	0.05984	424.37	0.04237
18	282.07	0.1908	348.29	0.11954	389.39	0.07622	404.368	0.06039	421.039	0.0428
19	259.761	0.19339	333.884	0.12332	380.687	0.07762	396.701	0.0629	416.275	0.04333
20	237.286	0.19646	317.954	0.12617	371.197	0.07933	388.018	0.0648	410.978	0.0445
21	213.131	0.20081	300.032	0.13192	360.489	0.08216	378.535	0.06781	404.781	0.04621
22	188.04	0.20425	280.15	0.13655	347.703	0.08627	368.362	0.07008	397.085	0.04914
23	163.94	0.20617	259.895	0.14134	333.772	0.08978	356.845	0.07413	388.091	0.05204
24	141.576	0.20668	240.075	0.14425	320.055	0.09263	344.419	0.07685	379.395	0.05388
25	121.635	0.20538	221.314	0.14678	306.375	0.09531	332.72	0.07917	370.867	0.05596
26	106.542	0.20049	204.077	0.14738	291.512	0.09885	324	0.078	360.173	0.05978
27	95.3868	0.19551	191.102	0.14499	277.509	0.10002	318.042	0.07711	345.948	0.06505

28	87.2342	0.1886	177.163	0.14658	263.971	0.10251	313.028	0.07522	329.59	0.07017
29	80.7617	0.18305	163.753	0.14395	251.329	0.10254	308.123	0.07444	312.067	0.07556
30	73.7108	0.17786	153.703	0.14239	244.489	0.09941	302.273	0.0737	291.778	0.08224
31	66.4947	0.17341	140.915	0.14256	236.431	0.10063	295.261	0.07406	268.058	0.08962
32	58.1217	0.17002	124.985	0.1438	234.497	0.09274	287.05	0.0744	245.671	0.09406
33	49.3081	0.16659	110.112	0.14305	236.897	0.09066	279.784	0.07395	227.914	0.09667
34	41.9543	0.1626	98.7559	0.14147	231.668	0.08962	274.697	0.07259	213.023	0.09828
35	36.7487	0.15811	88.4572	0.14008	223.825	0.08975	259.256	0.07991	199.864	0.09926
36	30.5517	0.15541	77.3806	0.13928	217.092	0.08803	230.735	0.08778	185.638	0.10143
37	21.683	0.15332	66.3041	0.13806	209.141	0.08905	201.996	0.09423	169.981	0.10322
38	15.4033	0.14924	56.2542	0.13669	197.502	0.08992	175.437	0.09964	154.456	0.10502
39	11.8778	0.1457	48.258	0.13431	181.099	0.09389	152.801	0.10275	141.53	0.1049
40	9.48161	0.14141	39.9505	0.13334	157.606	0.09899	134.817	0.10465	129.97	0.10569
41	9.01339	0.13716	30.9897	0.1316	139.771	0.09901	119.049	0.10608	118.676	0.10539
42			25.4514	0.12876	121.685	0.1038	104.007	0.10734	109.182	0.10506
43			20.2865	0.12703	103.348	0.10383	89.2923	0.10843	99.3206	0.10501
44			14.3438	0.1249	86.9101	0.10717	77.4842	0.10794	90.9919	0.10385
45			11.6057	0.12165	65.422	0.10983	68.9461	0.10718	84.4623	0.10286
46			11.2946	0.11849	48.4107	0.11048	61.3889	0.10624	77.4329	0.10209
47					36.5206	0.1103	55.3941	0.10476	71.1032	0.10084
48					28.5701	0.10894	50.2712	0.10349	65.0066	0.10003
49					21.4074	0.10841	46.3836	0.10155	59.1433	0.09878
50					16.1786	0.10624	44.2763	0.09956	54.4126	0.09752
51					15.1042	0.10387	38.3541	0.09958	50.3816	0.09606
52							28.9077	0.09933	47.35	0.09447
53							21.9318	0.09826	44.0518	0.09326
54							18.2623	0.09661	40.5205	0.0919
55							16.7000	0.09474	37.1224	0.09074
56									32.2585	0.0901
57									27.1281	0.08913
58									22.3308	0.08841
59									19.3991	0.08678
60									18.8661	0.08522

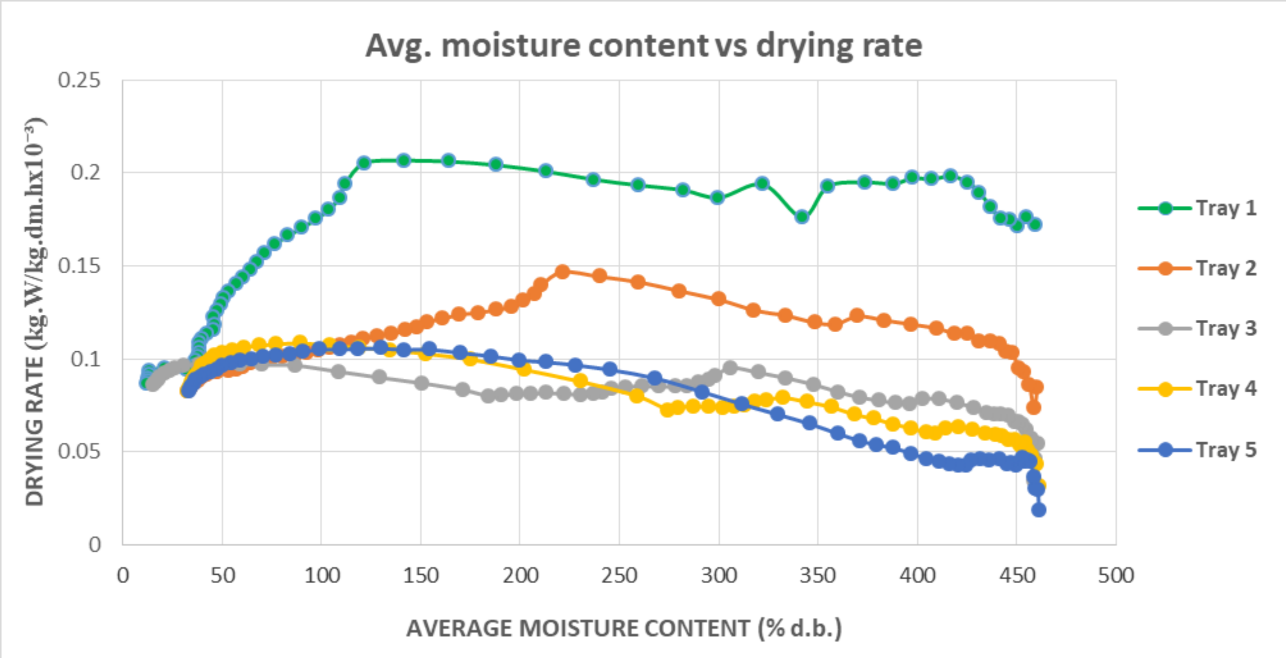

Fig. 4.2 Variation of drying rate with average moisture content (% d.b.)

4.2.2 Heat utilization factor

The Heat utilization factor (HUF) determines the amount of heat utilized by the dryer from the ambient air heated by it. HUF is the ratio of drop in temperature of air during drying process and the increase in temperature of ambient air by heating. Average HUF for full load test was calculated as 0.842 as below:

$$HUF = \frac{Tdi - Tc}{Tdi - Ta} = \frac{110.738 - 44.398}{110.738 - 31.943} = 0.842$$

Where,

T_{di} = Avg. Dryer cabinet inlet temperature, °C = 110.738

T_c = Avg.Temperature of exhaust air, °C = 44.398

T_a= Avg. Ambient air temperature, °C = 31.943

4.2.3 Drying efficiency

Performance testing was carried out with 25 kg of fresh turmeric as input which was dried for 3120 minutes (52 hrs). It was consuming 40 kWh of electric power with output of 4.64 kg of dried turmeric. It was observed that average thermal efficiency of dryer was 33.483 % calculated as below. Similar trends have been reported by Gyanwali *et al.* (2014) for ginger.

$$\eta_d = \left(\frac{Q_w}{Q_g}\right) \times 100$$

$$= \frac{48215.6661}{144000} \times 100$$ (See details in chapter III)

$$= 33.483\ \%$$

4.2.4 Variation of temperature and RH during drying

Fig. 4.3 shows the variation in ambient air temperature and the tray's temperatures inside the drying chamber.The observations recorded during full load testing are presented in **Table 4.4**. It was observed that maximum temperatures for Tray 1 (T1) (bottom), Tray 5 (T5) (top) were 99.3°C and 58.1°C respectively and minimum temperatures were 61.1°C and 30.0°C respectively, while the average temperature of trays in drying chamber was 56.45°C. The outlet of the electric heater was found to be about 78.8°C higher than the average ambient temperature 31.94°C.

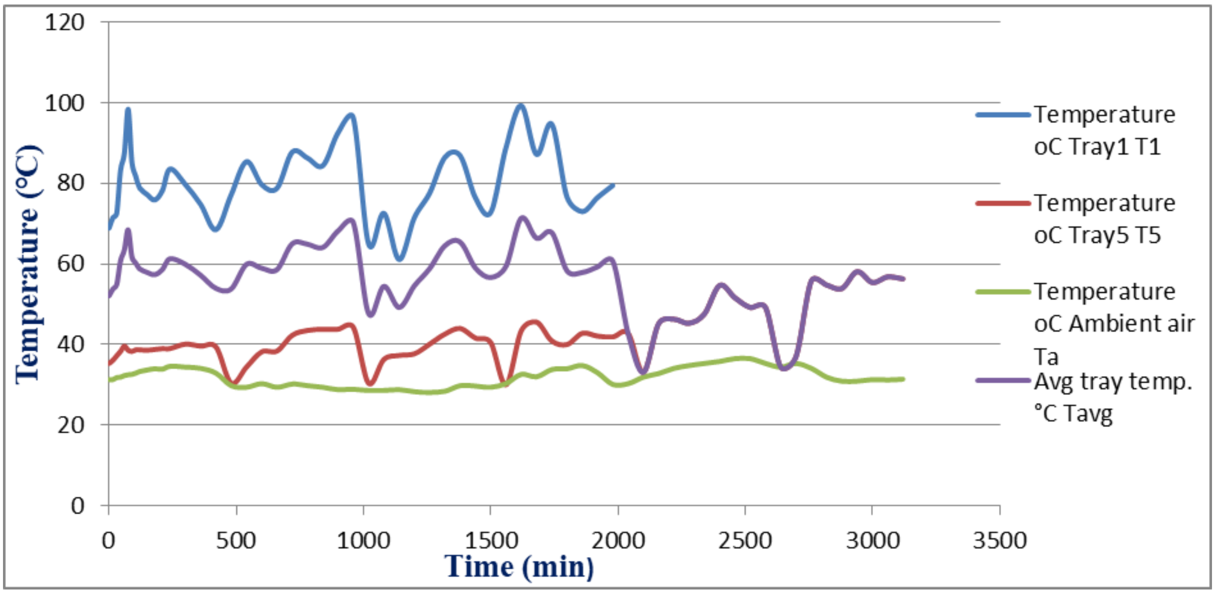

Fig. 4.3 Variation in different temperatures with time during drying

Fig. 4.4 shows that the average temperature of the trays in the drying chamber was more than the temperature of surrounding air and exhaust air. The average temperatures of trays in the drying chamber, heated air and exhaust air were recorded as 56.45°C, 110.74°C and 44.40°C respectively.

Table 4.4 Variation in different temperatures with time during drying

Elapsed ti	Temperature					Avg tray	Elapsed ti	Temperature					Avg tray
min	°C					temp.	min	°C					temp.
	Tray1	Tray5	Ambient air	Heated air	Exhaust a	°C		Tray1	Tray5	Ambient air	Heated air	Exhaust a	°C
	T1	T5	Ta	Th	Te	Tavg		T1	T5	Ta	Th	Te	Tavg
0	68.9	35.3	31.3	92.3	40.7	52.1	1620	99.3	43.4	32.6	137.1	49.5	71.35
15	71.5	36.1	31.3	94.2	41.2	53.8	1680	87.2	45.6	32	114.8	48.2	66.4
30	72.5	37.2	31.8	94.8	42.1	54.85	1740	94.7	40.9	33.8	129.2	52.3	67.8
45	83.2	38.3	31.9	115.9	43.7	60.75	1800	76.6	40	34	93.5	50.3	58.3
60	87.4	39.6	32.3	124.7	41.2	63.5	1860	73	42.8	34.8	91.8	43.4	57.9
75	98.4	38.6	32.5	127	39.6	68.5	1920	76.5	42.1	33	98.3	41.2	59.3
90	85.1	38.3	32.6	114.8	40.4	61.7	1980	79.5	41.9	30.1	106	47.6	60.7
105	81.7	38.7	32.9	110.3	40.8	60.2	2040		42.8	30.3	102.1	42.6	42.8
120	78.9	38.7	33.3	102.3	42	58.8	2100		33.1	31.9	132.5	42.5	33.1
150	77.2	38.6	33.7	100.7	41.2	57.9	2160		45.2	32.8	113.4	43.1	45.2
180	75.9	38.8	34	98.2	41.8	57.35	2220		46.3	34.1	109.4	44.7	46.3
210	78.3	39	33.9	101.9	41.4	58.65	2280		45.3	34.8	108	47.7	45.3
240	83.6	39.02	34.6	113.5	43.1	61.31	2340		47.6	35.3	118.5	45.8	47.6
300	79.7	40.1	34.4	104.6	41.2	59.9	2400		54.7	35.8	127.2	56.8	54.7
360	74.8	39.6	34.1	98.1	42.3	57.2	2460		51.6	36.5	131	50.8	51.6
420	68.5	39.4	32.9	86.9	42.2	53.95	2520		49.2	36.5	97.6	50.5	49.2
480	77.2	30.4	29.8	110.9	35.1	53.8	2580		49.2	35.3	107.2	50.3	49.2
540	85.4	34.4	29.4	126.3	38.5	59.9	2640		34.4	34.4	121.1	41.3	34.4
600	79.7	38.2	30.3	103.8	39.8	58.95	2700		37	35.3	125.1	49.3	37
660	78.8	38.4	29.4	102.1	40.1	58.6	2760		55.8	34.1	107.8	47.8	55.8
720	87.8	42.3	30.2	118.9	45.5	65.05	2820		54.8	31.9	114.8	47.8	54.8
780	86.3	43.5	29.8	117.3	45.3	64.9	2880		53.9	30.9	124.2	45.5	53.9
840	84.4	43.8	29.4	119.4	47.6	64.1	2940		58.1	30.9	133.4	59.3	58.1
900	92.6	43.8	28.8	117.8	47.6	68.2	3000		55.4	31.3	106	49.6	55.4
960	96.3	44.3	28.9	122.7	48.3	70.3	3060		56.8	31.2	111.2	49.6	56.8
1020	65	30.4	28.6	110	32.9	47.7	3120		56.3	31.4	111	52.8	56.3
1080	72.6	36.3	28.6	99.4	33.9	54.45	Avg.	80.480952	42.280656	31.942623	110.7377	44.398361	56.449344
1140	61.1	37.3	28.8	75.9	39.3	49.2	standard deviation (on sample)	8.7244327	6.8139142	2.3121029	13.109108	5.1416759	8.0232107
1200	71.5	37.7	28.3	94.7	38.2	54.6							
1260	77.6	40.1	28.1	107.1	44.1	58.85							
1320	86.5	42.6	28.4	122	47.9	64.55	standard deviation (population)	8.5191232	6.7578316	2.2930729	13.001213	5.0993568	7.9571749
1380	86.9	44	29.8	121	48.1	65.45							
1440	76.4	41.6	29.7	101.8	41.5	59							
1500	72.8	40.5	29.4	98.3	41.3	56.65	variance (on sample)	76.115726	46.429426	5.3458197	171.84872	26.436831	64.37191
1560	88.9	30	30.3	133.2	38.1	59.45							

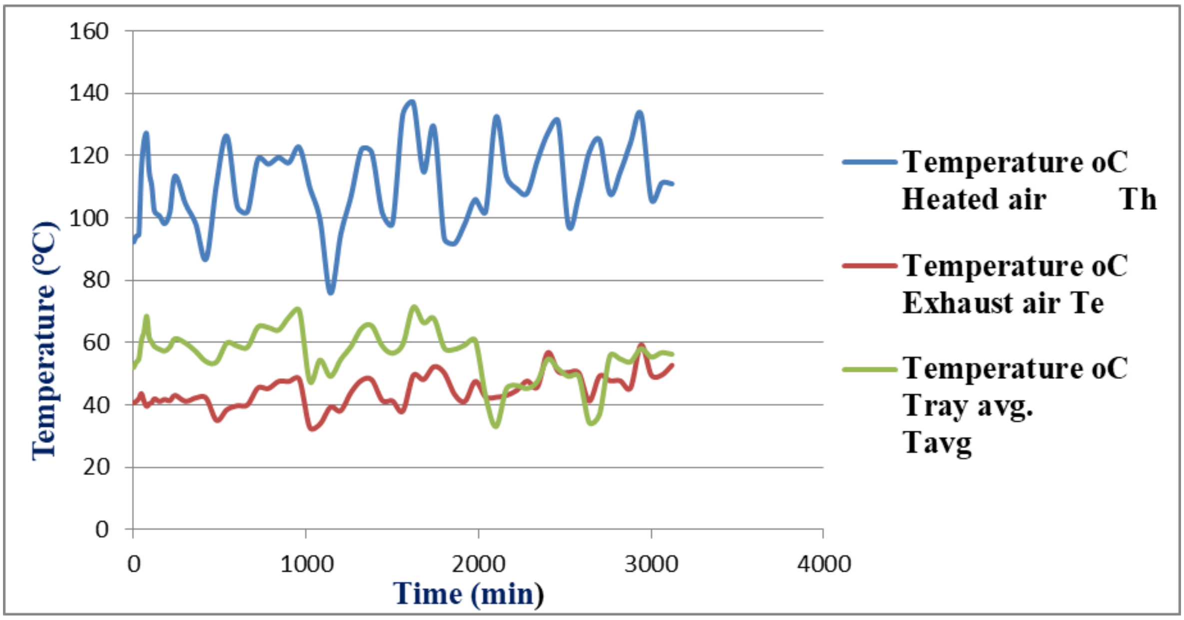

Fig. 4.4 Temperature profile in full load conditions

The relative humidity at bottom most tray 1 and top most tray 5 were recorded and are presented under **Table 4.5**. It was observed from Table 4.3 and **Fig. 4.5** that the average relative humidity inside the electric dryer reduced from 46.45 to 11.75 per cent and achieved its minimum value at end of the experiment. This reduction in RH shows continuous removal of moisture from turmeric rhizomes due to drying. The average relative humidity inside electric dryer for bottom tray (tray1) was found to be 10.03 per cent as compared to 76 per cent of ambient air and 61.39 percent of top tray (tray5). The relative humidity of drying chamber outlet was more than drying chamber inlet. This was due to addition of water vapours into heated air. The relative humidity of ambient air ranged from 62 to 86 per cent. For bottom tray it was ranged from 19.4 to 5.2 and for top tray it was 94 to 17 percent. At last the relative humidity of drying chamber outlet was similar to drying chamber inlet. This was due to that no more addition of water vapours in heated air, at this stage it reaches at equilibrium moisture condition.

Table 4.5 Variation in different relative humidities with time during drying

Elapsed time (min)	Relative humidity (%)			Elapsed time (min)	Relative humidity (%)		
	Bottom Tray 1	Top Tray 5	Ambient air		Bottom Tray 1	Top Tray 5	Ambient Air
0	14.9	78	78	1440	10.2	59	82
15	13.9	78	78	1500	11.2	64	84
30	13.6	77	77	1560	7.1	94	85
45	9.6	75	77	1620	5.9	81	76
60	8.4	72	77	1680	7.8	69	78

75	5.9	70	75	1740	6.2	63	70
90	8.7	75	72	1800	10.4	63	69
105	9.7	75	72	1860	11.7	58	68
120	10.6	78	71	1920	9.5	59	67
150	11.0	76	69	1980	8.4	61	81
180	12.1	80	70	2040		54	83
210	10.7	79	71	2100		91	80
240	9.2	79	69	2160		91	77
300	10.1	75	67	2220		44	69
360	11.6	78	68	2280		41	66
420	14.3	78	70	2340		34	65
480	10.2	94	84	2400		30	65
540	9.1	91	82	2460		27	62
600	9.0	80	79	2520		34	64
660	9.2	78	83	2580		33	68
720	7.3	68	79	2640		30	74
780	7.1	63	79	2700		38	66
840	6.5	60	80	2760		21	70
900	5.8	61	81	2820		19	77
960	5.2	59	81	2880		20	81
1020	19.1	93	84	2940		17	82
1080	12.5	81	83	3000		19	82
1140	19.4	77	85	3060		17	82
1200	12.7	70	85	3120		18	82
1260	10.2	70	86	**Mean**	10.028	61.393	76.000
1320	7.7	65	86	**MeanS.D.**	3.203	22.721	6.814
1380	7.5	63	83	**Variance**	10.260	516.243	46.433

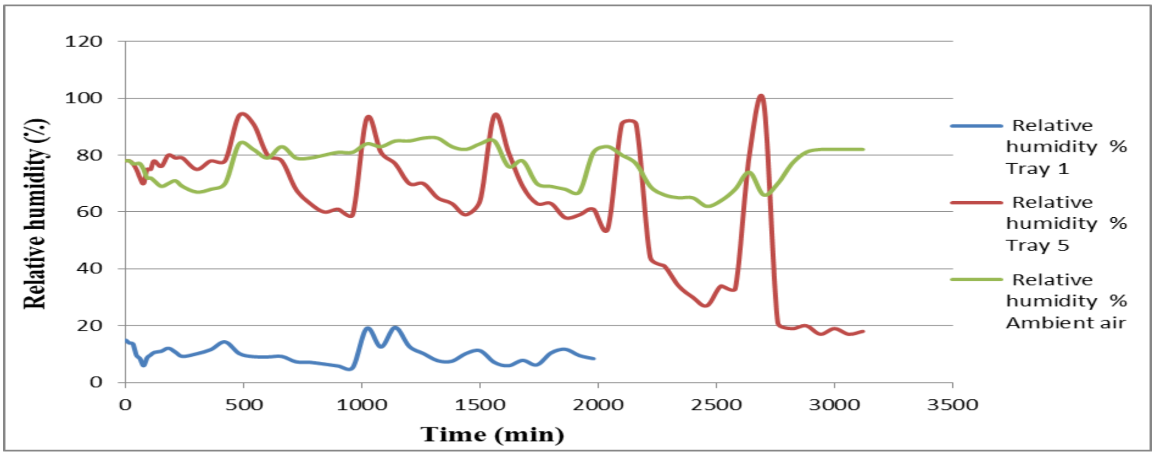

Fig. 4.5 Variation in different relative humidities with time during drying

4.3 Physical properties of turmeric rhizomes

The physical properties were determined for fresh / boiled / dried turmeric rhizomes. These included size, shape, surface area & volume, bulk density, true density and porosity.

4.3.1 Size

The axial dimensions of turmeric rhizomes were measured as explained under chapter IV. The average values of length, width and thickness obtained for fresh, boiled and dried turmeric rhizomes are given in the **Table 4.6.**The data revealed that there was decrease in length; width and thickness after drying. The dimensions of rhizomes increased after boiling. The arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD) and equivalent mean diameter (EMD) were also calculated as per given formulae. Increase in dimensions of rhizomes after boiling could be attributed due to expansion of rhizomes by penetration of water into the intercellular spaces of the sample. This absorption of water at saturation temperature causes gelatinization of starch and hence swelling of the turmeric rhizomes. A similar trend in results was reported in a study of physical properties of ginger where axial dimensions were increased with increase in moisture content and vice versa (Ajav and Ogunlade, 2014).

Table 4.6 Size of turmeric at fresh, boiled and dried conditions

PROPERTY	FRESH (mm)	BOILED(mm)	DRIED(mm)
Length	80.85	83.18	52.95
Width	18.26	22.51	13.12
Thickness	19.69	20.11	12.66
AMD	39.60	43.38	28.45
GMD	30.75	37.90	21.07
SMD	58.55	61.88	42.36
EMD	42.97	45.57	31.84

4.3.2 Shape

The shape of turmeric rhizomes was determined by calculating sphericity. The average values of sphericity for fresh, boiled and dried rhizomes were found to be 0.382, 0.396 and 0.356 respectively. The sphericity of the boiled rhizomes had higher values of sphericity whereas the dried rhizomes had lowest sphericity. Increase in the sphericity of the boiled samples may be due to the proportional increase in the sample dimensions such as length, width and thickness due to absorption of moisture and gelatinization of starch after boiling. Similar results were also reported in a study on effect of moisture content on physical properties of corn grains where sphericity increased from 0.59 to 0.62 when moisture content increased from 12–22% (w.b). The increasing trend in sphericity with gain in moisture content was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling (Seifi and Alimardani,2010).

4.3.3 Surface area and volume

The average values of surface area were 2728.31, 3122.17 and 1364.00 mm^2 respectively and the average values of volume were found to be 15246.03, 19225.03 and 5289.64 mm^3 respectively for fresh, boiled and dried turmeric rhizomes. It was seen that there was increase in volume of rhizomes after boiling and decrease in volume after it was dried. The increase in surface area and volume were due to starch gelatinization and consequent expansion of axial dimension which in turn increased these properties of the sample. The decreased surface area and volume of dried rhizomes were due to reduced axial dimension as the moisture present in it was reduced. The variation in volume and surface area with respect to moisture content was similar to the results reported by ginger rhizomes (Ajav and Ogunlade, 2014).

4.3.4 Bulk Density

The bulk density of the turmeric rhizomes at different stages is represented in the **Fig. 4.6.** The bulk density of fresh, boiled and dried rhizomes was found as 590.48, 614.93, 428.70 kg/m^3. Bulk density was increased with increase in moisture content. There was significant difference in bulk densities between the different stages of turmeric rhizomes. Dried rhizome had lowest and the boiled rhizome had highest bulk density. This behavior of increase in bulk density might be due to the fact that the increase in mass due to increased moisture content in the sample was higher than the volumetric expansion of the rhizomes bulk. Similar trend was reported for ginger rhizomes by (Onu and Okafor, 2002) as the moisture content decreased from 81 to 45.6 percent.

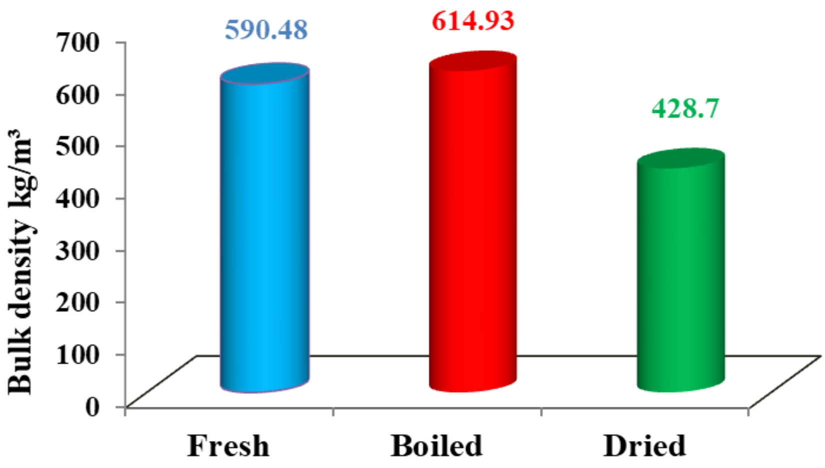

Fig 4.6 Bulk density of turmeric rhizomes at different stages of turmeric processing

4.3.5 True density

The true density of the turmeric rhizomes at different stages is represented in the **Fig. 4.7**. The true density of fresh, boiled and dried rhizomes was found to be 1158.32, 1110.79, 1178.22 kg/m^3. There was significant difference in true densities between the different stages of turmeric rhizomes. It was found that true density is inversely proportional to the moisture content of the turmeric rhizomes. This might be due to increase in weight of the rhizomes by the absorbed moisture content after boiling. Similar trend in results were reported for arecanut kernels by Kaleemullah and Gunasekar, 2002 and round red lentil grains by Austria, 2007.

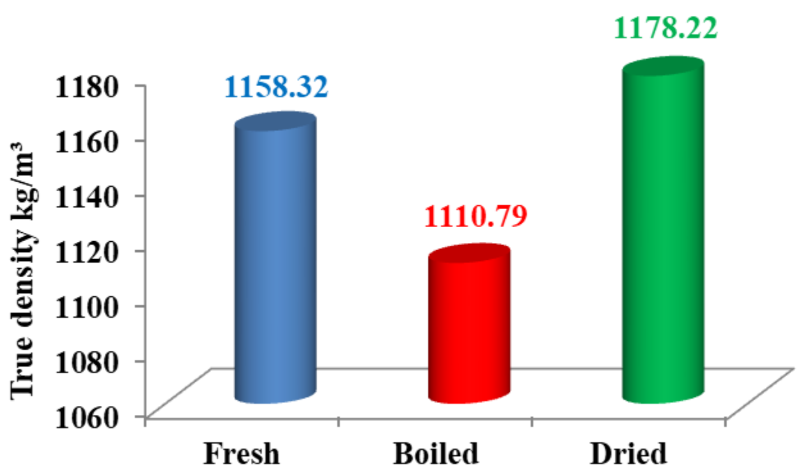

Fig 4.7 True density of turmeric rhizomes at different stages of turmeric processing

4.3.6 Porosity

The porosity of fresh, boiled and dried rhizomes were found to be 49.02, 44.64 and 63.61% respectively. The porosity was inversely proportional to moisture content and therefore decreased with increasing moisture content and it is represented in **Fig. 4.8.**

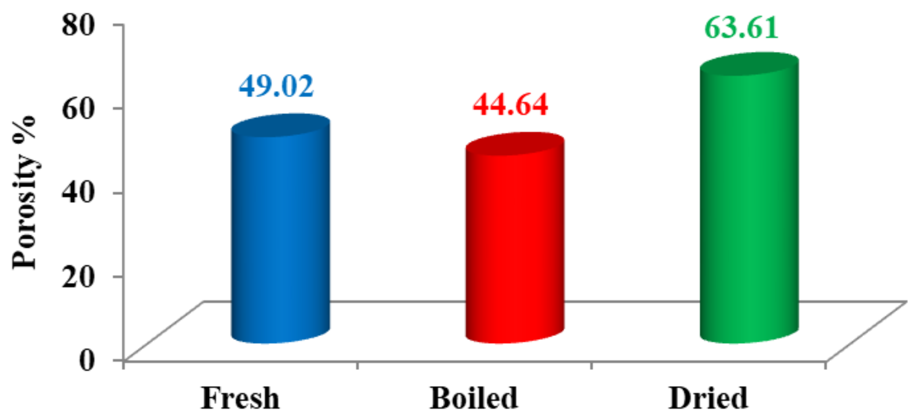

Fig 4.8 Porosity of turmeric rhizomes at different stages of processing

4.4 Final product

The dried turmeric weighing 4.640 kg was fed into laboratory model TNAU turmeric polisher which provided 4.090 kg of polished turmeric in 28 minutes of time. Polished turmeric rhizomes were ground in laboratory model CIAE mini grain mill to get 2.650 kg fine turmeric powder after sieving.

All the resultant products are shown in Plate 4.1.

Plate 4.1 Resultant products of turmeric

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CHAPTER - V
SUMMARY AND CONCLUSIONS

India is to be the home of turmeric. It accounts for 80 per cent of the world output and 60 per cent of world exports. Indian turmeric is considered the best in the world market because of its high curcumin content. India is the largest producer and exporter of turmeric with an annual production of about 931480 tons from 245790 hectares of area with yield of 3790 kg/ha during the year 2018-19 (Anonymous 2019). At the time of harvesting, turmeric like all other agricultural commodities, invariably contains high moisture that must be brought down to the desired level at which attack of micro-organisms would be minimized. At the same time, the retention of quality attributes should also be at the maximum. Post harvest processing of turmeric, generally practiced in rural level, consists of two important processes i.e. curing and drying. The curing operation is carried with traditional *bhatti* (oven) which is an inefficient process. The curing of turmeric with traditional methods requires more time and energy. The rhizomes are then spread on the floor for open sun drying. At commercial level, the post harvest processing of turmeric involves many unit operations such as washing, cleaning, curing, drying, polishing, size reduction and packaging.

Sun drying offers a cheap method of drying but often results to inferior quality of products due to its dependence on weather conditions and vulnerability to the attack of dust, dirt, rains, insects, pests and micro-organism. In traditional method, turmeric is dried under open sun by spreading it on ground or in places that are otherwise unclean, or cow dung smeared floors. Farmers often dry harvested turmeric rhizomes to final moisture content in the range of 15-35%, depending upon the weather conditions. Uneven and non uniform drying promote microbes, especially fungus, to start growth immediately. Most of the farmers depend upon the weather to dry their produce which results to ineffective drying when it is cloudy or during winter season. On the other hand, conventional fuel operated dryers are costly for rural farmers. As a solution to the mentioned issues, a project was planned for developing a tray dryer for drying turmeric rhizomes by electrical energy. Therefore the attempt has been made to develop a modern technique for drying turmeric with the following **objectives:**

1. To develop the electrically heated dryer for turmeric.
2. To evaluate the performance of developed dryer.

The research work was carried out to design and develop the electrically heated dryer for turmeric. The electrically heated dryer was designed, fabricated and tested for its performance in actual use. The performance evaluation of the developed system was evaluated at Department of Processing and Food Engineering, College of Agricultural Engineering, DrRPCAU, Pusa, Bihar. The developed system contains drying chamber with five drying trays, electrical heater, air inlet, drying air chimney as its components. The performance of designed system was evaluated under full load conditions.

After procuring freshly harvested turmeric from TCA, Dholi, the turmeric rhizomes without protruding fingers were taken and cleaned to remove the foreign materials and washed with clean water to remove dirt adhering to the rhizomes before the start of the experiment. The initial moisture content of the rhizomes was determined by using hot air oven method at the temperature of 102±2^{o}C for 24 hours. Laboratory autoclave was used for boiling of turmeric rhizomes. Firstly 20 litres water was added in autoclave for 25 kg turmeric and heated for 35 minutes, then turmeric was added into this pre heated water and rhizomes boiled up to 80 minutes. At last boiled rhizomes were tempered for 105 minutes. So the total time for boiling process was 220 minutes.

Firstly the initial moisture content of boiled turmeric was determined again as 82.19 % w. b. The Dryer was run empty for about 30 min in order to establish steady state conditions. The experimental procedure was started by loading of cured turmeric on the trays of the drier cabinet. After loading 25 kg of fresh boiled and cured turmeric in five trays, complete sealing of cabinet was done so that there is no any air leakage. Then the blower was connected to the setup and the flow was adjusted as per calculation. The sampling procedure was adopted for taking observations of reducing weight of turmeric during drying in each tray at fixed time intervals. The sample weights were taken on an electronic top pan digital balance (WENSER make, 300 g / .01 g). The temperatures and relative humidity at various sections of the dryer were taken with the help of data logger and digital temperature/RH meters at regular intervals of time up to six days along with observation of air flow rate at entrance and exit, ambient temperature and RH. Drying was continued till three consecutive near constant weights were recorded from each tray. At the same time, electric energy was also measured with an energy-meter. A Voltage variac was used to supply constant voltage to heater-blower for maintaining required air inlet temperature.

Some important physical properties (size, shape, surface area and volume, bulk density, true density, porosity) of fresh raw, boiled and dried turmeric rhizomes were determined using standard methods. The performance of the dryer was evaluated by determining moisture content reduction pattern, time taken for drying, drying rate, heat utilization factor and dryer efficiency.

The complete flow diagram of the process is presented in Fig. 5.1 below –

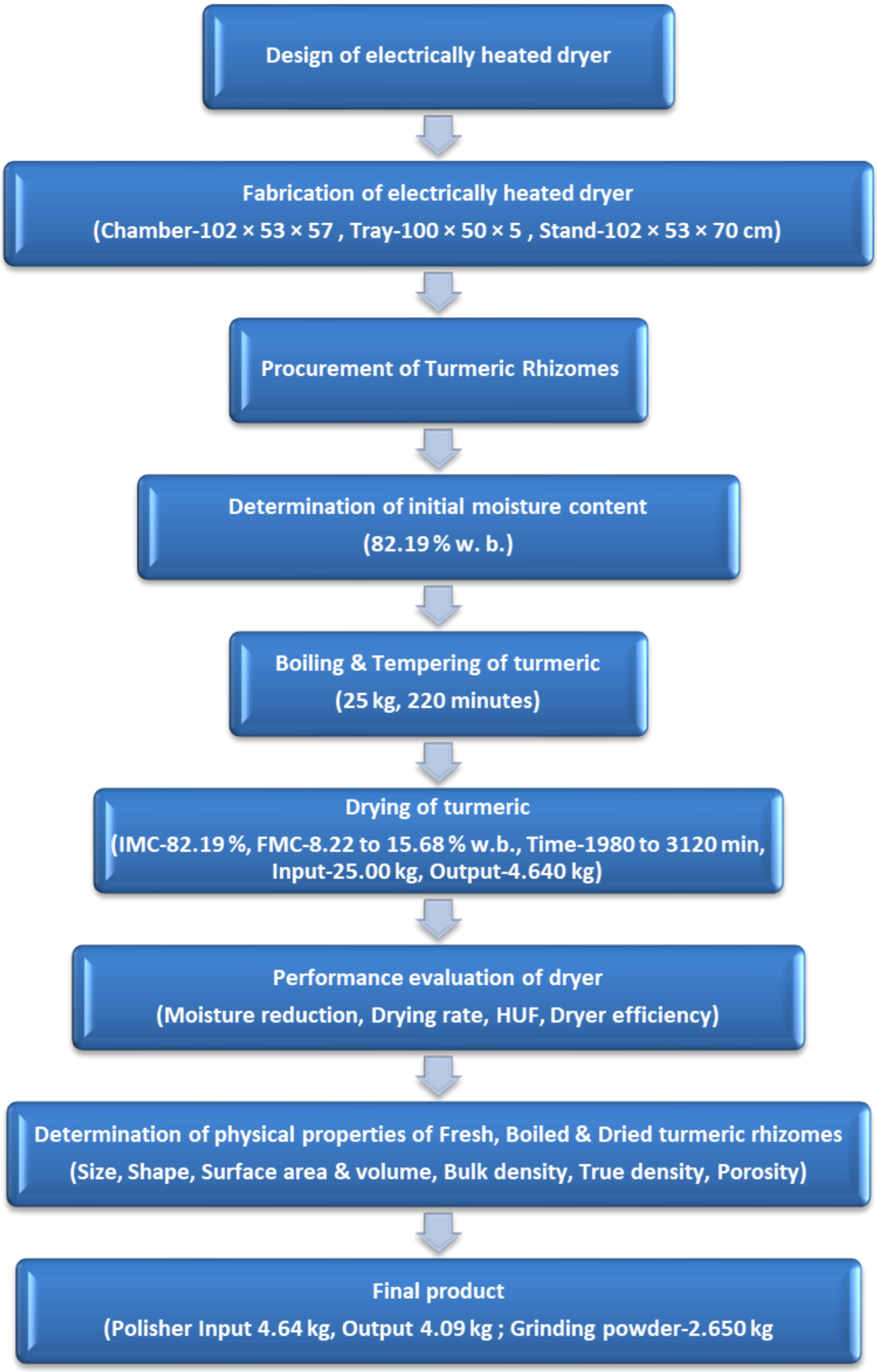

Fig. 5.1 Complete process flow diagram

The specific **results** of the study are as follows –

1. The dryer was successfully designed and fabricated with final dimensions of drying chamber - 102 × 53 × 57 cm, drying trays - 100 × 50 × 5 cm with 10 mm perforations and drying chamber stand - 102 × 53 × 70 cm.
2. The turmeric rhizomes were dried from initial moisture content of 82.19 % (w.b.) to final moisture content in the range of 8.22% in 1980 minutes, 10.07% in 2280 minutes, 12.96% in 2580 minutes,13.98% in 2820 minutes, 15.68% in 3120 minutes for tray 1, tray 2, tray3 ,tray4 and tray 5 respectively.
3. Overall drying rate during the process varied from 0.172 $\times 10^{-3}$ to 0.086 × 10^{-3} kgW / kg.dm.h.

4 Drying curves show the falling rate and constant drying rate period.

5 Average HUF during turmeric drying was found as 0.842.

6 The drying efficiency of developed dryer was found as 33.483%.

7 It was observed that maximum temperatures for Tray 1 (T1) (bottom), Tray 5 (T5) (top) were 99.3°C and 58.1°C respectively and minimum temperatures were 61.1°C and 30.0°C respectively, while the average temperature of trays in drying chamber was 56.45°C. The average relative humidity inside electric dryer for bottom tray (tray1) was found to be 10.03 per cent as compared to 76 per cent of ambient air and 61.39 percent of top tray (tray5).

8 The relative humidity of ambient air ranged from 62 to 86 per cent. For bottom tray it was ranged from 19.4 to 5.2 and for top tray it was 94 to 17 percent.

9 The arithmetic mean diameter (AMD) and geometric mean diameter (GMD) of fresh, boiled and dried turmeric rhizomes were found as 39.60, 43.38, 28.45 and 30.75, 37.90, 21.07 respectively.

10 The average values of sphericity for fresh, boiled and dried rhizomes were found to be 0.382, 0.396 and 0.356 respectively.

11 The average values of surface area were 2728.31, 3122.17 and 1364.00 mm^2 respectively and the average values of volume were found to be 15246.03, 19225.03 and 5289.64 mm^3 respectively for fresh, boiled and dried turmeric rhizomes.

12 The bulk density of fresh, boiled and dried rhizomes were found as 590.48, 614.93, 428.70 kg/m^3 and the true density of fresh, boiled and dried rhizomes was found to be 1158.32, 1110.79, 1178.22 kg/m^3.

13 The porosity of fresh, boiled and dried rhizomes were found to be 49.02%, 44.64% and 63.61% respectively.

14 The dried turmeric weighing 4.640 kg was fed into laboratory model TNAU turmeric polisher which provided 4.090 kg of polished turmeric in 28 minutes of time.

15 Polished turmeric rhizomes were ground in laboratory model CIAE mini grain mill to get 2.650 kg fine turmeric powder after sieving.

The present study led to the following **conclusions** –

1. The total moisture content reduction (from initial to final moisture content) was found 73.97, 72.12, 69.23, 68.20 and 66.51(%w.b.) in tray1, tray2, tray3, tray4 and tray5 in 1980, 2280, 2580, 2820, and 3120 minutes respectively.

2. During full load condition, the average temperature in the drying chamber was 56.45°C, which is near to the optimum temperature required for drying of turmeric rhizomes.

3. The developed system is suitable for drying of 25 kg/batch turmeric for the farming community with good quality.

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SUGGESTIONS FOR FUTURE WORK

The following suggestions are recommended for further improvement of the present work -

i. Experiment may be conducted by rotating the drying trays inside the drying chamber at regular time intervals to achieve the uniform drying pattern with the equal moisture content.

ii. Mechanism for temperature control may be provided by using thermostat.

iii. Cost economics for dryer may be work out.

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APPENDICES

Appendix (A)
Specifications of Instruments / Equipment used

1. Multi Thermometer

Make	:	Instrumentrics
Model	:	H-9288
Range	:	-50℃ to 300℃
Accuracy	:	±1℃
Resolution	:	0.1℃

2. Voltage Variac

Make	:	Omega Electronics
Range	:	0 -270 volt

3. Digital Static Kwh Meter

Make	:	Capital Power System Ltd.
Type	:	C512
Supply	:	240V, 50Hz, 5-20 A, Ac: Single phase

4. Digital Top Pan Balance

Make	:	Wenser
Model	:	PGB2010
Resolution	:	0.01 Gm

5. Thermo-hygrometer

Make	:	Zeal
Model	:	1000
Range	:	0-100℃
Rh	:	0-100%

6. Data Logger

Make	:	Sikka
Model	:	MH3350
Temp.Range	:	-40 to +120℃
Rh Range	:	0-100%
Resolution	:	0.1℃/0.1%RH
Accuracy	:	±0.1%/±0.2%

7. Hot Air Oven

Make	:	Century
Temp.Range	:	Ambient To 200℃
Resolution	:	0.1℃

Appendix (B1) : Experimental data and calculations of drying for TRAY 1 (Bottom Most)

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	G	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
1	0	TRUE	101.93	–	83.78	82.19	–	461.482313	–	–
2	15	7.5	101.15	0.78	83	82.05266139	82.1213307	457.185676	459.3339948	0.17190083
3	30	22.5	100.33	1.6	82.18	81.90597727	81.97931933	452.668699	454.9271877	0.17630854
4	45	37.5	99.6	2.33	81.45	81.77336044	81.83966886	448.647488	450.6580933	0.17116621
5	60	52.5	98.76	3.17	80.61	81.61833435	81.69584739	444.02034	446.3339138	0.17465565
6	75	67.5	97.95	3.98	79.8	81.4663267	81.54233052	439.558448	441.7893939	0.175427
7	90	82.5	96.99	4.94	78.84	81.28288174	81.37460422	434.270279	436.9143636	0.18145087
8	105	97.5	95.91	6.02	77.76	81.07211657	81.17749915	428.32109	431.2956845	0.18953168
9	120	112.5	94.86	7.07	76.71	80.86260489	80.96736073	422.537155	425.4291225	0.19476584
10	150	135	92.93	9.00	74.78	80.46515334	80.66387912	411.905733	417.2214442	0.19834711
11	180	165	91.22	10.71	73.07	80.09895527	80.28205431	402.486183	407.195958	0.19669421
12	210	195	89.4	12.53	71.25	79.69381096	79.89638312	392.460697	397.4734398	0.19724518
13	240	225	87.83	14.1	69.68	79.33082887	79.51231992	383.812338	388.1365172	0.19421488
14	300	270	84.24	17.69	66.09	78.44998457	78.89040672	364.036791	373.9245642	0.19493113
15	360	330	80.93	21.00	62.78	77.56859879	78.00929168	345.803626	354.9202084	0.19283747
16	420	390	79.54	22.39	61.39	77.1765992	77.37259899	338.146799	341.9752125	0.17622983
17	480	450	73.78	28.15	55.63	75.39477772	76.28568846	306.417787	322.2822931	0.19387052
18	540	510	71.42	30.51	53.27	74.58172361	74.98825066	293.417706	299.9177469	0.18677686
19	600	570	67.3	34.63	49.15	73.02565676	73.80369018	270.72265	282.0701781	0.1907989
20	660	630	63.32	38.61	45.17	71.3301753	72.17791603	248.798784	259.760717	0.19338843
21	720	690	59.14	42.79	40.99	69.30379946	70.31698738	225.773217	237.2860006	0.19646465
22	780	750	54.55	47.38	36.4	66.72092942	68.01236444	200.489161	213.1311891	0.20080526
23	840	810	50.03	51.9	31.88	63.71430542	65.21761742	175.590701	188.039931	0.2042503

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
	min	Min	G	g	G	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
24	900	870	45.8	56.13	27.65	60.36302838	62.0386669	152.289708	163.9402045	0.2061708
25	960	930	41.91	60.02	23.76	56.6840062	58.52351729	130.861608	141.5756583	0.20668044
26	1020	990	38.56	63.37	20.41	52.92081691	54.80241156	112.408104	121.634856	0.20538
27	1080	1050	36.43	65.5	18.28	50.16817733	51.54449712	100.67498	106.5415416	0.20048975
28	1140	1110	34.51	67.42	16.36	47.39573167	48.7819545	90.0986425	95.38681108	0.19550529
29	1200	1170	33.47	68.46	15.32	45.76118016	46.57845592	84.3697933	87.23421789	0.18859504
30	1260	1230	32.16	69.77	14.01	43.55182525	44.65650271	77.1536466	80.76171992	0.18305129
31	1320	1290	30.91	71.02	12.76	41.26906179	42.41044352	70.2680104	73.71082851	0.17786126
32	1380	1350	29.54	72.39	11.39	38.54525051	39.90715615	62.7213532	66.49468184	0.17340999
33	1440	1410	27.87	74.06	9.72	34.86281665	36.70403358	53.5221434	58.12174829	0.17001837
34	1500	1470	26.34	75.59	8.19	31.07922172	32.97101918	45.0941247	49.30813404	0.16658953
35	1560	1530	25.2	76.73	7.05	27.96137698	29.52029935	38.8144246	41.95427464	0.16259801
36	1620	1590	24.45	77.48	6.30	25.75160327	26.85649013	34.6830429	36.74873372	0.15810632
37	1680	1650	22.95	78.98	4.80	20.89876688	23.32518508	26.4202795	30.55166119	0.15541126
38	1740	1710	21.23	80.7	3.08	14.49018841	17.69447765	16.9456442	21.68296185	0.15332003
39	1800	1770	20.67	81.26	2.52	12.17352201	13.33185521	13.8608792	15.40326169	0.14923783
40	1860	1830	19.95	81.98	1.80	9.003844612	10.58868331	9.89475278	11.87781598	0.14570337
41	1920	1890	19.8	82.13	1.65	8.314479798	8.659162205	9.06847644	9.481614608	0.1414084
42	1980	1950	19.78	82.15	1.63	8.22177452	8.268127159	8.95830626	9.01339135	0.13715669

Appendix (B2) : Experimental data and calculations of drying for TRAY 2

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
1	0	TRUE	90.23	–	74.16	82.19	–	461.4823133	–	–
2	15	7.5	89.89	0.34	73.82	82.12263544	82.15631772	459.3665648	460.4244391	0.08462974
3	30	22.5	89.64	0.59	73.57	82.07277666	82.09770605	457.8108674	458.5887161	0.07342875
4	45	37.5	89.19	1.04	73.12	81.98232649	82.02755158	455.010612	456.4107397	0.08628915
5	60	52.5	88.74	1.49	72.67	81.89095898	81.93664274	452.2103567	453.6104844	0.09271935
6	75	67.5	88.32	1.91	72.25	81.80484262	81.8479008	449.596785	450.9035708	0.09508401
7	90	82.5	87.74	2.49	71.67	81.68456462	81.74470362	445.987567	447.792176	0.10329807
8	105	97.5	87.3	2.93	71.23	81.59225315	81.63840889	443.2495395	444.6185533	0.10418704
9	120	112.5	86.76	3.47	70.69	81.47768211	81.53496763	439.8892331	441.5693863	0.10796515
10	150	135	85.84	4.39	69.77	81.27916705	81.37842458	434.1642666	437.0267498	0.10927194
11	180	165	84.95	5.28	68.88	81.08303355	81.1811003	428.6259838	431.3951252	0.10952085
12	210	195	83.84	6.39	67.77	80.8325823	80.95780792	421.7186872	425.1723355	0.1136101
13	240	225	82.92	7.31	66.85	80.6199192	80.72625075	415.9937207	418.856204	0.11372122
14	300	270	80.87	9.36	64.8	80.12864721	80.37428321	403.2370019	409.6153613	0.11649035
15	360	330	78.79	11.44	62.72	79.60405762	79.86635242	390.2935993	396.7653006	0.11864758
16	420	390	76.65	13.58	60.58	79.034621	79.31933931	376.9768294	383.6352143	0.12072184
17	480	450	74.42	15.81	58.35	78.4063921	78.72050655	363.1000084	370.0384189	0.1229776
18	540	510	73.06	17.17	56.99	78.0044306	78.20541135	354.6370144	358.8685114	0.11871673
19	600	570	71.02	19.21	54.95	77.3726232	77.6885269	341.9425235	348.2897689	0.11953951
20	660	630	68.43	21.8	52.36	76.51620196	76.94441258	325.8254982	333.8840108	0.12332409
21	720	690	65.9	24.33	49.83	75.61462367	76.06541282	310.0818403	317.9536692	0.12616677
22	780	750	62.67	27.56	46.6	74.35780597	74.98621482	289.9822296	300.0320349	0.13192284
23	840	810	59.51	30.72	43.44	72.99619728	73.67700162	270.3182142	280.1502219	0.13654547

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
24	900	870	56.16	34.07	40.09	71.38539352	72.1907954	249.4718687	259.8950415	0.14133997
25	960	930	53.14	37.09	37.07	69.75919646	70.57229499	230.6790439	240.0754563	0.14425171
26	1020	990	50.13	40.1	34.06	67.94342111	68.85130878	211.9484469	221.3137454	0.14678429
27	1080	1050	47.6	42.63	31.53	66.23957353	67.09149732	196.204789	204.076618	0.14737606
28	1140	1110	45.96	44.27	29.89	65.03489339	65.63723346	185.9994139	191.1021015	0.14499067
29	1200	1170	43.12	47.11	27.05	62.73199675	63.88344507	168.3266912	177.1630526	0.14657747
30	1260	1230	41.65	48.58	25.58	61.41665546	62.07432611	159.1791904	163.7529408	0.14395354
31	1320	1290	39.89	50.34	23.82	59.71430684	60.56548115	148.2270805	153.7031355	0.14238841
32	1380	1350	37.54	52.69	21.47	57.19242674	58.45336679	133.6035248	140.9153027	0.14255567
33	1440	1410	34.77	55.46	18.7	53.78210239	55.48726457	116.3663974	124.9849611	0.14379797
34	1500	1470	32.76	57.47	16.69	50.94638889	52.36424564	103.8585901	110.1124937	0.14304916
35	1560	1530	31.12	59.11	15.05	48.36130141	49.65384515	93.65321501	98.75590255	0.1414724
36	1620	1590	29.45	60.78	13.38	45.43306282	46.89718212	83.26115623	88.45718562	0.14008159
37	1680	1650	27.56	62.67	11.49	41.69099057	43.56202669	71.50008373	77.38061998	0.13927905
38	1740	1710	25.89	64.34	9.82	37.9298455	39.81041803	61.10802495	66.30405434	0.13805978
39	1800	1770	24.33	65.9	8.26	33.95000822	35.93992686	51.40047304	56.254249	0.13669363
40	1860	1830	23.32	66.91	7.25	31.08935249	32.51968035	45.11545546	48.25796425	0.13431158
41	1920	1890	21.66	68.57	5.59	25.80811173	28.44873211	34.78562458	39.95054002	0.13334241
42	1980	1950	20.44	69.79	4.37	21.37982877	23.59397025	27.19382117	30.98972288	0.13160227
43	2040	2010	19.88	70.35	3.81	19.16517606	20.27250241	23.70905894	25.45144006	0.12875654
44	2100	2070	18.78	71.45	2.71	14.43044196	16.79780901	16.86399029	20.28652462	0.12703351
45	2160	2130	17.97	72.26	1.9	10.57338342	12.50191269	11.82353065	14.34376047	0.12490493
46	2220	2190	17.9	72.33	1.83	10.22367039	10.3985269	11.38793537	11.60573301	0.12164685
47	2280	2250	17.87	72.36	1.8	10.07295467	10.14831253	11.20125168	11.29459352	0.11849474

Appendix (B3) : Experimental data and calculations of drying for TRAY 3

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
1	0	TRUE	78.39	–	64.43	82.19	–	461.4823133	–	–
2	15	7.5	78.2	0.19	64.24	82.1467276	82.1683638	460.1214045	460.801859	0.05444126
3	30	22.5	78.07	0.32	64.11	82.1169988	82.1318632	459.1902564	459.65583	0.04584527
4	45	37.5	78.03	0.36	64.07	82.1078316	82.1124152	458.9037493	459.047003	0.03438395
5	60	52.5	77.59	0.8	63.63	82.0063681	82.0570998	455.7521711	457.32796	0.05730659
6	75	67.5	77.31	1.08	63.35	81.9411991	81.9737836	453.7466213	454.749396	0.06189112
7	90	82.5	77.03	1.36	63.07	81.8755563	81.9083777	451.7410715	452.743846	0.06494747
8	105	97.5	76.78	1.61	62.82	81.8165421	81.8460492	449.950402	450.845737	0.06590258
9	120	112.5	76.54	1.85	62.58	81.7595257	81.7880339	448.2313594	449.090881	0.06626074
10	150	135	75.97	2.42	62.01	81.6226682	81.6910969	444.148633	446.189996	0.06934097
11	180	165	75.46	2.93	61.5	81.4984641	81.5605661	440.4956673	442.32215	0.0699618
12	210	195	74.96	3.43	61.00	81.3750547	81.4367594	436.9143284	438.704998	0.07020057
13	240	225	74.42	3.97	60.46	81.23991	81.3074823	433.0464824	434.980405	0.07109599
14	300	270	73.23	5.16	59.27	80.9350553	81.0874826	424.5228958	428.784689	0.0739255
15	360	330	72.01	6.38	58.05	80.6120553	80.7735553	415.7844289	420.153662	0.07617001
16	420	390	70.71	7.68	56.75	80.2556088	80.433832	406.4729477	411.128688	0.0785919
17	480	450	69.64	8.75	55.68	79.9522415	80.1039252	398.8088825	402.640915	0.07834885
18	540	510	68.9	9.49	54.94	79.7369245	79.844583	393.5085009	396.158692	0.07553327
19	600	570	67.75	10.64	53.79	79.3929756	79.5649501	385.2714214	389.389961	0.07621777
20	660	630	66.47	11.92	52.51	78.9961501	79.1945629	376.1031938	380.687308	0.07762438
21	720	690	65.1	13.29	51.14	78.5541336	78.7751419	366.2903252	371.19676	0.07933381
22	780	750	63.48	14.91	49.52	78.0068384	78.280486	354.6867872	360.488556	0.08215781
23	840	810	61.53	16.86	47.57	77.3098342	77.6583363	340.7195655	347.703176	0.08626688
24	900	870	59.59	18.8	45.63	76.5711378	76.940486	326.8239705	333.771768	0.08978032
25	960	930	57.7	20.69	43.74	75.8037106	76.1874242	313.2865095	320.05524	0.09263073
26	1020	990	55.77	22.62	41.81	74.9663636	75.3850371	299.4625413	306.374525	0.09531434
27	1080	1050	53.55	24.84	39.59	73.9285546	74.4474591	283.5613966	291.511969	0.09885387
28	1140	1110	51.86	26.53	37.9	73.0789452	73.5037499	271.4564711	277.508934	0.10002262

Sr. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
29	1200	1170	49.77	28.62	35.81	71.9484448	72.513695	256.4864745	263.971473	0.10250716
30	1260	1230	48.33	30.06	34.37	71.1126443	71.5305446	246.1722184	251.329346	0.10253786
31	1320	1290	47.86	30.53	33.9	70.8289616	70.9708029	242.8057599	244.488989	0.0994074
32	1380	1350	46.08	32.31	32.12	69.7021289	70.2655452	230.0561934	236.430977	0.10062913
33	1440	1410	47.32	31.07	33.36	70.4960714	70.0991002	238.9379138	234.497054	0.0927352
34	1500	1470	46.75	31.64	32.79	70.1363444	70.3162079	234.8551875	236.896551	0.09065903
35	1560	1530	45.86	32.53	31.9	69.5567837	69.846564	228.4804042	231.667796	0.0896242
36	1620	1590	44.56	33.83	30.6	68.6686288	69.1127063	219.1689231	223.824664	0.08975379
37	1680	1650	43.98	34.41	30.02	68.2554366	68.4620327	215.01457	217.091747	0.08803213
38	1740	1710	42.34	36.05	28.38	67.0258408	67.6406387	203.2677784	209.141174	0.08904752
39	1800	1770	40.73	37.66	26.77	65.7224184	66.3741296	191.7358671	197.501823	0.08992359
40	1860	1830	37.76	40.63	23.8	63.0263268	64.3743726	170.462714	181.099291	0.09388576
41	1920	1890	34.17	44.22	20.21	59.1417647	61.0840458	144.7487007	157.605707	0.09898818
42	1980	1950	32.78	45.61	18.82	57.409216	58.2754903	134.7925785	139.77064	0.09900582
43	2040	2010	29.12	49.27	15.16	52.0561161	54.732666	108.5771777	121.684878	0.10380499
44	2100	2070	27.66	50.73	13.7	49.5254555	50.7907858	98.11966815	103.348423	0.10382726
45	2160	2130	24.53	53.86	10.57	43.0849613	46.3052084	75.70048661	86.9100774	0.10717128
46	2220	2190	21.66	56.73	7.7	35.5435873	39.3142743	55.1436013	65.422044	0.10983118
47	2280	2250	19.78	58.61	5.82	29.4172952	32.4804413	41.67776703	48.4106842	0.11048484
48	2340	2310	18.34	60.05	4.38	23.8753599	26.6463276	31.36351098	36.520639	0.11029682
49	2400	2370	17.56	60.83	3.6	20.4939692	22.1846646	25.77662229	28.5700666	0.10893625
50	2460	2430	16.34	62.05	2.38	14.5577785	17.5258739	17.03815537	21.4073888	0.10841079
51	2520	2490	16.1	62.29	2.14	13.2841056	13.920942	15.3191127	16.178634	0.10623891
52	2580	2550	16.04	62.35	2.08	12.9597319	13.1219188	14.88935203	15.1042324	0.10386819

Appendix (B4) : Experimental data and calculations of drying for TRAY 4

Sl. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
1	0	TRUE	77.27	–	63.51	82.19	–	461.482	–	–
2	15	7.5	77.16	0.11	63.4	82.1646	82.1773	460.683	461.083	0.03198
3	30	22.5	76.97	0.3	63.21	82.1206	82.1426	459.302	459.993	0.0436
4	45	37.5	76.81	0.46	63.05	82.0833	82.102	458.14	458.721	0.04457
5	60	52.5	76.61	0.66	62.85	82.0366	82.06	456.686	457.413	0.04797
6	75	67.5	76.39	0.88	62.63	81.9848	82.0107	455.088	455.887	0.05116
7	90	82.5	76.14	1.13	62.38	81.9257	81.9553	453.271	454.179	0.05475
8	105	97.5	76.01	1.26	62.25	81.8948	81.9102	452.327	452.799	0.05233
9	120	112.5	75.79	1.48	62.03	81.8422	81.8685	450.728	451.527	0.05378
10	150	135	75.32	1.95	61.56	81.7289	81.7856	447.313	449.02	0.05669
11	180	165	74.95	2.32	61.19	81.6387	81.6838	444.624	445.968	0.0562
12	210	195	74.45	2.82	60.69	81.5154	81.5771	440.991	442.807	0.05855
13	240	225	74.02	3.25	60.26	81.408	81.4617	437.866	439.428	0.05905
14	300	270	73.13	4.14	59.37	81.1817	81.2949	431.399	434.633	0.06017
15	360	330	72.17	5.1	58.41	80.9314	81.0566	424.423	427.911	0.06177
16	420	390	71.17	6.1	57.41	80.6635	80.7975	417.157	420.79	0.06333
17	480	450	70.36	6.91	56.6	80.4409	80.5522	411.271	414.214	0.06277
18	540	510	69.86	7.41	56.1	80.3009	80.3709	407.638	409.454	0.05984
19	600	570	68.96	8.31	55.2	80.0438	80.1724	401.098	404.368	0.06039
20	660	630	67.75	9.52	53.99	79.6874	79.8656	392.305	396.701	0.0629
21	720	690	66.57	10.7	52.81	79.3273	79.5074	383.731	388.018	0.0648
22	780	750	65.14	12.13	51.38	78.8735	79.1004	373.34	378.535	0.06781
23	840	810	63.77	13.5	50.01	78.4197	78.6466	363.385	368.362	0.07008
24	900	870	61.97	15.3	48.21	77.7928	78.1062	350.305	356.845	0.07413
25	960	930	60.35	16.92	46.59	77.1967	77.4948	338.533	344.419	0.07685
26	1020	990	58.75	18.52	44.99	76.5757	76.8862	326.907	332.72	0.07917
27	1080	1050	57.95	19.32	44.19	76.2523	76.414	321.094	324	0.078

Sl. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
28	1140	1110	57.11	20.16	43.35	75.903	76.0777	314.99	318.042	0.07711
29	1200	1170	56.57	20.7	42.81	75.673	75.788	311.066	313.028	0.07522
30	1260	1230	55.76	21.51	42	75.3196	75.4963	305.18	308.123	0.07444
31	1320	1290	54.96	22.31	41.2	74.9604	75.14	299.367	302.273	0.0737
32	1380	1350	53.83	23.44	40.07	74.4347	74.6975	291.156	295.261	0.07406
33	1440	1410	52.7	24.57	38.94	73.8866	74.1606	282.944	287.05	0.0744
34	1500	1470	51.83	25.44	38.07	73.4482	73.6674	276.623	279.784	0.07395
35	1560	1530	51.3	25.97	37.54	73.1739	73.3111	272.771	274.697	0.07259
36	1620	1590	47.58	29.69	33.82	71.0765	72.1252	245.74	259.256	0.07991
37	1680	1650	43.45	33.82	29.69	68.3273	69.7019	215.729	230.735	0.08778
38	1740	1710	39.67	37.6	25.91	65.3093	66.8183	188.262	201.996	0.09423
39	1800	1770	36.14	41.13	22.38	61.9209	63.6151	162.611	175.437	0.09964
40	1860	1830	33.44	43.83	19.68	58.8463	60.3836	142.992	152.801	0.10275
41	1920	1890	31.19	46.08	17.43	55.8776	57.3619	126.642	134.817	0.10465
42	1980	1950	29.1	48.17	15.34	52.7086	54.2931	111.455	119.049	0.10608
43	2040	2010	27.05	50.22	13.29	49.1246	50.9166	96.5588	104.007	0.10734
44	2100	2070	25.05	52.22	11.29	45.0627	47.0937	82.0258	89.2923	0.10843
45	2160	2130	23.8	53.47	10.04	42.1774	43.62	72.9427	77.4842	0.10794
46	2220	2190	22.7	54.57	8.94	39.3754	40.7764	64.9495	68.9461	0.10718
47	2280	2250	21.72	55.55	7.96	36.64	38.0077	57.8283	61.3889	0.10624
48	2340	2310	21.05	56.22	7.29	34.6233	35.6317	52.9598	55.3941	0.10476
49	2400	2370	20.31	56.96	6.55	32.2413	33.4323	47.5826	50.2712	0.10349
50	2460	2430	19.98	57.29	6.22	31.1222	31.6818	45.1846	46.3836	0.10155
51	2520	2490	19.73	57.54	5.97	30.2494	30.6858	43.368	44.2763	0.09956
52	2580	2550	18.35	58.92	4.59	25.0039	27.6267	33.3402	38.3541	0.09958
53	2640	2610	17.13	60.14	3.37	19.6627	22.3333	24.4751	28.9077	0.09933
54	2700	2670	16.43	60.84	2.67	16.2399	17.9513	19.3886	21.9318	0.09826
55	2760	2730	16.12	61.15	2.36	14.6291	15.4345	17.136	18.2623	0.09661
56	2820	2790	16	61.27	2.24	13.9888	14.309	16.264	16.7	0.09474

Appendix (B5) : Experimental data and calculations of drying for TRAY 5 (Top Most)

Sl. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	B	C	D	E	F	G	H	I	J
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
1	0	TRUE	84.27	–	69.27	82.19	–	461.482	–	–
2	15	7.5	84.2	0.07	69.2	82.1752	82.1826	461.016	461.249	0.01867
3	30	22.5	84.05	0.22	69.05	82.1434	82.1593	460.016	460.516	0.02933
4	45	37.5	83.93	0.34	68.93	82.1179	82.1306	459.217	459.617	0.03022
5	60	52.5	83.72	0.55	68.72	82.073	82.0954	457.818	458.517	0.03667
6	75	67.5	83.43	0.84	68.43	82.0107	82.0418	455.885	456.852	0.0448
7	90	82.5	83.25	1.02	68.25	81.9718	81.9912	454.686	455.286	0.04533
8	105	97.5	83.1	1.17	68.1	81.9392	81.9555	453.687	454.186	0.04457
9	120	112.5	82.86	1.41	67.86	81.8869	81.9131	452.088	452.887	0.047
10	150	135	82.62	1.65	67.62	81.8343	81.8606	450.489	451.288	0.044
11	180	165	82.34	1.93	67.34	81.7725	81.8034	448.623	449.556	0.04289
12	210	195	81.95	2.32	66.95	81.6858	81.7292	446.024	447.324	0.04419
13	240	225	81.68	2.59	66.68	81.6253	81.6555	444.225	445.125	0.04317
14	300	270	80.81	3.46	65.81	81.4274	81.5263	438.429	441.327	0.04613
15	360	330	80.15	4.12	65.15	81.2745	81.351	434.031	436.23	0.04578
16	420	390	79.41	4.86	64.41	81.1	81.1873	429.101	431.566	0.04629
17	480	450	78.85	5.42	63.85	80.9658	81.0329	425.369	427.235	0.04517
18	540	510	78.55	5.72	63.55	80.8931	80.9294	423.371	424.37	0.04237
19	600	570	77.85	6.42	62.85	80.7213	80.8072	418.707	421.039	0.0428
20	660	630	77.12	7.15	62.12	80.5388	80.63	413.843	416.275	0.04333
21	720	690	76.26	8.01	61.26	80.3193	80.4291	408.113	410.978	0.0445
22	780	750	75.26	9.01	60.26	80.0578	80.1886	401.45	404.781	0.04621
23	840	810	73.95	10.32	58.95	79.7045	79.8812	392.721	397.085	0.04914
24	900	870	72.56	11.71	57.56	79.3158	79.5102	383.46	388.091	0.05204
25	960	930	71.34	12.93	56.34	78.962	79.1389	375.331	379.395	0.05388
26	1020	990	70	14.27	55	78.5593	78.7607	366.403	370.867	0.05596
27	1080	1050	68.13	16.14	53.13	77.9708	78.2651	353.943	360.173	0.05978
28	1140	1110	65.73	18.54	50.73	77.1665	77.5686	337.952	345.948	0.06505
29	1200	1170	63.22	21.05	48.22	76.2599	76.7132	321.228	329.59	0.07017
30	1260	1230	60.47	23.8	45.47	75.1803	75.7201	302.905	312.067	0.07556

Sl. No.	Elapsed Time	Average drying time	Sample weight.	Moisture removed	Moisture present in sample	Moisture Content	Average moisture content	Moisture Content	Average moisture content	Drying Rate
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
	min	Min	G	g	g	% w.b.	% w.b.	% d.b.	% d.b.	Kg W/Kg.dm.h × 10^{-3}
31	1320	1290	57.13	27.14	42.13	73.7292	74.4548	280.651	291.778	0.08224
32	1380	1350	53.35	30.92	38.35	71.8679	72.7986	255.466	268.058	0.08962
33	1440	1410	50.41	33.86	35.41	70.2272	71.0475	235.877	245.671	0.09406
34	1500	1470	48.02	36.25	33.02	68.7453	69.4863	219.952	227.914	0.09667
35	1560	1530	45.94	38.33	30.94	67.3302	68.0378	206.093	213.023	0.09828
36	1620	1590	44.07	40.2	29.07	65.944	66.6371	193.634	199.864	0.09926
37	1680	1650	41.67	42.6	26.67	63.9825	64.9632	177.643	185.638	0.10143
38	1740	1710	39.37	44.9	24.37	61.8784	62.9304	162.318	169.981	0.10322
39	1800	1770	37.01	47.26	22.01	59.4475	60.6629	146.594	154.456	0.10502
40	1860	1830	35.49	48.78	20.49	57.7107	58.5791	136.466	141.53	0.1049
41	1920	1890	33.54	50.73	18.54	55.252	56.4813	123.474	129.97	0.10569
42	1980	1950	32.1	52.17	17.1	53.2446	54.2483	113.879	118.676	0.10539
43	2040	2010	30.69	53.58	15.69	51.0965	52.1705	104.484	109.182	0.10506
44	2100	2070	29.14	55.13	14.14	48.4952	49.7959	94.1568	99.3206	0.10501
45	2160	2130	28.19	56.08	13.19	46.7595	47.6274	87.8271	90.9919	0.10385
46	2220	2190	27.18	57.09	12.18	44.7811	45.7703	81.0975	84.4623	0.10286
47	2280	2250	26.08	58.19	11.08	42.4521	43.6166	73.7683	77.4329	0.10209
48	2340	2310	25.28	58.99	10.28	40.631	41.5416	68.438	71.1032	0.10084
49	2400	2370	24.25	60.02	9.25	38.1093	39.3702	61.5752	65.0066	0.10003
50	2460	2430	23.52	60.75	8.52	36.1884	37.1489	56.7113	59.1433	0.09878
51	2520	2490	22.83	61.44	7.83	34.2598	35.2241	52.1139	54.4126	0.09752
52	2580	2550	22.31	61.96	7.31	32.7275	33.4937	48.6492	50.3816	0.09606
53	2640	2610	21.92	62.35	6.92	31.5306	32.1291	46.0507	47.35	0.09447
54	2700	2670	21.32	62.95	6.32	29.6037	30.5672	42.053	44.0518	0.09326
55	2760	2730	20.86	63.41	5.86	28.0514	28.8275	38.988	40.5205	0.0919
56	2820	2790	20.3	63.97	5.3	26.0666	27.059	35.2568	37.1224	0.09074
57	2880	2850	19.4	64.87	4.4	22.6367	24.3516	29.2602	32.2585	0.0901
58	2940	2910	18.76	65.51	3.76	19.9974	21.317	24.9959	27.1281	0.08913
59	3000	2970	17.96	66.31	2.96	16.4338	18.2156	19.6656	22.3308	0.08841
60	3060	3030	17.88	66.39	2.88	16.0599	16.2469	19.1326	19.3991	0.08678
61	3120	3090	17.8	66.47	2.8	15.6827	15.8713	18.5996	18.8661	0.08522