DEVELOPMENT OF STEAM ASSISTED SYSTEM FOR SOLAR DRYER

A thesis submitted to the

Dr. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH

DAPOLI – 415 712, MAHARASHTRA (INDIA)

In the partial fulfilment of the requirements for the degree of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

In

RENEWABLE ENERGY SOURCES

By

MR. GADADE SHIVAJI RAJARAM

(Reg. No. ENDPM – 2018/145)

DEPARTMENT OF ELECTRICAL AND OTHER ENERGY SOURCES,

COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,

Dr. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH,

DAPOLI – 415 712, DIST. RATNAGIRI, M. S. (INDIA)

OCTOBER, 2020

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Mr. Gadade Shivaji Rajaram
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Approved by the advisory committee

Dr. A. G. Mohod
(Chairman and Research Guide, SAC)

Dr. Y. P. Khandetod
(Member, SAC)

Dr. K. G. Dhande
(Member, SAC)

Er. R. M. Dharskar
(Member, SAC)

DEPARTMENT OF ELECTRICAL AND OTHER ENERGY SOURCES,
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415 712 DIST. –   RATNAGIRI M.S. (INDIA)

OCTOBER, 2020

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled "Development of Steam Assisted System for Solar Dryer" or no part thereof has been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

Place: CAET, Dapoli

Date: **23 / 10 /** 2020

(Er. Shivaji Rajaram Gadade)

(Reg. No. ENDPM -2018/145)

Dr. A. G. Mohod

B.Tech. (Agril. Engg.), M. Tech. (Energy Management), Ph.D. (REE)
Head,
Department of Agricultural Engineering,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the research project report entitled **"Development of steam assisted system for solar dryer"** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **RENEWABLE ENERGY SOURCES** embodies the result of **bonafied** research work carried out by **Mr. Shivaji Rajaram Gadade (Reg. No. ENDPM-2018/145)** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

(A. G. Mohod)

Place: CAET, Dapoli
Date: 23/10 / 2020

Chairman,
Advisory Committee & Research Guide

Dr. K. G. Dhande

M.Tech. (FMP), Ph.D. (FMP)
Professor and Head,
Department of Electrical and Other Energy Sources,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

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Place: CAET, Dapoli
Date:23 /10/ 2020

Dr. K. G. Dhande
Professor and Head
Deptt. of Electrical and Other Energy Sources

Dr. Y. P. Khandetod

B.Tech. (Agril. Engg.), M. Tech. (P.H.E.), Ph.D. (AGFE)
Dean,
Faculty of Agricultural Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the research project report entitled **"Development of steam assisted system for solar dryer"** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfilment of the requirements for the award of the degree of **Master of Technology in Agricultural Engineering**, embodies the record of a piece of bonafied research work carried out by **Mr. Shivaji Rajaram Gadade (Reg. No. ENDPM-2018/145)** under the guidance and supervision of **Dr. A. G. Mohod**, Head of Department, Department of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

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Place: CAET, Dapoli
Date:23/10/ 2020

(Y. P. Khandetod)
Dean
Faculty of Agricultural Engineering

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SRG,

Place: CAET, Dapoli **Mr. Shivaji Rajaram Gadade**

Date: 23 / 10 /2020 **(Reg. No. ENDPM-2018/145)**

TABLE OF CONTENT

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATION

AC	Alternate Current
Agri.	Agriculture
Agril.	Agricultural
Al	Aluminium
Anon.	Anonymous
AOAC	Association of Official Analytical Chemists
Avg.	Average
Dr.B.S.K.K.V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
B-C Ratio	Benefit-Cost Ratio
bdm	Bone dry matter
^{o}C	Degree Centigrade
CAET	College of Agricultural Engineering and Technology
cm	Centimetre
d.b.	Dry basis
Eff.	Efficiency
EMC	Equilibrium moisture content
Engg.	Engineering
EOES	Electrical and Other Energy Sources
e.g.	Example
et al.	Et al (and others)
etc.	Etcetera
D.R.	Drying Rate
Fig.	Figure
g	Gram
GI	Galvanized iron
GI	Geographical Indication
h	Hour
ha	Hectare
IMC	Initial moisture content
IS	Indian standard

kcal	Kilo calories
kg	Kilo gram
kJ	Kilo joules
kmph	Kilo meter per hour
Kcal kg^{-1}	Kilocalorie per kilogram
m	Meter
m^2	Square meter
m^3/ hr	Cubic meter per hour
MC	Moisture content
min.	Minute
MR	Moisture ratio
MT	Metric Tonne
MS	Mild steel
No.	Number
NPV	Net present value
NPW	Net present worth
PBP	Payback period
Rs	Rupees
Rh	Relative humidity
Sr. N.	Serial number
STD	Solar tunnel dryer
SWG	Standard wire gauge
Temp	Temperature
UV	Ultra violet
Vs	Versus
viz.	Namely
W	Watt
w.b.	Wet basis
µm	micro meter

LIST OF SYMBOLS

Description	Symbols
Full stop	.
Comma	,
Addition	+
Subtraction	-
Multiplication	×
Per cent	%
And	&
Degree Celsius	°C
Degree	°
Lambda	λ
Nita	η
Diameter	ϕ
Phase	Ø
Temperature difference	ΔT

ABSTRACT

"DEVELOPMENT OF STEAM ASSISTED SYSTEM FOR SOLAR DRYER"

by

Mr. Gadade Shivaji Rajaram

College of Agricultural Engineering and Technology

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Dist. Ratnagiri, Maharashtra State (India)

2020

Research Guide	:	**Dr. A. G. Mohod**
Department	:	**Agricultural Engineering & Technology**

Solar dryer's uses solar energy to dry the material by raising the temperature of air surrounding it, solar drying does not required any conventional (fossil fuels) source of energy. After the sunshine period is over the drying cannot be completed which leads to increase in overnight moisture leads to increase in drying time. To overcome these processing losses during the drying and to retain the superior quality of the dried product, it was necessary to have a backup heating option which can provide the hot air inside the dryer during an evening period so that product can be completely dried upto its desired moisture content without increase in its drying time and processing cost required for it. The steam assisted hot air generation system consists of boiler, heat exchanger, fan and solar tunnel dryer. The indirect type of steam boiler was used for steam formation. The radiator was removed from the old AC ducts available at Energy Park. The axial fan with 6 blades and 1350 rpm was selected. The semi cylindrical shaped solar tunnel dryer consist of a drying chamber of 10 m x 3.75 m was selected for drying of mango pulp. The experiments were conducted without and with steam assisted hot air generation system of solar tunnel in the view to find out the temperature inside the solar tunnel dryer at different locations inside the dryer. The maximum temperature inside the solar tunnel dryer without steam assisted system was 64.28 ^{o}C achieved at 1:00 pm with ambient temperature

of 36.2 ^{o}C, relative humidity inside the dryer was 20.33 % and ambient relative humidity was 27.83 % at the solar intensity of 617.67 W/m^{2}. The minimum temperature required to dry the product is 50 ^{o}C, so as to maintain the 50 ^{o}C temperature inside the solar tunnel dryer, the steam assisted hot air generation system was in spectrum during 3:00 pm to 7:00 pm. The average temperature was raised by 5.22 ^{o}C with steam assisted hot air generation system compared to without steam assisted hot air generation system in solar tunnel dryer. The total energy consumption by steam assisted hot air generation system was 8 kWh for 4 hours. The effectiveness and capacity ratio of heat exchanger was found to be 0.265 and 1.342, respectively. The corrected LMTD, COP and Heat utilization factor of heat exchanger was calculated to be 58.84 ^{o}C, 0.643 and 0.356, respectively.

The mango pulp available in the market was used for drying. The drying of these samples was continued till the moisture content reached to 25% on wet basis. The time required for drying mango pulp without steam assisted hot air generation system was 19 h as compared to 14 h with steam assisted hot air generation system in the solar tunnel dryer. The avg. moisture ratio for drying mango pulp without steam assisted hot air generation system was 0.450 compared to 0.453 with steam assisted hot air generation system in the solar tunnel dryer. The avg. drying rate for drying mango pulp without steam assisted hot air generation system was 0.079 gm/100 gm bdm-min compared to 0.111 gm/100 gm bdm-min with steam assisted hot air generation system in the solar tunnel dryer. The avg. drying efficiency for drying mango pulp without steam assisted hot air generation system was 16.8 % compared to 22.30 % with steam assisted hot air generation system in the solar tunnel dryer. The Net Present Worth of steam assisted hot air generation system for mango pulp drying was Rs 3,11,767.9. The Benefit- Cost ratio of steam assisted hot air generation system for mango pulp drying was 1.08. The Payback period of steam assisted hot air generation system for mango pulp drying was 1 year 4 months and 13 days.

Keywords- Baby boiler, solar tunnel dryer, heat exchanger, hot air generation, mango pulp, moisture ratio, drying rate, BC ratio, payback period.

I. INTRODUCTION

Drying is one of the methods used to preserve food products for longer periods. The heat from the sun coupled with the wind has been used to dry food for preservation for several thousand years. Drying is a thermo-physical & physiochemical operation by which the excess moisture from a product is removed. Drying makes food grains & other products suitable for safe storage & protects them against an attack of insects, moulds & other micro-organisms during storage. During drying, the moisture from solids gets vaporize & diffused in the dilute environment. Drying removes the volatile materials present inside solid matters. High prices & shortage of fossils fuels have increased the emphasis on using alternative renewable energy resources. Drying of agricultural products using renewable energy such as solar energy is environmentally friendly & has a less environmental impact. Drying depends upon the quality of air (temperature, humidity and quantity of air used), materials properties which are used for drying (size of the pieces being dried and physical structure and composition) and airflow patterns within the drying system.

Solar dryers uses solar energy to dry the material by raising the temperature of the air surrounding it. In India, the average solar radiation available is 5 kW/m^2/day for 250-300 days in the year with approximately 6-7 full sunshine hours (Sengar, 2012). Solar dryers can be used in small-scale food processing industries to produce hygienic, good quality food products. The solar dryer has ample potential for drying products which require hot air less than 60^oC. The solar-dried products have much better quality as compared to open sun-dried products. Solar drying of any product is the most feasible drying method because of the quality of the product after drying and time of operation required.

A solar tunnel dryer (STD) is a poly house framed structure covered with a UV-stabilized polythene sheet, where agricultural and industrial products on large scale could be dried under at least partially controlled environment and which is large enough to permit a person to enter into it and carry out operations such as to load and unload the material to be dried. The semi-cylindrical shaped solar tunnel dryer consists of a drying chamber of 10 m x 3.75 m for drying of 100 kg of material per batch. The solar tunnel dryer is used to dry different materials like fish, prawns, mango pulp, anola and grapes etc. One significant disadvantage of this dryer is that it works in the sunlight only. For commercial producers, this factor limits its ability to dry produce when there is not adequate solar radiation. The solar drying process is interrupted during cloudy or rainy days and also at night (Mohod, 2014).

Mangoes are a popular, nutritional tropical fruit, which is now one of the most important fruits crops in tropical and subtropical areas of the world. They are originated in India & cultivated for more than 4000 years. Beginning in the 16^{th} Century, mangoes are gradually distributed from India to other tropical countries in Asia such as the Philippines, Indonesia, China, and Thailand. Mango is known as the king of fruit and it is the national fruit of India. It is the seasonal fruit and available in abundance. Taxonomically, mangoes belong to the genus Mangifera. It is one of the 73 genera, which include around 850 species, of the family Anacardiaceae in the order Sapindales (Burondkar, 2018).

There are over 1500 varieties of mangos are available in India from which only 20 are being commercialized. The worldwide mango production is 50.65 million MT in the year of 2017-18 (www.statista.com). The production of mangoes in India is 21822.3 thousand MT while the area under cultivation is 2258.1 thousand ha having the productivity of 9.7 MT/ha in the year 2017-18. India ranks first in the mango production in the world. India contributes to almost 48.06 % of overall mango production. Also according to APEDA, the export of Mango pulp and other products is 49,180.46 MT in the year 2017-18 for counting 65,767.02 lac rupees (APEDA, 2019). The mango production in Maharashtra is 791.36 thousand MT with an area under cultivation of 166.76 thousand ha. The major mango growing regions in Maharashtra are Ratnagiri, Sindhudurgh and Raigarh known as Konkan belt give the production of 297.35 thousand MT and area under cultivation is 96.33 thousand ha (Horticulture Statistics at a glance, 2018).

In Maharashtra, the main varieties of mangoes grown are Alphanso, Mankhurd, Mulgao, Pairi, Rajapuri, Kesar, Gulabi and Vanraj. Mostly the Alphanso variety of mango is very popular and grown in the Konkan belt. This is the leading commercial variety of Maharashtra state and one of the choicest varieties of the country. This variety is known by different names in different regions, viz. Badami, Gundu, Khader, Appas, Happus and Kagdi Happus. The fruit of this variety is medium in size, ovate oblique in shape and orange-yellow in colour. The fruit quality is excellent and keeping quality is good. It has been found good for canning purpose. The Ratnagiri alphanso has received the Geographical Indicator (G.I.) tag in the year 2017. The weight of Ratnagiri alphanso is 160-200 gm per fruit. Length of fruit is 11 cm and fruit perimeter is 20.8 cm. The weight of pulp obtained from it is 134.1 gm and contains 70 % of fruit pulp in a single fruit. The nutritional value of the pulp from alphanso is the TSS (^{o}Brix) of 17.2, acidity is

0.92 %, total sugars is 13.23 % and the ascorbic acid is 70.2 mg/100 gm is present in the Ratnagiri alphanso (G. I. Journal No. 98, 2017).

The ripen mango is very perishable in nature which can get spoiled in 4-5 days. There are various products like chutney, pickle, amchoor, pectins, jam, murabba, toffees, aam papad and mango powder etc. which can be prepared from raw and ripen mango. Mostly the ripen mango is used for making juice, pulp and nectar, squash, leather, slices, etc. As the life of ripe mango fruit is very short so it is better to make their products immediately which have very high demand in the local as well as in the global market.

Fruit leather is a confectionery product prepared by dehydration of fruit pulp into leathery sheets. The mango leather is very popular for their taste, chewy nature and also it has nutritive value. The mango leather is prepared from the mango pulp mixing with concentrated sugar solution. The mango leather is also known as Aamta in Assamese, amawat in Hindi, Mamiditandra in Telugu, and aamsotto in Bengali and amba poli / aamba vadi in Marathi. The mango puree is poured into the thick layer of 3 to 6 mm on the wooden and plastic trays for drying (Mohod, 2018). After drying these puree is cut into the square pieces or in round shape. Generally, the mango leather is dried up to the moisture of 20-25 % w.b. at the temperature of ^{o}C (Gujral, 2003). After drying, the leather pieces should be dusted lightly with starch to preserve them from sticking together.

The mango leather is dried by the open sun drying method or using an electrical oven. The open sun drying reduces quality and requires more drying time. The operating cost becomes very high for drying of mango leather by using an electric oven. In the sun drying method, the losses of the product are high due to bird waste, dust, sand, animals and flies which reduces the quality of the product also, the large time is required. To reduce these processing losses & to maintain the quality of the mango leather, it is dried in a solar dryer under the partially controlled conditions. The drying can be done only in sunshine hours and if the material is partially dried then moisture can be absorbed during night period by the product which can reduce its quality and the chances of fungal attack and microorganisms are very high which can spoil the product quality. Also, more time is required to remove the moisture gain by the product during the night period. Thus the more operating cost is required for it. If the material remains in the partially dried stage then the quality and texture get decreased due to uneven drying. So that the market value of product reduces.

There are various auxiliary heating options available which can increase the drying period for drying during an evening period and in cloudy conditions. They are as by using the phase change material, placing gravel bed in the dryer, using electricity as backup heating option to provide hot air inside the drying chamber, using the biomass-based solar dryer, by using waste heat obtained from the diesel engine. These methods are practised on the domestic scale to dry the small quantity of material in a single batch during an evening period and in the rainy season. These methods are not suited for drying of the large quantity of material in a single batch of drying.

To overcome these processing losses during drying and to retain the superior quality of the dried product, it is necessary to have a backup heating option which can provide the hot air inside the dryer during an evening period such that product can be completely dried up to its desired moisture content without an increase in its drying time and processing cost required for it. This will help to maintain the quality and texture of the product. Also, the losses occurred due to incomplete drying can be reduced with the help of such a system. This can become the boost on a commercial scale for mango leather production which can completely remove the moisture from the product and will help to preserve the quality of the product. Hence the following objectives are considered for the project.

1. To develop the steam-assisted hot air generation system suitable for solar drying.
2. To evaluate the performance of the developed system.

II. REVIEW OF LITERATURE

The brief review of the research literature regarding development, evaluation, and performance of steam assisted hot air generation and solar dryer carried out by different researchers has divided under the following subheadings**.**

1. Solar drying & solar tunnel dryer,
2. Auxiliary heating options for solar drying,
3. Steam assisted hot air generation,
4. Drying of mango pulp**.**

2.1 Solar drying & Solar tunnel dryer

Berinyuy (2004) developed the solar tunnel dryer with capacity of 17 kg for fresh leafy vegetables per drying batch. The average maximum temperature within the drying tunnel was 61.9 ^{o}C and the minimum air flow was estimated as 9.65 m^3/h. The dryer enabled reduction in exposure time in the open-air of approximately 50% in addition to a net amelioration of the quality of the dried products. The payback period using green pepper was found to be 18 months for a natural convection solar dryer.

Janjai *et. al*, (2006) developed the solar tunnel dryer with a polycarbonate cover. The dryer consists of two parts, namely a solar collector and a drying tunnel. Both parts are connected in series on the same structure. A polycarbonate cover was used to reduce heat losses while allowing the incident solar radiation to transmit into the dryer. A dc-fan driven by a 15-watt solar cell module was employed to ventilate the dryer. The temperature of the drying air in the dryer was varied between 35 to 60 °C and the air flow rate in the dryer was about 100-500 m^3/h from 9 A.M. to 5 P.M. This dryer could be used to dry 30 to 70 kg of jackfruits from an initial moisture content of 80% (w.b.) to a final moisture content of 30% (w.b.) within 3 days, compared to 4 to 5 days with natural sun drying in the same weather condition. High-quality products in terms of flavour, colour and texture were obtained. The payback period of this dryer was found to be approximately 3 years.

Bhor *et. al,* (2010) developed and evaluated the performance of the solar tunnel dryer for Dhoma fish drying. It was noted that the drying rate was higher in solar tunnel dryer compared to open sun drying due to higher temperature (53.5^{o}C) attained inside the solar tunnel dryer. The fish sample with salt treatment moisture content reduced up to 19.29 % (d.b.) in 35 hours for an upper tray, 19.63 % (d.b.) in 37 hours for a lower tray and 19.41 % (d.b.) in 39 hours for open sun drying. The fish sample without salt treatment moisture content reduced up to 19.05 % (d.b.) in 32 hours for the upper tray, 19.90 % (d.b.) in 35 hours for lower tray and 23.73. % (d.b.) in 37 hours for open sun drying respectively. The drying rate attained in the tunnel dryer was 55.65 g/h as compared to open sun drying was 29.41 g/h.

Mohod *et.al,* (2009) developed the low-cost solar dryer (LCSD) for drying of Prawns, the size of dryer was 92 cm x 75 cm for 10 kg capacity. The time required for reducing the moisture content from 75% to 16% were observed in open sun drying and solar drying. Salted fish inside the dryer required 8 h to dry prawns up to 16.15% while unsalted fish required 15 h to reach moisture content up to 15.15% in open condition. Overall collection efficiency was found as 70.97%. They concluded that average drying efficiency for salted fish was 14% and unsalted fish was 11% whereas pickup efficiency for salted and unsalted fish was found as 10 % and 9% respectively.

Basunia *et.al,* (2010) designed and developed 12 m x 2 m size solar tunnel dryer for batch drying for 180-200 kg of freshly harvested dates. Half of the partially air-tight tunnel base was used as the flat plate air heating solar collector and the remaining half as a dryer. The drying temperature could easily be raised from 5-30 ºC above ambient temperatures inside the tunnel at an air velocity of approximately 0.5 m/sec. The 190.2 kg of freshly harvested dates was dried up to a final moisture content of 18.6% (w.b.) within two days (20 hours) while in the open sun drying the time required was 5-7 days. They concluded that the drying was faster in solar tunnel dryer compare to natural open sun drying. The improvement in the quality of dates in terms of colour, brightness, flavour, and taste and food value was distinctly recognizable.

Manjarekar *et. al,* (2010) developed & evaluated the performance of the solar tunnel dryer for fish drying. The comparative performance revealed that fish attained safe moisture limit in 18-28 hours in solar tunnel dryer as compared to 34 hours in open sun drying, the moisture content reduced from 344.86% (d.b.) to about 19% (d.b.). They concluded that the average drying efficiency of fish dried by solar tunnel dryer was found about 18% higher than the open sun-dried fish. The solar tunnel dried fish was found of better organoleptic and keeping quality up to 3 months.

Mohod *et. al,* (2011) developed & evaluated the performance of solar tunnel dryer of 100 kg capacity for fish drying. The drying of unsalted Peeled Prawns (Parapaeneopsis stylifera) required 15 hours inside the dryer placed on the upper tray as compared to 27 hours in open sun drying method. The salted fish required 13 and 25 hours to reduce up to 16.18 % (w.b.) inside the dryer and in open sun respectively. The average 28 % saving in time was observed using solar tunnel dryer over open sun drying method with average drying efficiency of 19 %. The payback period for solar tunnel dryer was found to be 2.84 years.

Mahajan *et. al,* (2011) designed and developed a semi-cylindrical shaped solar tunnel dryer of 1.5 MT capacity with base area of 3.75 m × 21 m and maximum ceiling height of 2 m for drying of lemon and evaluated that in the first day of drying the minimum inside temperature was 38.1 ^{o}C at 8:00 am in the month of April while maximum temperature attended inside the tunnel dryer was 72.9^{o}C at 02:30 pm. Corresponding, minimum ambient temperature was 26.9 ^{o}C at 8:00 am while the maximum ambient temperature was 42.5^{o}C at 02:30 pm. The solar radiations were increased from 300 W/m^2 at 8:00 am to 880 W/m^2 at 00:30 pm. The initial moisture content of lemon fruits was 80.7% (w.b.) which was reduced to 5.88% (w.b.) in 6 days, whereas OSD required 10 days.

Rathore *et. al,* (2012) developed a semi-cylindrical forced convection type solar tunnel dryer (STD) and commissioned at M/s Miraj Products Pvt. Ltd., Nathdwara for drying of 500 kg of processed tobacco from 138% (d.b.) to 8.7% (d.b.) moisture content. The area of the dryer was 16×3.75 m^2, equipped with 12 solar flat plate collectors of 2 m^2 each propelled with 2 exhaust fans of 1 kW capacity placed on both ends of the tunnel. During no-load, without flat plate collectors, temperatures inside the dryer were about 18-20 ℃ higher than the ambient temperature during summer day-light, whereas in no-load with flat plate collectors, it was about 30 ℃ higher than the ambient temperature. The time required for drying was 8 h as compared to 12 h of drying in open sun drying.

Sengar *et. al,* (2012) developed and evaluated the performance of rotary solar dryer for Kokam drying. The dryer of size 92cm x 75 cm was made by locally available bamboo, which consists of three main parts, collector, drying chamber and inlet and outlet openings for 10 kg capacity. The time required to reduce the moisture content up to 10% as safe storage for the solar dryer was observed to ripen and unripe kokam fruits. The maximum temperature inside the solar dryer was 57 °C whereas the maximum ambient temperature observed was 35.3 °C and solar irradiation was 600 W/m^2. Humidity varied from 32.2% to 22.3% inside the solar dryer whereas outside humidity varied from 43.02% to 29.35%. They concluded that maximum drying efficiency for salted ripen kokam was 9.88 % and unsalted salted ripen kokum was 7.66 %. For salted and unsalted unripe kokum, maximum efficiency was found as 4.72 % and 4.20 % respectively.

Hossain & Bala (2013) designed & developed a mixed-mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh. The dryer consist of (1. air inlet; 2. fan; 3. solar module; 4. solar collector; 5. side metal frame; 6. outlet of the collector; 7. wooden support; 8. plastic net; 9. roof structure for supporting the plastic cover; 10.base structure for supporting the dryer; 11.rolling bar; 12.outlet of the drying tunnel.) Moisture content of red chilli was reduced from 2.85 to 0.05 kg/kg (d.b.) in 20 h in a solar tunnel drier and 32 h time was required to reduce the moisture content to 0.09 and 0.40 kg/kg (d.b.) in improved and traditional sun drying methods, respectively.

Sawant *et. al,* (2013) evaluated the performance of natural convection solar dryer for sapota drying at 1 kg/m^2 area. Sapota was sliced in 5mm pieces and dipped in 1% potassium meta-bisulphate for 10 minutes to retain its colour. The solar radiations measured was ranged between 400 W/m^2 to 1200 W/m^2. They concluded that the moisture content of 78 % (w.b.) was reduced to 7.9% (w.b.) in 23 h for solar dryer and 35 h for open sun drying. The total sugar of fresh fruit was increased from 18% to 32.10% solar dried fruit and 30.17% in open sun-dried fruit, whereas the protein content of fresh sapota was reduced from 10.25% in fresh fruits to 8.68% and 6.55% in solar dried and the open sun-dried fruit respectively.

Mohod *et.al*, (2014) developed the semi cylindrical walk-in type natural convection solar tunnel dryer, with drying area of 37.5 m^2 and evaluated for the drying of fish products in comparison with the conventional method of open sun drying. The experiments were conducted without fish and with fish to evaluate the performance of solar tunnel dryer. The average rise in temperature inside the solar tunnel dryer was found to be 11.24 ^{o}C and 18.29 ^{o}C over the ambient temperature during no load test in winter and summer respectively. The average 28% saving in time was observed for selected fish drying using solar tunnel dryer over open sun drying method with average drying efficiency of 19%. The economics was calculated for drying of prawns (Parapaeneopsis stylifera) by solar tunnel dryer and open sun drying system on the basis of business as a whole. The economics of the solar tunnel dryer was presented in term of Net present worth, Benefit–Cost Ratio, Payback period, Profitability index and internal rate of return. The payback period for solar tunnel dryer was found to be 2.84 years.

Mane *et. al*, (2015) designed & developed a greenhouse type solar tunnel dryer for industrial drying of selected species of fish Croaker, Anchovy and Ribbon in the western coastal town Veraval, Gujarat, India and was installed at Jose and Brothers Fish Industry. The solar tunnel dryer was designed for drying 250 kg/h fish in batch mode to reduce the moisture content to 16% (w.b.) from initial moisture of 84% (w.b.). The single-span arc type G.I pipe frames were used to construct the dryer with a collector area of 150.9 m^2 and covered with a single layer 200 µ thick UVS poly-ethane sheet. The performance of the dryer was evaluated using the drying parameters like pre-treatment with salt and without salt in the temperature range of T_1 (40-45 ^oC) and T_2 (45-49 ^oC). The test results showed that developed dryer can reduce moisture content of salt-treated fish up to 42.85% to 66.66 % (d.b.) between 8 to 16 h, whereas in case of unsalted fish moisture content was reduced up to 17.64 % - 25 % (d.b.) in 24 to 32 hours of drying depending on a variety of fish and initial moisture content.

Vardhini *et. al*, (2016) designed, developed and evaluated the field performance of greenhouse solar tunnel dryer for drying 5 kg per batch of green chillies. A tunnel-like framed structural covered with UV-stabilized polycarbonate sheet, hemispherical type at Thanjavur, Tamil Nadu with an exposed area of 4.71 m^2 for drying green chillies, with an initial moisture content of 85% (w.b.) and to the desired moisture content of 8-10% (w.b.) within two days. The mean ambient conditions for wind speed, relative humidity and maximum solar insolation were 0.77 m/s, 31% and 1026 W/m^2 respectively. The dryer developed can be used in semi-urban and rural areas for drying various agriculture crops for small scale industries which reduce cost.

Lingayat *et. al*, (2017) developed the indirect type dryer with size of the drying cabinet was 1 m × 0.4 m × 1 m (width, depth, and height) & total area of the collectors was 2 m^2 for drying of the ripe banana slices and found that moisture content of banana was reduced from 356% (d.b.) to final moisture content of 16.3292%, 19.4736% 21.1592%, 31.1582%, 42.3748% for Tray-1, Tray-2, Tray-3, Tray-4 and open sun drying respectively on dry basis. The average thermal efficiency of the collector was found to be 31.50% and that of drying chamber was found to be 22.8%. They stated that the temperature of drying air was the most important and effective factor during drying.

2.2 Auxiliary heating options for solar drying

Gewali *et. al*, (2005) developed & evaluated a hybrid solar biomass cabinet dryer with two pieces of solar collectors (800 x 2015mm), a drying chamber (1600 x 600 x 600mm), a heat exchanger (1600 x 350 x 50mm), a chimney (500 x 75 x 400mm) and a flue gas outlet (350 x 500 x 1700mm). The dryer was designed for drying 10 kg of fresh cauliflower per batch. The effective drying time for the drying of the product was 10 h during two days of drying and drying efficiency of the dryer was found to be 16.32%.

Madholpa and Ngwalo (2007) designed a solar dryer with thermal storage and biomass backup heater for pineapple drying. The dryer was tested for three different operation modes like solar, biomass and solar-biomass for drying of twelve batches of pineapple. The average values of the final-day moisture pickup efficiency were 15%, 11% and 13% in the solar, biomass and solar–biomass modes of operation respectively. The rate of drying of pineapple in biomass mode of operation of dryer operation was higher than that of solar mode but moisture picks up efficiency was most satisfactory in solar mode.

Bolaji *et. al,* (2008) designed, developed and evaluated the performance of a mixed-mode solar dryer for yam chips drying. The temperature rise inside the drying cabinet was up to 74% (24^{o}C) more than ambient temperature. The dryer was able to remove 85.4% (d.b.) of moisture, from 6.2 kg of yam chips in one day of 10.00 h drying time. The drying rate, collector efficiency and percentage of moisture removed (d.b.) for drying yam chips were 0.62 kg/h, 57.5 and 85.4%, respectively.

Ehiem *et. al*, (2009) designed the industrial fruit and vegetable dryer and evaluated it for drying of tomato. It consisted of three units i.e. drying chamber, blower and heat exchanger. The tomatoes were dried at 50 °C in 14 hours. The dryer was designed and constructed for 258.64 kg of tomato's giving a mean thermal efficiency of 82% and an average drying rate of 40 g/h at a relative humidity of 35%.

Amer *et. al*, (2010) designed and fabricated the hybrid solar dryer using solar energy and a heat exchanger. Drying was operated during night period with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at the water tank. The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer. The air temperature rise was between 30 to 40°C above the ambient temperature. The capacity of the dryer was about 30 kg to dry banana slices in 8 hours in a sunny day from an initial moisture content of 82% to the final moisture content of 18% (w.b.). In the same time, it reduced to only 62% (w.b.) moisture content by open sun drying method.

Kamble *et. al*, (2013) developed the solar cabinet dryer with gravel bed for a heat storage system for drying of green chilli. Drying time for drying green chilli from initial moisture content of 88.5% (w.b.) to 7.3% (w.b.) was found to be 56 h in solar dryer whereas 104 h in the open sun drying. Drying time due to gravel bed heat storage system was extended by 4h after sunset. Drying efficiency of the solar cabinet dryer was found to be 34 %. The ascorbic acid content in chilli, dried in a solar dryer with gravel bed heat storage system and open sun drying was found to be 55.3 mg/100g (d.b.) and 50.22 mg/100g (d.b.), respectively.

Şevik *et. al,* (2012) worked on mushroom drying with a solar-assisted heat pump system. Drying air temperature, relative humidity, the weight of product values, etc. were monitored and controlled with different scenarios by using PLC. Mushrooms were dried at 45 °C and 55 °C drying air temperature and 310 kg/h mass flow rate. Mushrooms were dried from initial moisture content 13.24 g water/g dry matter (d.b.) to final moisture content 0.07 g water/g dry matter (d.b.). Mushrooms were dried by using the heat pump system, solar energy system and solar-assisted heat pump system respectively at 250–220 min, 270–165 min and 230–190 min. The coefficients of performance of the system were calculated in a range from 2.1 to 3.1 for the results of experiments. The energy utilization ratios were found to vary between 0.42 and 0.66. Specific moisture extraction rate values were found to vary between 0.26 and 0.92 kg/kWh.

Joshi *et.al,* (2014) designed & fabricated the solar dryer with alternate energy backup of electricity for fish drying. They conducted an experiment using food-grade stainless steel (SS 304) trays, drying chamber and solar heat collecting panels under controlled climatic conditions. The average dry bulb temperature and average atmospheric relative humidity (RH) were found to be 36^{o}C and 47% respectively. The average solar radiation was found to be 704 W/m^2 and panel outlet temperature was 66.2^{o}C. The time required for reducing the moisture content of prawn up to 8.7% was 8 h in the solar dryer. The collection efficiency of solar heat collecting panels was 82% and the distribution of hot air temperature inside the drying chamber was found to be uniform throughout the experiment. The average tray temperature inside the drying chamber at full load was 49^{o}C. Average drying rate at the end of drying was 0.82 kg/ h.

Salve *et. al,* (2015) developed the forced circulation drying method for potato chips drying using PCM filled trays in the drying chamber to improve the drying effect. The two PCM materials viz. Paraffin wax (melting point 68-70 ^{o}C) and Paraffin wax (melting point 48-50 ^{o}C) were used as the source of latent heat during the evening period. The Energy Utilization effect of PCM was tested in off sunshine hours. Potato chips of approximately 1 kg dried with mass flow rates of hot air 0.00161 kg/s, 0.00288 kg/s, 0.00389 kg/s. The average thermal efficiency of drying chamber estimated to 52%.

Hussein *et. al.* (2017) designed, developed and tested hybrid photovoltaic solar dryer in Modibbo Adama University of Technology Yola, Nigeria. The dryer was consists of a solar collector, photovoltaic solar panel, battery and drying chamber. The dryer was operated as both a solar-energy dryer and as a hybrid solar dryer. The dryer was powered by 2 modules of 180 Wp

PV modules. The battery used was rated 12 V & 200 Ah. The drying performance of the dryer was evaluated with a fresh tomato slice and compared with open sun drying under the same climatic conditions. The raised temperature in the dryer was 62 ℃ in the drying chamber of hybrid dryer and 54^{o}C in the drying chamber of the solar dryer. The moisture content of tomato slices was reduced from 94.22 % (w.b.) to 10 % (w.b.) in 6 hours for hybrid drying & 9 hours in the solar dryer. The average drying rate and the efficiency were found to be 0.08 kg/h and 71% for hybrid dryer and 0.0578 kg/h and 65% for solar-energy dryer respectively.

Kalbande *et.al*, (2017) developed the solar dryer assisted with reflector for drying of Safed Musli (Chlorophypum boribilianum) in batch. They found that at no load test without reflector the maximum temperature of 51.24°C was achieved in the afternoon and average temperature in the solar dryer was found to be 41.02°C at corresponding ambient temperature of 21.7°C, solar radiation 430.86 W/m^2, relative humidity 23.26%, in the morning of December 2014. The maximum temperature recorded in December 2014 was 58.46 °C at 13.30 h. The average temperature of domestic dryer was found to be 44.22°C at ambient temperature of 31.3°C, relative humidity 31.7%, solar radiation 553.80 W/m^2 during the month of March 2015.The average moisture content of Safed Musli samples placed in T_1, T_2 and T_3 trays reduced from 651.5 to 4.5, 654.7 to 7.7 and 656 to 14.5 % (d.b.) in 8 h, respectively in domestic solar dyer integrated with reflector. The average moisture content of Safed Musli sample reduced from 613% to 7.8% (d.b.) in 12 h. Average drying rate was found to be 0.5526, 0.54103 and 0.53455 gm/100gm bdm min, respectively. The average drying efficiency of Safed Musli samples dried in domestic solar dryer with reflector was found to be 22.92 % respectively.

Pavane *et. al*, (2018) designed and developed the pyramid shape solar biomass dryer, assisted with biomass for drying of nutmeg in a batch. They revealed that at no load test the average temperature in the solar biomass hybrid dryer was found to be 55.84 °C at the corresponding ambient temperature of 27.16 °C, solar radiation 239.21 W/m^2, relative humidity 87.58 %, in the winter season of December 2017. The average moisture content of nutmeg sample reduced from 613% (d.b.) to 7.8% (d.b.) in 19 h. Average drying rate was found to be 0.2564 to 0.0005 gm/100gm bdm min, respectively. They concluded that the maximum efficiency of biomass combustor and pyramid shape solar-biomass hybrid dryer was found to be 74.84 % and 29.10 %.

Rajagopal *et. al*, (2014) developed an indirect type forced convection solar dryer with evacuated tube collector, drying chamber and blower. Solar drying of copra was carried for forced convection and was compared with natural convection solar drying. The temperature of the drying chamber ranges from 49 ºC to 78 ºC for natural and forced convection while the ambient temperature ranges from 28 ºC to 32 ºC. The initial moisture content of copra ranges from 51.7% to 52.3% (w.b.) and the final moisture content obtained about 7 to 8% (w.b.). They concluded that the forced convection solar dryer requires less time than the natural convection solar dryer to attain the equilibrium moisture content of the product.

2.3 Steam assisted hot air generation

Shawik *et. al*, (2001) designed and developed a recirculatory tray dryer of 5 kg/batch using central air distribution system. The dryer was tested for blanched potato chips at a constant airflow rate of 1.5 m^3/min and 65 ^oC temperature. For removing moisture from 85.69 per cent (d.b.) to 9.89 per cent (d.b.), the observed drying time was 3 hours. They found that the heat utilization factor and thermal heat efficiency were be 18.94 per cent and 22.16 per cent respectively.

Bains *et. al*, (2003) studied behaviour of apple puree drying in a forced-air circulation cabinet drier with a cross-flow arrangement using a 3 × 2 factorial design of experiments involving air temperature (70 °C and 94 °C), flow rate (2·0 and 4·1 m/s) and relative humidity (5 and 15%) as main factors. The results showed that all three factors influenced the rate of drying with the higher temperature-higher air velocity- lower relative humidity condition yielding the fastest drying rate, but also adversely affecting the product quality.

Sarsavadia (2007) developed a solar-assisted forced convection dryer to study the effect of airflow rate (2.43, 5.25, 8.09 kg/min), air temperature (55, 65, 75 ^oC), and fraction of air recycled (up to 90 %) on the total energy requirement of drying of onion slices. The energy required per unit mass of water removed with and without using recirculation of air was found between 12.04-38.78 and 23.55-62.12 MJ/kg water respectively for drying onion slices from 86 % to 7 % (w.b.). The maximum saving in total energy up to 70.7 % was achieved by recycling of the exhaust air.

Khalifa *et. al*, (2012) evaluated the performance of a solar drying system and a system equipped with an auxiliary heater as a supplement to the solar energy. They compared the performances of both to that of natural drying. Beans and peas were dehydrated in a system that consists of two flat plate collectors, a blower, and a drying chamber. Tests with four different airflow rates, namely, 0.0383, 0.05104, 0.0638 and 0.07655 m^3/s were conducted. It was found that the drying time was reduced from 56 h for natural drying to 12–14 h for solar drying and to

8-9 h for mixed (solar and auxiliary) drying. They concluded that the efficiency of the mixed drying system was increased from 25% to 40% compared to solar drying.

Mohod *et. al,* (2012) performed the energy analysis of baby boiler for steaming of raw cashew nut seeds. The baby boiler of 12 lit capacity used for steaming was operated at a pressure of 4.5 kg/ cm^2 and steam was released for 20 min in the cooker. They revealed that the thermal efficiency of the boiler using electricity as fuel was higher (69.31%) as compared to 4.66% (Wood) and 4.47% (Cashew nut shell). It was observed that the energy consumed per kg of cashew nut steaming using electricity (248.99 kJ/kg) was minimum followed by wood (3829.96 kJ/kg) and cashew nut shell (3835.64 kJ/kg).

Gbabo *et. al,* (2017) designed and fabricated the steam-heated platform dryer with a capacity of 4 tons per day in Niger State, Nigeria for drying of parboiled paddy rice. The system was made up of a boiler, pressure relief valve, drain valve, drying bed, furnace and heat exchanger pipes. Evaluation of the system was carried by comparing its performance with the direct sun dry method. They found that the steam heated platform dryer showed a uniform drying rate and a limited drying time of 2 hours for 335 kg of parboiled paddy with a head rice recovery of 90% and a moisture removal rate of 16kg/hr. While for the sun-dried method a moisture content of 22% (w.b.), moisture removal rate of 8kg/hr and head rice recovery of 50% was obtained.

2.4 Drying of mango pulp

Mir and Nath (1995) prepared the mango bars by washing and peeling the mangoes, then pulping and heating the pulp at 91–93 ◦C for 2 minutes. They added powdered cane sugar, 0.6% citric acid and 1734 ppm potassium metabisulphite. The total solids of the mango puree were raised to 30%. The mango puree was spread uniformly on aluminium trays and dried for 14–16 hours in a cross-flow cabinet dryer and dried at 63±2◦C.

Gujral *et. al,* (2003) used fully ripe mangoes of Langra variety from the local market for pulp extraction. Mangoes were washed and peeled and then passed through a pulper to get mango pulp with 14.3% total solids. The obtained mango pulp was 70.89%. The pulp was blanched at 80 ^{o}C for 5min, on cooling 0.2% of potassium meta bisulfate was added. Sugar was added to the pulp at a rate of 20% to increase its sweetness and total solids. Mango pulp of 250g was added to aluminium trays measuring 25.5 cm x 13 cm and 2 cm deep for drying. Drying was carried out using hot air at a temperature of 60±1 ^{o}C and relative humidity of 15% in a cabinet dryer.

Bala *et. al*, (2005) developed the dryer with transparent plastic-covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using two direct-current fans operated by a photovoltaic module for drying jackfruit bulbs and leather. The loading capacity of dryer was 120 - 150 kg of fruits. Sixteen experimental runs were conducted for drying jackfruit bulbs and leather (eight runs each). They concluded that the use of a solar tunnel dryer led to a considerable reduction in drying time and dried products of better quality in comparison to open sun drying.

Azeredo *et. al,* (2006) studied the effect of drying and storage time on the physicochemical properties of mango leathers. They prepared the mango leather with mango puree passed through a 1 mm sieve and then spread on to Petri dishes. The drying was carried out in an oven at 60–80 °C until the moisture content of the mango leather reached 15–18%.

Pushpa *et. al,* (2006) prepared the mango leather from alphonso mango pulp with TSS of 16º Brix and defatted soy flour (protein 52%) with the addition of sugar and lime juice. The different levels of incorporation of 10, 15, 20 and 25 percentage were studied. A 750 W, 2450 MHz microwave oven was used to dry the sample from 30% to15% moisture content at five different power levels (4, 8, 12, 16 and 20 W/g using 50 g of the sample) with a power cycle of the 30s on / 30s off. The dried fruit leather was evaluated for quality parameters viz., dehydration behaviour, texture, colour, water activity and sensory properties. The results showed that the mass reduction of the sample was rapid at a higher microwave power level and drying time was very short (one minute).

Mohamed Akoy *et. al*, (2014) designed and developed the natural convection solar dryer for drying of mango slices. They concluded that the minimum of 16.8m^2 solar collector area was required to dry a batch of 100 kg sliced mango (195.2kg fresh mango at 51.22% pulp) in 20 hours (two days drying period). The initial and final moisture content considered were 81.4% and 10% (w.b.), respectively. The average ambient conditions were 30ºC air temperature and 15% relative humidity with daily global solar radiation incident on the horizontal surface of about 20MJ/m^2/day.

Gurveer *et. al,* (2017) dried the mango pulp of 2 mm thickness by Refractance window (RW) technique using Mylar sheet. Drying kinetics, water activity and colour change were determined and the results were compared between mango pulp dried on Mylar sheet (MS), aluminium sheet (AS) and aluminium foil (AF), all placed on the top surface of hot water. The recommended moisture content of 18%-33% (db) for intermediate moisture food like mango leather, was achieved within 12 minutes using RW dryer with Mylar sheet. A final moisture content of 2.5% (db) was achieved in RW drying after 35 minutes. After 25 minutes of drying, water activity of the product was 0.4 with corresponding equilibrium moisture content (EMC) value of 0.25 kg water kg^{-1} dry matter at 30.2ºC. The maximum moisture diffusivity of RW dried sample on Mylar sheet was (9±2)×10-9 m^2 s^{-1}. The same values for drying on the aluminium sheet and foil were (1.05±0.25)×10-8 m^2 s^{-1} and (1.2±0.4)×10-8 m^2 s^{-1}, respectively.

Isaac and Cherotich (2017) developed the natural convection solar tunnel dryer comprising with three major units, a solar collector unit, a drying unit, and a vertical bare flat-plate chimney. The 2 kg of mango slices were dried in the dryer. The results showed that, under solar radiation between 568.4 and 999.5 W/m^2, air temperature attained was 65.8 ^oC at the collector unit. The average relative humidity values were 30.8%, 6.4%, and 8.4% for the ambient, collector, and drying unit, respectively. Under these conditions, mango with an initial moisture content of 85.5% (w.b.) was dried to 13.0% (w.b.) in 9.5 hours. The collector, drying, and pick-up efficiencies were found to be 24.7%, 12.8%, and 35%, respectively. The average temperature difference between the chimney air and ambient air was 12.1 ^oC.

Burondkar *et. al*, (2018) worked on mango fruit crop to overcome the constraints regarding mango farming. They concluded that taxonomically, mangoes belong to the genus Mangifera. They were one of the 73 genera, which include around 850 species, of the family Anacardiaceae in the order Sapindales. Five key integrated technologies were suggested for the yield and quality improvement in mango, which was most crucial, high impact generating, and cost-effective were identified and clubbed into five points and scheduled to fit into annual mango growth cycle in Konkan.

Mohod *et. al*, (2018) developed the walk-in type semi-cylindrical shaped solar tunnel dryer of 10 m x 3.75 m size at Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli for drying of mango leather. It was made up of pipe frame structure covered with U. V. stabilized sheet of 200 µm thickness. Based on the laboratory experience, a commercial-scale solar tunnel dryer of 15 m x 3.75 m size was installed at M/s Shirodkar food products Pvt. Ltd, Kudal for mango leather drying. The dryer was loaded with 315 kg mango pulp per batch in the dryer with 1.5 kg pulp in each tray. They concluded that the average temperature inside the solar dryer was found to be 62+5 ^0C and required 10 hours for the upper layer of trays, 13 hours for 2nd layer of trays and 17 hours for the third level of trays as compared to 26 hours in open sun drying. The mango leather was dried up to 15-25 % (w.b.).

II. REVIEW OF LITERATURE

The brief review of the research literature regarding development, evaluation, and performance of steam assisted hot air generation and solar dryer carried out by different researchers has divided under the following subheadings**.**

1. Solar drying & solar tunnel dryer,
2. Auxiliary heating options for solar drying,
3. Steam assisted hot air generation,
4. Drying of mango pulp**.**

2.1 Solar drying & Solar tunnel dryer

Berinyuy (2004) developed the solar tunnel dryer with capacity of 17 kg for fresh leafy vegetables per drying batch. The average maximum temperature within the drying tunnel was 61.9 ^{o}C and the minimum air flow was estimated as 9.65 m^3/h. The dryer enabled reduction in exposure time in the open-air of approximately 50% in addition to a net amelioration of the quality of the dried products. The payback period using green pepper was found to be 18 months for a natural convection solar dryer.

Janjai *et. al*, (2006) developed the solar tunnel dryer with a polycarbonate cover. The dryer consists of two parts, namely a solar collector and a drying tunnel. Both parts are connected in series on the same structure. A polycarbonate cover was used to reduce heat losses while allowing the incident solar radiation to transmit into the dryer. A dc-fan driven by a 15-watt solar cell module was employed to ventilate the dryer. The temperature of the drying air in the dryer was varied between 35 to 60 °C and the air flow rate in the dryer was about 100-500 m^3/h from 9 A.M. to 5 P.M. This dryer could be used to dry 30 to 70 kg of jackfruits from an initial moisture content of 80% (w.b.) to a final moisture content of 30% (w.b.) within 3 days, compared to 4 to 5 days with natural sun drying in the same weather condition. High-quality products in terms of flavour, colour and texture were obtained. The payback period of this dryer was found to be approximately 3 years.

Bhor *et. al,* (2010) developed and evaluated the performance of the solar tunnel dryer for Dhoma fish drying. It was noted that the drying rate was higher in solar tunnel dryer compared to open sun drying due to higher temperature (53.5^{o}C) attained inside the solar tunnel dryer. The fish sample with salt treatment moisture content reduced up to 19.29 % (d.b.) in 35 hours for an upper tray, 19.63 % (d.b.) in 37 hours for a lower tray and 19.41 % (d.b.) in 39 hours for open sun drying. The fish sample without salt treatment moisture content reduced up to 19.05 % (d.b.) in 32 hours for the upper tray, 19.90 % (d.b.) in 35 hours for lower tray and 23.73. % (d.b.) in 37 hours for open sun drying respectively. The drying rate attained in the tunnel dryer was 55.65 g/h as compared to open sun drying was 29.41 g/h.

Mohod *et.al,* (2009) developed the low-cost solar dryer (LCSD) for drying of Prawns, the size of dryer was 92 cm x 75 cm for 10 kg capacity. The time required for reducing the moisture content from 75% to 16% were observed in open sun drying and solar drying. Salted fish inside the dryer required 8 h to dry prawns up to 16.15% while unsalted fish required 15 h to reach moisture content up to 15.15% in open condition. Overall collection efficiency was found as 70.97%. They concluded that average drying efficiency for salted fish was 14% and unsalted fish was 11% whereas pickup efficiency for salted and unsalted fish was found as 10 % and 9% respectively.

Basunia *et.al,* (2010) designed and developed 12 m x 2 m size solar tunnel dryer for batch drying for 180-200 kg of freshly harvested dates. Half of the partially air-tight tunnel base was used as the flat plate air heating solar collector and the remaining half as a dryer. The drying temperature could easily be raised from 5-30 ºC above ambient temperatures inside the tunnel at an air velocity of approximately 0.5 m/sec. The 190.2 kg of freshly harvested dates was dried up to a final moisture content of 18.6% (w.b.) within two days (20 hours) while in the open sun drying the time required was 5-7 days. They concluded that the drying was faster in solar tunnel dryer compare to natural open sun drying. The improvement in the quality of dates in terms of colour, brightness, flavour, and taste and food value was distinctly recognizable.

Manjarekar *et. al,* (2010) developed & evaluated the performance of the solar tunnel dryer for fish drying. The comparative performance revealed that fish attained safe moisture limit in 18-28 hours in solar tunnel dryer as compared to 34 hours in open sun drying, the moisture content reduced from 344.86% (d.b.) to about 19% (d.b.). They concluded that the average drying efficiency of fish dried by solar tunnel dryer was found about 18% higher than the open sun-dried fish. The solar tunnel dried fish was found of better organoleptic and keeping quality up to 3 months.

Mohod *et. al,* (2011) developed & evaluated the performance of solar tunnel dryer of 100 kg capacity for fish drying. The drying of unsalted Peeled Prawns (Parapaeneopsis stylifera) required 15 hours inside the dryer placed on the upper tray as compared to 27 hours in open sun drying method. The salted fish required 13 and 25 hours to reduce up to 16.18 % (w.b.) inside the dryer and in open sun respectively. The average 28 % saving in time was observed using solar tunnel dryer over open sun drying method with average drying efficiency of 19 %. The payback period for solar tunnel dryer was found to be 2.84 years.

Mahajan *et. al,* (2011) designed and developed a semi-cylindrical shaped solar tunnel dryer of 1.5 MT capacity with base area of 3.75 m × 21 m and maximum ceiling height of 2 m for drying of lemon and evaluated that in the first day of drying the minimum inside temperature was 38.1 ^{o}C at 8:00 am in the month of April while maximum temperature attended inside the tunnel dryer was 72.9^{o}C at 02:30 pm. Corresponding, minimum ambient temperature was 26.9 ^{o}C at 8:00 am while the maximum ambient temperature was 42.5^{o}C at 02:30 pm. The solar radiations were increased from 300 W/m^2 at 8:00 am to 880 W/m^2 at 00:30 pm. The initial moisture content of lemon fruits was 80.7% (w.b.) which was reduced to 5.88% (w.b.) in 6 days, whereas OSD required 10 days.

Rathore *et. al,* (2012) developed a semi-cylindrical forced convection type solar tunnel dryer (STD) and commissioned at M/s Miraj Products Pvt. Ltd., Nathdwara for drying of 500 kg of processed tobacco from 138% (d.b.) to 8.7% (d.b.) moisture content. The area of the dryer was 16×3.75 m^2, equipped with 12 solar flat plate collectors of 2 m^2 each propelled with 2 exhaust fans of 1 kW capacity placed on both ends of the tunnel. During no-load, without flat plate collectors, temperatures inside the dryer were about 18-20 ℃ higher than the ambient temperature during summer day-light, whereas in no-load with flat plate collectors, it was about 30 ℃ higher than the ambient temperature. The time required for drying was 8 h as compared to 12 h of drying in open sun drying.

Sengar *et. al,* (2012) developed and evaluated the performance of rotary solar dryer for Kokam drying. The dryer of size 92cm x 75 cm was made by locally available bamboo, which consists of three main parts, collector, drying chamber and inlet and outlet openings for 10 kg capacity. The time required to reduce the moisture content up to 10% as safe storage for the solar dryer was observed to ripen and unripe kokam fruits. The maximum temperature inside the solar dryer was 57 °C whereas the maximum ambient temperature observed was 35.3 °C and solar irradiation was 600 W/m^2. Humidity varied from 32.2% to 22.3% inside the solar dryer whereas outside humidity varied from 43.02% to 29.35%. They concluded that maximum drying efficiency for salted ripen kokam was 9.88 % and unsalted salted ripen kokum was 7.66 %. For salted and unsalted unripe kokum, maximum efficiency was found as 4.72 % and 4.20 % respectively.

Hossain & Bala (2013) designed & developed a mixed-mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh. The dryer consist of (1. air inlet; 2. fan; 3. solar module; 4. solar collector; 5. side metal frame; 6. outlet of the collector; 7. wooden support; 8. plastic net; 9. roof structure for supporting the plastic cover; 10.base structure for supporting the dryer; 11.rolling bar; 12.outlet of the drying tunnel.) Moisture content of red chilli was reduced from 2.85 to 0.05 kg/kg (d.b.) in 20 h in a solar tunnel drier and 32 h time was required to reduce the moisture content to 0.09 and 0.40 kg/kg (d.b.) in improved and traditional sun drying methods, respectively.

Sawant *et. al,* (2013) evaluated the performance of natural convection solar dryer for sapota drying at 1 kg/m^2 area. Sapota was sliced in 5mm pieces and dipped in 1% potassium meta-bisulphate for 10 minutes to retain its colour. The solar radiations measured was ranged between 400 W/m^2 to 1200 W/m^2. They concluded that the moisture content of 78 % (w.b.) was reduced to 7.9% (w.b.) in 23 h for solar dryer and 35 h for open sun drying. The total sugar of fresh fruit was increased from 18% to 32.10% solar dried fruit and 30.17% in open sun-dried fruit, whereas the protein content of fresh sapota was reduced from 10.25% in fresh fruits to 8.68% and 6.55% in solar dried and the open sun-dried fruit respectively.

Mohod *et.al,* (2014) developed the semi cylindrical walk-in type natural convection solar tunnel dryer, with drying area of 37.5 m^2 and evaluated for the drying of fish products in comparison with the conventional method of open sun drying. The experiments were conducted without fish and with fish to evaluate the performance of solar tunnel dryer. The average rise in temperature inside the solar tunnel dryer was found to be 11.24 ^oC and 18.29 ^oC over the ambient temperature during no load test in winter and summer respectively. The average 28% saving in time was observed for selected fish drying using solar tunnel dryer over open sun drying method with average drying efficiency of 19%. The economics was calculated for drying of prawns (Parapaeneopsis stylifera) by solar tunnel dryer and open sun drying system on the basis of business as a whole. The economics of the solar tunnel dryer was presented in term of Net present worth, Benefit–Cost Ratio, Payback period, Profitability index and internal rate of return. The payback period for solar tunnel dryer was found to be 2.84 years.

Mane *et. al,* (2015) designed & developed a greenhouse type solar tunnel dryer for industrial drying of selected species of fish Croaker, Anchovy and Ribbon in the western coastal town Veraval, Gujarat, India and was installed at Jose and Brothers Fish Industry. The solar tunnel dryer was designed for drying 250 kg/h fish in batch mode to reduce the moisture content to 16% (w.b.) from initial moisture of 84% (w.b.). The single-span arc type G.I pipe frames were used to construct the dryer with a collector area of 150.9 m^2 and covered with a single layer 200 µ thick UVS poly-ethane sheet. The performance of the dryer was evaluated using the drying parameters like pre-treatment with salt and without salt in the temperature range of T_1 (40-45 ^oC) and T_2 (45-49 ^oC). The test results showed that developed dryer can reduce moisture content of salt-treated fish up to 42.85% to 66.66 % (d.b.) between 8 to 16 h, whereas in case of unsalted fish moisture content was reduced up to 17.64 % - 25 % (d.b.) in 24 to 32 hours of drying depending on a variety of fish and initial moisture content.

Vardhini *et. al,* (2016) designed, developed and evaluated the field performance of greenhouse solar tunnel dryer for drying 5 kg per batch of green chillies. A tunnel-like framed structural covered with UV-stabilized polycarbonate sheet, hemispherical type at Thanjavur, Tamil Nadu with an exposed area of 4.71 m^2 for drying green chillies, with an initial moisture content of 85% (w.b.) and to the desired moisture content of 8-10% (w.b.) within two days. The mean ambient conditions for wind speed, relative humidity and maximum solar insolation were 0.77 m/s, 31% and 1026 W/m^2 respectively. The dryer developed can be used in semi-urban and rural areas for drying various agriculture crops for small scale industries which reduce cost.

Lingayat *et. al*, (2017) developed the indirect type dryer with size of the drying cabinet was 1 m × 0.4 m × 1 m (width, depth, and height) & total area of the collectors was 2 m^2 for drying of the ripe banana slices and found that moisture content of banana was reduced from 356% (d.b.) to final moisture content of 16.3292%, 19.4736% 21.1592%, 31.1582%, 42.3748% for Tray-1, Tray-2, Tray-3, Tray-4 and open sun drying respectively on dry basis. The average thermal efficiency of the collector was found to be 31.50% and that of drying chamber was found to be 22.8%. They stated that the temperature of drying air was the most important and effective factor during drying.

2.2 Auxiliary heating options for solar drying

Gewali *et. al*, (2005) developed & evaluated a hybrid solar biomass cabinet dryer with two pieces of solar collectors (800 x 2015mm), a drying chamber (1600 x 600 x 600mm), a heat exchanger (1600 x 350 x 50mm), a chimney (500 x 75 x 400mm) and a flue gas outlet (350 x 500 x 1700mm). The dryer was designed for drying 10 kg of fresh cauliflower per batch. The effective drying time for the drying of the product was 10 h during two days of drying and drying efficiency of the dryer was found to be 16.32%.

Madholpa and Ngwalo (2007) designed a solar dryer with thermal storage and biomass backup heater for pineapple drying. The dryer was tested for three different operation modes like solar, biomass and solar-biomass for drying of twelve batches of pineapple. The average values of the final-day moisture pickup efficiency were 15%, 11% and 13% in the solar, biomass and solar–biomass modes of operation respectively. The rate of drying of pineapple in biomass mode of operation of dryer operation was higher than that of solar mode but moisture picks up efficiency was most satisfactory in solar mode.

Bolaji *et. al,* (2008) designed, developed and evaluated the performance of a mixed-mode solar dryer for yam chips drying. The temperature rise inside the drying cabinet was up to 74% (24^oC) more than ambient temperature. The dryer was able to remove 85.4% (d.b.) of moisture, from 6.2 kg of yam chips in one day of 10.00 h drying time. The drying rate, collector efficiency and percentage of moisture removed (d.b.) for drying yam chips were 0.62 kg/h, 57.5 and 85.4%, respectively.

Ehiem *et. al*, (2009) designed the industrial fruit and vegetable dryer and evaluated it for drying of tomato. It consisted of three units i.e. drying chamber, blower and heat exchanger. The tomatoes were dried at 50 °C in 14 hours. The dryer was designed and constructed for 258.64 kg of tomato's giving a mean thermal efficiency of 82% and an average drying rate of 40 g/h at a relative humidity of 35%.

Amer *et. al*, (2010) designed and fabricated the hybrid solar dryer using solar energy and a heat exchanger. Drying was operated during night period with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at the water tank. The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer. The air temperature rise was between 30 to 40°C above the ambient temperature. The capacity of the dryer was about 30 kg to dry banana slices in 8 hours in a sunny day from an initial moisture content of 82% to the final moisture content of 18% (w.b.). In the same time, it reduced to only 62% (w.b.) moisture content by open sun drying method.

Kamble *et. al*, (2013) developed the solar cabinet dryer with gravel bed for a heat storage system for drying of green chilli. Drying time for drying green chilli from initial moisture content of 88.5% (w.b.) to 7.3% (w.b.) was found to be 56 h in solar dryer whereas 104 h in the open sun drying. Drying time due to gravel bed heat storage system was extended by 4h after sunset. Drying efficiency of the solar cabinet dryer was found to be 34 %. The ascorbic acid content in chilli, dried in a solar dryer with gravel bed heat storage system and open sun drying was found to be 55.3 mg/100g (d.b.) and 50.22 mg/100g (d.b.), respectively.

Şevik *et. al,* (2012) worked on mushroom drying with a solar-assisted heat pump system. Drying air temperature, relative humidity, the weight of product values, etc. were monitored and controlled with different scenarios by using PLC. Mushrooms were dried at 45 °C and 55 °C drying air temperature and 310 kg/h mass flow rate. Mushrooms were dried from initial moisture content 13.24 g water/g dry matter (d.b.) to final moisture content 0.07 g water/g dry matter (d.b.). Mushrooms were dried by using the heat pump system, solar energy system and solar-assisted heat pump system respectively at 250–220 min, 270–165 min and 230–190 min. The coefficients of performance of the system were calculated in a range from 2.1 to 3.1 for the results of experiments. The energy utilization ratios were found to vary between 0.42 and 0.66. Specific moisture extraction rate values were found to vary between 0.26 and 0.92 kg/kWh.

Joshi *et.al,* (2014) designed & fabricated the solar dryer with alternate energy backup of electricity for fish drying. They conducted an experiment using food-grade stainless steel (SS 304) trays, drying chamber and solar heat collecting panels under controlled climatic conditions. The average dry bulb temperature and average atmospheric relative humidity (RH) were found to be 36^{o}C and 47% respectively. The average solar radiation was found to be 704 W/m^{2} and panel outlet temperature was 66.2^{o}C. The time required for reducing the moisture content of prawn up to 8.7% was 8 h in the solar dryer. The collection efficiency of solar heat collecting panels was 82% and the distribution of hot air temperature inside the drying chamber was found to be uniform throughout the experiment. The average tray temperature inside the drying chamber at full load was 49^{o}C. Average drying rate at the end of drying was 0.82 kg/ h.

Salve *et. al,* (2015) developed the forced circulation drying method for potato chips drying using PCM filled trays in the drying chamber to improve the drying effect. The two PCM materials viz. Paraffin wax (melting point 68-70 ^{o}C) and Paraffin wax (melting point 48-50 ^{o}C) were used as the source of latent heat during the evening period. The Energy Utilization effect of PCM was tested in off sunshine hours. Potato chips of approximately 1 kg dried with mass flow rates of hot air 0.00161 kg/s, 0.00288 kg/s, 0.00389 kg/s. The average thermal efficiency of drying chamber estimated to 52%.

Hussein *et. al.* (2017) designed, developed and tested hybrid photovoltaic solar dryer in Modibbo Adama University of Technology Yola, Nigeria. The dryer was consists of a solar collector, photovoltaic solar panel, battery and drying chamber. The dryer was operated as both a solar-energy dryer and as a hybrid solar dryer. The dryer was powered by 2 modules of 180 Wp PV modules. The battery used was rated 12 V & 200 Ah. The drying performance of the dryer was evaluated with a fresh tomato slice and compared with open sun drying under the same climatic conditions. The raised temperature in the dryer was 62 ℃ in the drying chamber of hybrid dryer and 54^{o}C in the drying chamber of the solar dryer. The moisture content of tomato slices was reduced from 94.22 % (w.b.) to 10 % (w.b.) in 6 hours for hybrid drying & 9 hours in the solar dryer. The average drying rate and the efficiency were found to be 0.08 kg/h and 71% for hybrid dryer and 0.0578 kg/h and 65% for solar-energy dryer respectively.

Kalbande *et.al,* (2017) developed the solar dryer assisted with reflector for drying of Safed Musli (Chlorophypum boribilianum) in batch. They found that at no load test without reflector the maximum temperature of 51.24°C was achieved in the afternoon and average temperature in the solar dryer was found to be 41.02°C at corresponding ambient temperature of 21.7°C, solar radiation 430.86 W/m^2, relative humidity 23.26%, in the morning of December 2014. The maximum temperature recorded in December 2014 was 58.46 °C at 13.30 h. The average temperature of domestic dryer was found to be 44.22°C at ambient temperature of 31.3°C, relative humidity 31.7%, solar radiation 553.80 W/m^2 during the month of March 2015.The average moisture content of Safed Musli samples placed in T_1, T_2 and T_3 trays reduced from 651.5 to 4.5, 654.7 to 7.7 and 656 to 14.5 % (d.b.) in 8 h, respectively in domestic solar dyer integrated with reflector. The average moisture content of Safed Musli sample reduced from 613% to 7.8% (d.b.) in 12 h. Average drying rate was found to be 0.5526, 0.54103 and 0.53455 gm/100gm bdm min, respectively. The average drying efficiency of Safed Musli samples dried in domestic solar dryer with reflector was found to be 22.92 % respectively.

Pavane *et. al,* (2018) designed and developed the pyramid shape solar biomass dryer, assisted with biomass for drying of nutmeg in a batch. They revealed that at no load test the average temperature in the solar biomass hybrid dryer was found to be 55.84 °C at the corresponding ambient temperature of 27.16 °C, solar radiation 239.21 W/m^2, relative humidity 87.58 %, in the winter season of December 2017. The average moisture content of nutmeg sample reduced from 613% (d.b.) to 7.8% (d.b.) in 19 h. Average drying rate was found to be 0.2564 to 0.0005 gm/100gm bdm min, respectively. They concluded that the maximum efficiency of biomass combustor and pyramid shape solar-biomass hybrid dryer was found to be 74.84 % and 29.10 %.

Rajagopal *et. al,* (2014) developed an indirect type forced convection solar dryer with evacuated tube collector, drying chamber and blower. Solar drying of copra was carried for forced convection and was compared with natural convection solar drying. The temperature of the drying chamber ranges from 49 ºC to 78 ºC for natural and forced convection while the ambient temperature ranges from 28 ºC to 32 ºC. The initial moisture content of copra ranges from 51.7% to 52.3% (w.b.) and the final moisture content obtained about 7 to 8% (w.b.). They concluded that the forced convection solar dryer requires less time than the natural convection solar dryer to attain the equilibrium moisture content of the product.

2.3 Steam assisted hot air generation

Shawik *et. al,* (2001) designed and developed a recirculatory tray dryer of 5 kg/batch using central air distribution system. The dryer was tested for blanched potato chips at a constant airflow rate of 1.5 m^3/min and 65 ^oC temperature. For removing moisture from 85.69 per cent (d.b.) to 9.89 per cent (d.b.), the observed drying time was 3 hours. They found that the heat utilization factor and thermal heat efficiency were be 18.94 per cent and 22.16 per cent respectively.

Bains *et. al,* (2003) studied behaviour of apple puree drying in a forced-air circulation cabinet drier with a cross-flow arrangement using a 3 × 2 factorial design of experiments involving air temperature (70 °C and 94 °C), flow rate (2·0 and 4·1 m/s) and relative humidity (5 and 15%) as main factors. The results showed that all three factors influenced the rate of drying with the higher temperature-higher air velocity- lower relative humidity condition yielding the fastest drying rate, but also adversely affecting the product quality.

Sarsavadia (2007) developed a solar-assisted forced convection dryer to study the effect of airflow rate (2.43, 5.25, 8.09 kg/min), air temperature (55, 65, 75 ^oC), and fraction of air recycled (up to 90 %) on the total energy requirement of drying of onion slices. The energy required per unit mass of water removed with and without using recirculation of air was found between 12.04-38.78 and 23.55-62.12 MJ/kg water respectively for drying onion slices from 86 % to 7 % (w.b.). The maximum saving in total energy up to 70.7 % was achieved by recycling of the exhaust air.

Khalifa *et. al,* (2012) evaluated the performance of a solar drying system and a system equipped with an auxiliary heater as a supplement to the solar energy. They compared the performances of both to that of natural drying. Beans and peas were dehydrated in a system that consists of two flat plate collectors, a blower, and a drying chamber. Tests with four different airflow rates, namely, 0.0383, 0.05104, 0.0638 and 0.07655 m^3/s were conducted. It was found that the drying time was reduced from 56 h for natural drying to 12–14 h for solar drying and to 8-9 h for mixed (solar and auxiliary) drying. They concluded that the efficiency of the mixed drying system was increased from 25% to 40% compared to solar drying.

Mohod *et. al,* (2012) performed the energy analysis of baby boiler for steaming of raw cashew nut seeds. The baby boiler of 12 lit capacity used for steaming was operated at a pressure of 4.5 kg/ cm^2 and steam was released for 20 min in the cooker. They revealed that the thermal efficiency of the boiler using electricity as fuel was higher (69.31%) as compared to 4.66% (Wood) and 4.47% (Cashew nut shell). It was observed that the energy consumed per kg of cashew nut steaming using electricity (248.99 kJ/kg) was minimum followed by wood (3829.96 kJ/kg) and cashew nut shell (3835.64 kJ/kg).

Gbabo *et. al,* (2017) designed and fabricated the steam-heated platform dryer with a capacity of 4 tons per day in Niger State, Nigeria for drying of parboiled paddy rice. The system was made up of a boiler, pressure relief valve, drain valve, drying bed, furnace and heat exchanger pipes. Evaluation of the system was carried by comparing its performance with the direct sun dry method. They found that the steam heated platform dryer showed a uniform drying rate and a limited drying time of 2 hours for 335 kg of parboiled paddy with a head rice recovery of 90% and a moisture removal rate of 16kg/hr. While for the sun-dried method a moisture content of 22% (w.b.), moisture removal rate of 8kg/hr and head rice recovery of 50% was obtained.

2.4 Drying of mango pulp

Mir and Nath (1995) prepared the mango bars by washing and peeling the mangoes, then pulping and heating the pulp at 91–93 °C for 2 minutes. They added powdered cane sugar, 0.6% citric acid and 1734 ppm potassium metabisulphite. The total solids of the mango puree were raised to 30%. The mango puree was spread uniformly on aluminium trays and dried for 14–16 hours in a cross-flow cabinet dryer and dried at 63±2°C.

Gujral *et. al,* (2003) used fully ripe mangoes of Langra variety from the local market for pulp extraction. Mangoes were washed and peeled and then passed through a pulper to get mango pulp with 14.3% total solids. The obtained mango pulp was 70.89%. The pulp was blanched at 80 ^{o}C for 5min, on cooling 0.2% of potassium meta bisulfate was added. Sugar was added to the pulp at a rate of 20% to increase its sweetness and total solids. Mango pulp of 250g was added to aluminium trays measuring 25.5 cm x 13 cm and 2 cm deep for drying. Drying was carried out using hot air at a temperature of 60±1 ^{o}C and relative humidity of 15% in a cabinet dryer.

Bala *et. al,* (2005) developed the dryer with transparent plastic-covered flat-plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using two direct-current fans operated by a photovoltaic module for drying jackfruit bulbs and leather. The loading capacity of dryer was 120 - 150 kg of fruits. Sixteen experimental runs were conducted for drying jackfruit bulbs and leather (eight runs each). They concluded that the use of a solar tunnel dryer led to a considerable reduction in drying time and dried products of better quality in comparison to open sun drying.

Azeredo *et. al,* (2006) studied the effect of drying and storage time on the physicochemical properties of mango leathers. They prepared the mango leather with mango puree passed through a 1 mm sieve and then spread on to Petri dishes. The drying was carried out in an oven at 60–80 °C until the moisture content of the mango leather reached 15–18%.

Pushpa *et. al,* (2006) prepared the mango leather from alphonso mango pulp with TSS of 16º Brix and defatted soy flour (protein 52%) with the addition of sugar and lime juice. The different levels of incorporation of 10, 15, 20 and 25 percentage were studied. A 750 W, 2450 MHz microwave oven was used to dry the sample from 30% to15% moisture content at five different power levels (4, 8, 12, 16 and 20 W/g using 50 g of the sample) with a power cycle of the 30s on / 30s off. The dried fruit leather was evaluated for quality parameters viz., dehydration behaviour, texture, colour, water activity and sensory properties. The results showed that the mass reduction of the sample was rapid at a higher microwave power level and drying time was very short (one minute).

Mohamed Akoy *et. al,* (2014) designed and developed the natural convection solar dryer for drying of mango slices. They concluded that the minimum of 16.8m^2 solar collector area was required to dry a batch of 100 kg sliced mango (195.2kg fresh mango at 51.22% pulp) in 20 hours (two days drying period). The initial and final moisture content considered were 81.4% and 10% (w.b.), respectively. The average ambient conditions were 30ºC air temperature and 15% relative humidity with daily global solar radiation incident on the horizontal surface of about 20MJ/m^2/day.

Gurveer *et. al,* (2017) dried the mango pulp of 2 mm thickness by Refractance window (RW) technique using Mylar sheet. Drying kinetics, water activity and colour change were determined and the results were compared between mango pulp dried on Mylar sheet (MS), aluminium sheet (AS) and aluminium foil (AF), all placed on the top surface of hot water. The recommended moisture content of 18%-33% (db) for intermediate moisture food like mango leather, was achieved within 12 minutes using RW dryer with Mylar sheet. A final moisture content of 2.5% (db) was achieved in RW drying after 35 minutes. After 25 minutes of drying, water activity of the product was 0.4 with corresponding equilibrium moisture content (EMC) value of 0.25 kg water kg^{-1} dry matter at 30.2ºC. The maximum moisture diffusivity of RW dried sample on Mylar sheet was (9±2)×10-9 m^2 s^{-1}. The same values for drying on the aluminium sheet and foil were (1.05±0.25)×10-8 m^2 s^{-1} and (1.2±0.4)×10-8 m^2 s^{-1}, respectively.

Isaac and Cherotich (2017) developed the natural convection solar tunnel dryer comprising with three major units, a solar collector unit, a drying unit, and a vertical bare flat-plate chimney. The 2 kg of mango slices were dried in the dryer. The results showed that, under solar radiation between 568.4 and 999.5 W/m^2, air temperature attained was 65.8 ^oC at the collector unit. The average relative humidity values were 30.8%, 6.4%, and 8.4% for the ambient, collector, and drying unit, respectively. Under these conditions, mango with an initial moisture content of 85.5% (w.b.) was dried to 13.0% (w.b.) in 9.5 hours. The collector, drying, and pick-up efficiencies were found to be 24.7%, 12.8%, and 35%, respectively. The average temperature difference between the chimney air and ambient air was 12.1 ^oC.

Burondkar *et. al*, (2018) worked on mango fruit crop to overcome the constraints regarding mango farming. They concluded that taxonomically, mangoes belong to the genus Mangifera. They were one of the 73 genera, which include around 850 species, of the family Anacardiaceae in the order Sapindales. Five key integrated technologies were suggested for the yield and quality improvement in mango, which was most crucial, high impact generating, and cost-effective were identified and clubbed into five points and scheduled to fit into annual mango growth cycle in Konkan.

Mohod *et. al*, (2018) developed the walk-in type semi-cylindrical shaped solar tunnel dryer of 10 m x 3.75 m size at Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli for drying of mango leather. It was made up of pipe frame structure covered with U. V. stabilized sheet of 200 μm thickness. Based on the laboratory experience, a commercial-scale solar tunnel dryer of 15 m x 3.75 m size was installed at M/s Shirodkar food products Pvt. Ltd, Kudal for mango leather drying. The dryer was loaded with 315 kg mango pulp per batch in the dryer with 1.5 kg pulp in each tray. They concluded that the average temperature inside the solar dryer was found to be 62+5 ^0C and required 10 hours for the upper layer of trays, 13 hours for 2nd layer of trays and 17 hours for the third level of trays as compared to 26 hours in open sun drying. The mango leather was dried up to 15-25 % (w.b.).

IV. RESULTS AND DISCUSSION

This chapter deals with the results obtained and their discussion are reported with respect to drying and drying characteristics of mango pulp drying using solar tunnel dryer with and without steam assisted hot air generation system. This chapter is divided in to the following different sections:

1. Performance evaluation of solar tunnel dryer without steam assisted hot air generation system
2. Development of steam assisted hot air generation system for solar tunnel dryer
3. Performance evaluation of solar tunnel dryer with steam assisted hot air generation system
4. Testing of solar tunnel dryer with & without steam assisted hot air generation system for mango pulp drying
5. Economic evaluation of steam assisted hot air generation system for tunnel shaped solar dryer

4.1 Performance evaluation of solar tunnel dryer without steam assisted hot air generation system

4.1.1 Avg. variation of temperature with solar intensity and time inside the STD

Table 4.1: Temperature & Rh with solar intensity & time inside the STD

Time (h)	Ambient Temp (^oC)	Ambient Rh (%)	Temp inside STD (^oC)	Rh Inside STD (%)	Solar Intensity (W/m^2)
8	30.50	49.23	34.44	52.63	200.33
9	31.23	42.97	42.95	41.17	241.00
10	32.77	41	47.46	38.53	334.00
11	34.73	35.9	55.00	31.43	502.67
12	36.00	30.53	59.01	24.77	580.00
13	36.20	27.83	64.28	20.33	617.67
14	34.27	27.53	59.77	19.87	539.00
15	33.70	32.57	55.98	18.47	478.33
16	32.03	39.43	48.85	20.93	307.33
17	29.67	43.3	44.13	23.00	207.00
18	28.67	49	40.51	29.87	184.00
19	24.83	52.6	27.54	37.40	0.00

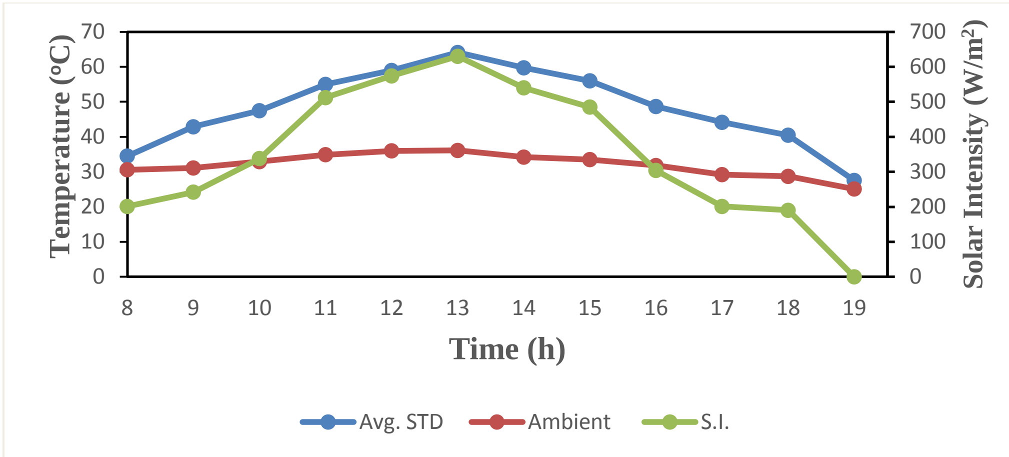

Fig 4.1 Variation of Temperature and Solar Radiation with time inside STD

Fig 4.1 revealed the temperature developed inside the solar tunnel dryer without steam assisted hot air generation system at no load test. The maximum temperature inside the solar tunnel dryer was 64.28 ^{o}C achieved at 1 pm with ambient temperature of 36.2 ^{o}C, relative humidity inside the dryer was 20.33% and relative humidity was 27.83 % at the solar intensity of 617.67 W/m^{2}. The maximum temperature at the height of 30 cm, 60 cm from absorber surface was found to be 64.64 ^{o}C and 65.0^{o}C respectively. The average temperature of exhaust air was found to be 63.21 ^{o}C.

4.1.2 Average variation of relative humidity and solar intensity with time inside solar tunnel dryer

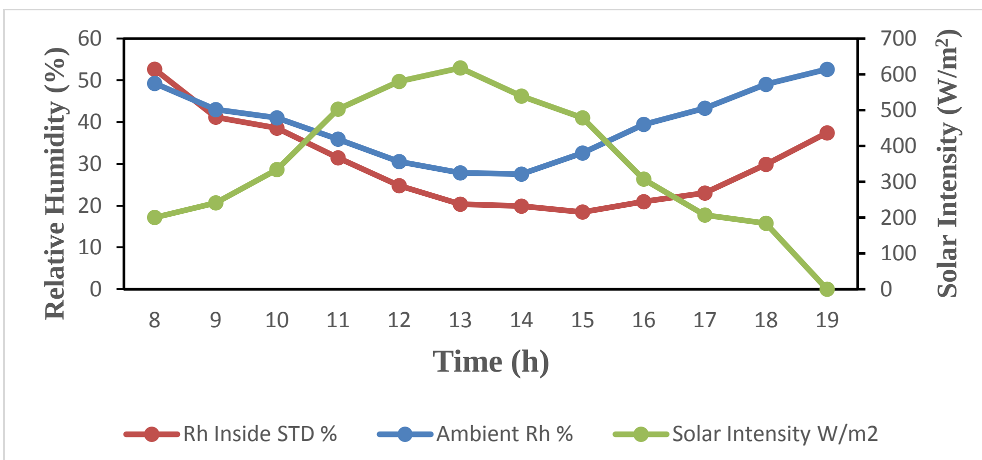

Fig 4.2 Variation of relative humidity and solar intensity with time inside STD

Fig 4.2 displays the relative humidity developed inside the solar tunnel dryer without steam assisted hot air generation system at no load test. The minimum relative humidity inside the solar tunnel dryer of 20.33 % was achieved at 1 pm with ambient temperature of 36.2 ^{o}C and relative humidity of 27.83 % at the solar intensity of 617.67 W/m^{2}. The average relative humidity inside the solar tunnel was found to be 29.87 %.

4.1.3 Selection of time for starting time for steam assisted hot air generation system

From above graphs it was noted that the temperature inside solar tunnel dryer drops below 50 ^{o}C at 4:00 pm. The minimum temperature required to dry the product is 50^{o}C, so that to maintain the 50 ^{o}C temperature inside the solar tunnel dryer, so it was decided to operate the steam assisted hot air generation system from 3:00 pm to 7:00 pm.

4.2 Development of steam assisted hot air generation system for solar tunnel dryer

4.2.1 Technical specifications of components and material used for development of steam assisted hot air generation system for solar tunnel dryer

The following components and materials were required for development of steam assisted hot air generation system. The technical specifications of components and material used for development of steam assisted hot air generation system was given below.

Table 4.2: Technical specifications of components and material used for development of steam assisted hot air generation system

Sr. No.	Component	Specification	Material used	Cost
1.	Boiler	Capacity = 8 Lit Height = 25 cm Diameter = 30 cm Height of stand = 20 cm Fuel= Electricity	Iron	6000
2.	Radiator	Length = 50 cm, Breadth = 35 cm Thickness = 7 cm Length of pipe used at inlet = 55 cm Length of pipe used at outlet = 30 cm Capacity = 1.5 ton	Aluminium and Copper	600
3.	Fan	Type = Axial fan No. of blade = 6 no Diameter of blade = 30 cm	Aluminium	1000
4.	Steam pipe	Type = R_2, Length = 3 m	Rubber	1200

4.3 Performance evaluation of solar tunnel dryer with steam assisted hot air generation system

The no load testing of stem assisted hot air generation system was carried out at Energy Park, Department of Electrical and Other Energy Sources, College of Agricultural Engineering & Technology, Dapoli. The obtained parameters of no load testing of steam assisted hot air generation system for solar tunnel dryer were noted below and depicted in Appendix- III.

4.3.1 Operational parameters of steam assisted hot air generation system for Solar tunnel dryer

Table 4.3: Operational parameters of steam assisted hot air generation system

Sr. No.	Parameter	Value
1.	T_{ib} (Temp. of water at Boiler inlet)	30.8 ^oC
2.	T_{ob} (Temp. of steam at Boiler outlet)	119.60 ^oC
3.	P_s (Steam pressure)	1 kg/cm^2
4.	m (Steam formed)	8 kg
5.	E_C (Energy Consumption)	8 kWh
6.	N (Fan rpm)	1182.33 rpm
7.	$\dot{m}_{wb}$(Mass flow rate of Boiler inlet)	2.75 kg/h
8.	$\dot{m}_s$ (Steam flow rate)	2 kg/h
9.	W_F (Fan speed)	3.5 m/s
10.	T_{RI} (Temp. Radiator inlet)	119.60 ^oC
11.	T_{RO} (Temp. Radiator outlet)	88.6 ^oC
12.	T_{HR} (Temp. Hot air)	55.7 ^oC
13.	$\dot{m}_{RO}$ (Mass flow rate of Condensed water)	1.23 lit/h
14.	Air flow rate of fan (m^3/min)	14.70 m^3/min
15.	Ta (Ambient temperature)	32.67 ^oC

4.3.2 Results of steam assisted hot air generation system for solar tunnel dryer

The results obtained from no load testing of steam assisted hot air generation system for solar tunnel dryer were noted below. The calculations of steam assisted hot air generation system for solar tunnel dryer were depicted in Appendix- IV.

Table 4.4: Result of steam assisted hot air generation system

Sr. no.	Parameter	Value
1.	Boiler efficiency	90%
2.	LMTD of radiator	59.86 ^{o}C
3.	Effectiveness of radiator	0.265
4.	Capacity ratio of radiator	1.342
5.	Correction factor of radiator	0.967
6.	Corrected LMTD of radiator	58.84 ^{o}C
7.	Overall heat transfer coefficient of radiator	125.66 W/m^2 °C
8.	Coefficient of Performance of radiator	0.643
9.	Heat Utilization Factor of radiator	0.356
10.	Power consumption of fan	132 W/hr

4.4 Effect of steam assisted hot air generation system on the performance of solar tunnel dryer

The no load testing of solar tunnel dryer was carried out with and without steam assisted hot air generation system. The temperature and relative humidity inside the solar tunnel dryer with solar intensity and ambient parameters were recorded. The results obtained were compared and depicted below.

4.4.1 Effect of steam assisted hot air generation system on the temperature of solar tunnel dryer

The raise in temperature inside the solar tunnel dryer due to steam assisted hot air generation system were depicted in given table. Fig 4.3 shows the avg. rise in temperature inside the solar tunnel dryer with steam assisted hot air generation system and without steam assisted hot air generation system. The graph shows that the average temperature was raised by 5.22 ^{o}C with steam assisted hot air generation system compared to without steam assisted hot air generation system in solar tunnel dryer. Also there was decrease in relative humidity inside the tunnel dryer.

Table 4.5: Effect of steam assisted hot air generation system on the temperature of solar tunnel dryer

Time (h)	Solar Intensity (W/m^2)	STD temp without system (^oC)	STD temp with system (^oC)	Temperature difference (^oC)
8	200.33	34.44	34.44	0
9	241.00	42.95	42.95	0
10	334.00	47.46	47.46	0
11	502.67	55.00	55	0
12	580.00	59.01	59.01	0
13	617.67	64.28	64.28	0
14	539.00	59.77	59.77	0
15	478.33	55.98	56.83	0.73
16	307.33	48.85	54.84	5.96
17	207.00	44.13	51.44	7.14
18	184.00	40.51	46.42	5.59
19	0.00	27.54	33.49	5.73

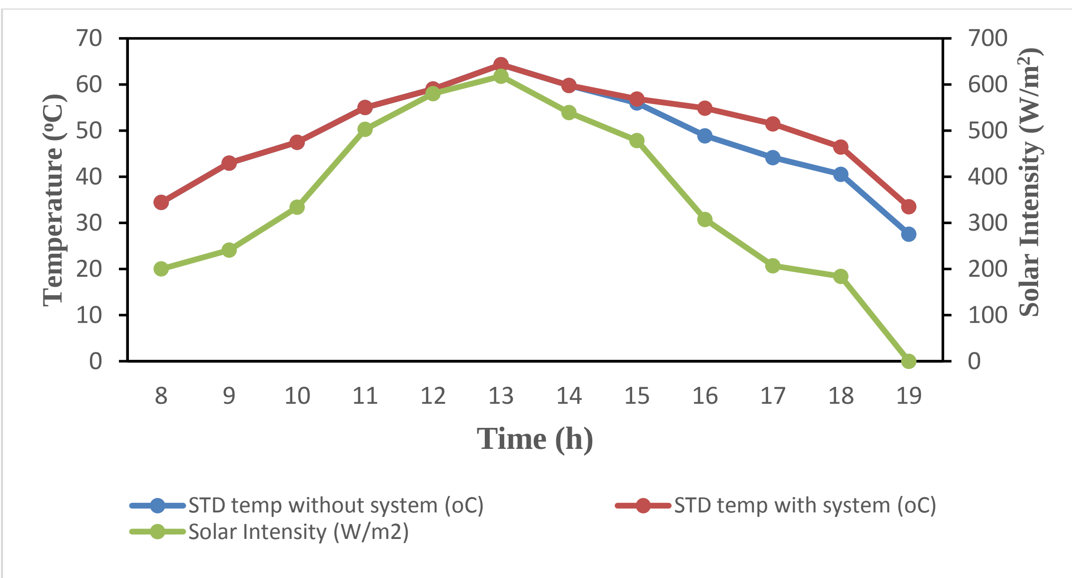

Fig 4.3 Avg. rise in temperature due to steam assisted hot air generation system in the STD

4.4.2 Effect of steam assisted hot air generation system on the relative humidity inside the solar tunnel dryer

The change in relative humidity inside solar tunnel dryer with and without steam assisted hot air generation system were depicted in given table. The atmospheric parameters were also recorded.

Table 4.6: Effect of steam assisted hot air generation system on the relative humidity inside the solar tunnel dryer

Time (h)	Rh inside STD without system (%)	Rh inside STD with system (%)	Solar Intensity (W/m^2)
8	52.63	52.63	200.33
9	41.17	41.17	241.00
10	38.53	38.53	334.00
11	31.43	31.43	502.67
12	24.77	24.77	580.00
13	20.33	20.33	617.67
14	19.87	19.87	539.00
15	18.47	16.9	478.33
16	20.93	19.43	307.33
17	23.00	21.47	207.00
18	29.87	28.4	184.00
19	37.40	33.23	0.00

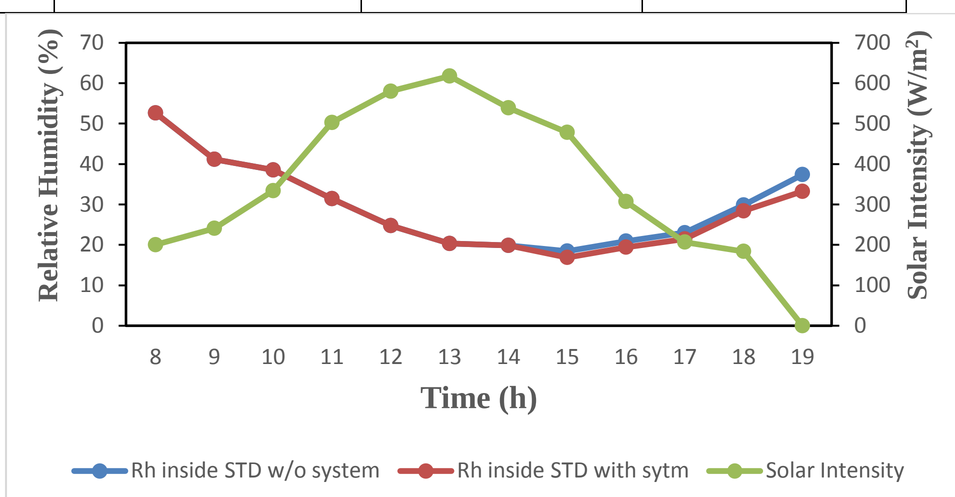

Fig 4.4 Avg. variation in relative humidity inside STD due to steam assisted hot air generation system

The relative humidity developed inside the solar tunnel dryer without and with steam assisted hot air generation system at no load test was discussed here. It was noted that there was decrease in relative humidity due to steam assisted hot air generation system during 3:00 pm to 7:00 pm inside the solar tunnel dryer.

4.5 Testing of solar tunnel dryer without steam assisted hot air generation system for mango pulp drying

The mango pulp available in the market was used for drying. The samples of the mango pulp was loaded in stainless steel trays inside the solar tunnel dryer. The drying of these samples was continued till the moisture content reached to 25 % of the selected samples on wet basis. The results obtained from drying experiments of mango pulp in tunnel shape solar dryer without and with steam assisted hot air generation system were summarized follows.

4.5.1 Variation of temperature above tray with solar intensity and time inside the dryer

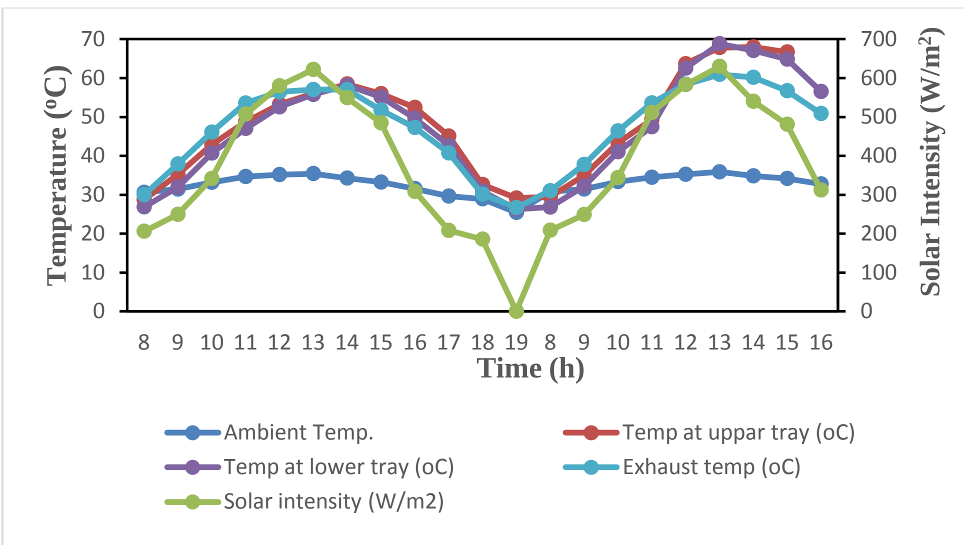

Fig 4.5 Average variation of temperature above tray with solar intensity and time inside the dryer

From the fig 4.5 avg. tray temperature inside the solar tunnel dryer without steam assisted hot air generation system was discussed here. It was noted that on day one of drying maximum temperature of lower tray was 58.47 ^oC and 58.13 ^oC of upper tray temperature achieved at 2:00 pm with solar intensity and ambient temperature of 549.33 W/m^2 and 34.27 ^oC respectively. The exhaust temperature noted was 57 ^oC, on day two of drying the maximum tray temperature of upper tray, lower tray and exhaust chimney was 68 ^oC and 67 ^oC respectively with ambient temperature of 34.83 ^{o}C with solar intensity of 540 W/m^2. The drying was completed at 4:00 pm on the day two. The time required for drying was 19 h.

4.5.2 Variation of relative humidity with solar intensity and time inside the dryer

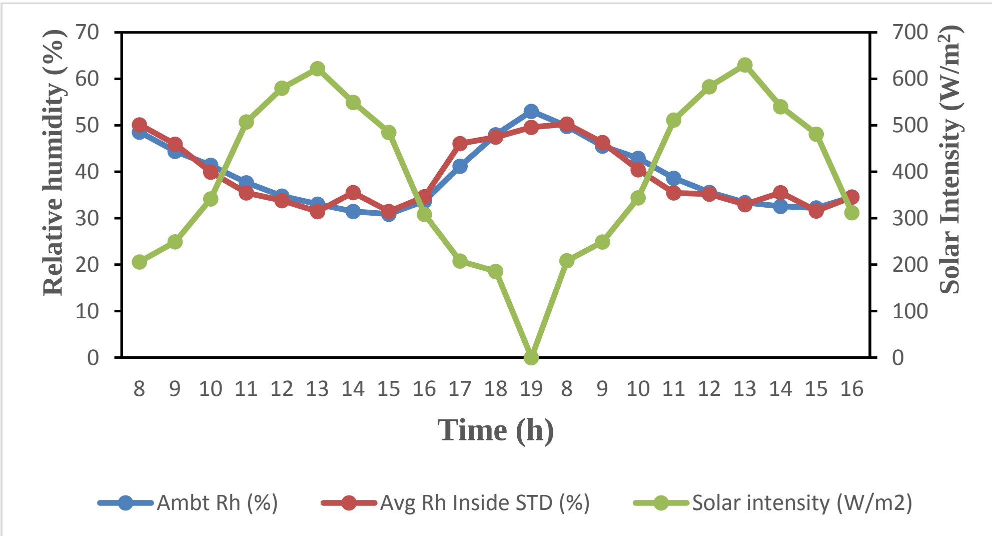

Fig 4.6 Variation of relative humidity with solar intensity and time inside the dryer

From fig 4.6 it was noted that the relative humidity developed inside the solar tunnel dryer without steam assisted hot air generation system at load test was discussed here. The minimum relative humidity inside the solar tunnel dryer on day one of drying was 31.43 % achieved at 1:00 pm with ambient temperature of 35.43 ^{o}C and ambient relative humidity of 33.03 % at the solar intensity of 622 W/m^2. The average relative humidity inside the solar tunnel was found to be 39.20 %.

4.6 Drying characteristics of mango pulp dried in solar tunnel dryer without steam assisted hot air generation system

The drying characteristics of mango pulp dried in solar tunnel dryer without steam assisted hot air generation system were studied and compared with steam assisted hot air generation system. The different drying characteristics in terms of moisture content (%, db), drying rate (gm 100 g^{-1} min^{-1}) and moisture ratio were studied. The variation of moisture content, drying rate and moisture ratio with respect to drying time is presented in Fig. 4.7 to 4.8.

4.6.1 Variation of moisture content of mango pulp in STD without steam assisted hot air generation system

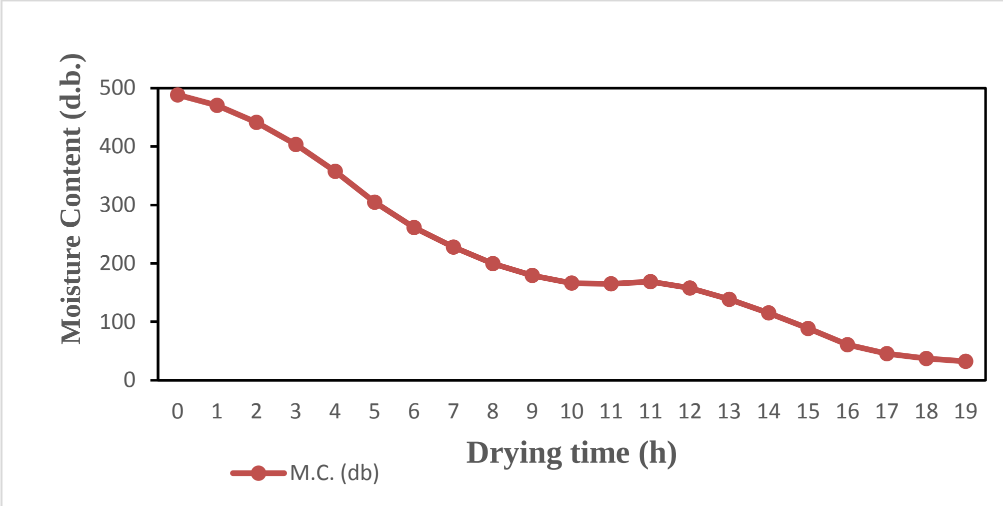

Fig 4.7 Variation of moisture content of mango pulp in STD without steam assisted system

The fig.4.7 revealed that the average moisture content % (d.b.) of mango pulp inside the solar tunnel dryer reduced from 488.235 (83 w.b.) to 32.53 % (24.4 w.b.) in 19 h in solar tunnel dryer. Similarly it was observed that the maximum moisture removal had taken place from 488.235 to 166.275 % (d.b.) in 10 h during first day of drying in solar tunnel dryer.

4.6.2 Variation of moisture ratio & drying rate against drying time of mango pulp in STD without steam assisted system

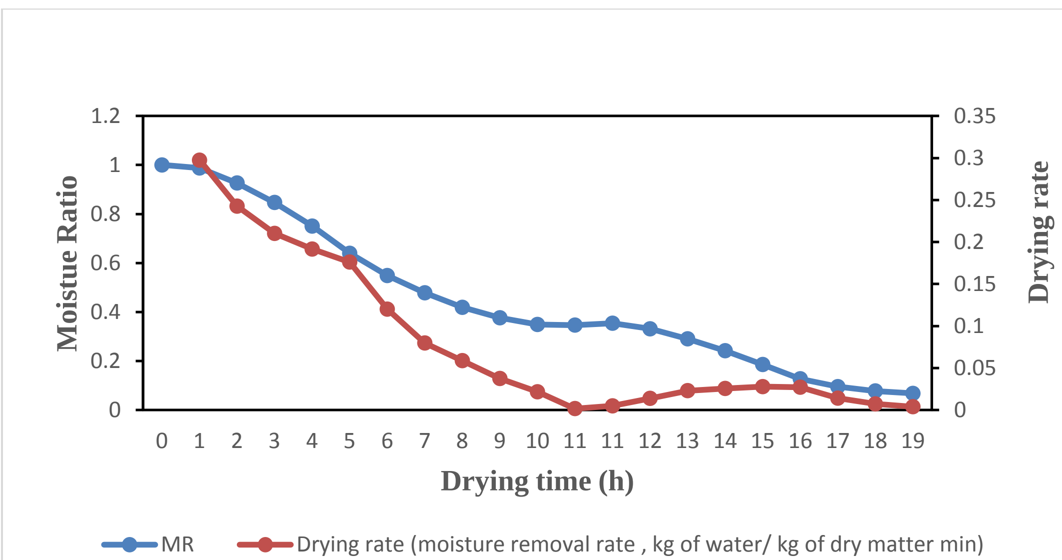

Fig 4.8 Variation of moisture ratio & drying rate of mango pulp in STD without steam assisted system

From fig 4.8 it was revealed that the moisture ratio varied from 1.00 to 0.068 for drying of mango pulp in solar tunnel dryer. The drying rate varied from 0.297 to 0.004 gm/100gm bdm-min. for drying of mango pulp in solar tunnel dryer. The average drying rate was found to be

0.079 gm/100 gm bdm-min. and average moisture ratio was 0.450 for mango pulp in solar tunnel dryer respectively.

4.7 Testing of solar tunnel dryer with steam assisted hot air generation system for mango pulp drying

4.7.1 Variation of temperature above tray with solar intensity and time inside the dryer

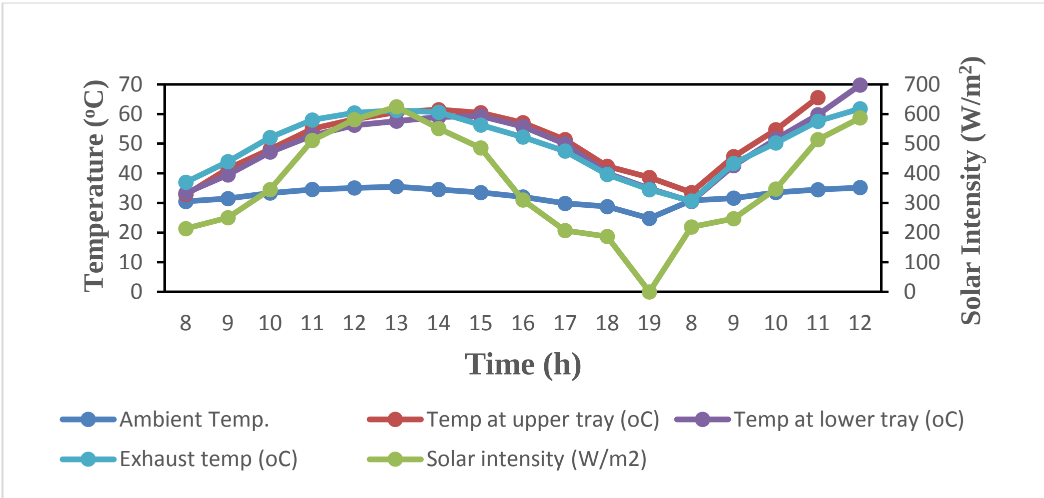

Fig 4.9 Variation of temperature above tray with solar intensity and time inside dryer

From the fig 4.9 avg. tray temperature inside the solar tunnel dryer without steam assisted hot air generation system was discussed. It was noted that the on day one of drying maximum temperature of lower tray was 61.43 °C and 59.03 °C of upper tray temperature achieved at 2:00 pm with solar intensity and ambient temperature of 551.00 W/m^2 and 34.43 °C respectively. The exhaust temperature was noted to be 60.57 °C. On day two of drying the maximum tray temperature of lower tray and exhaust chimney was 69.77 °C and 61.77 °C respectively with ambient temperature of 34.43 °C with solar intensity of 548.7 W/m^2. The drying was completed at 12:00 pm on day two. The time required for drying was 14 h. There was increase in tray temperature during 4:00 pm to 7:00 pm compared to the tray temperature without steam assisted hot air generation system.

4.7.2 Variation of relative humidity with solar intensity and time inside the dryer

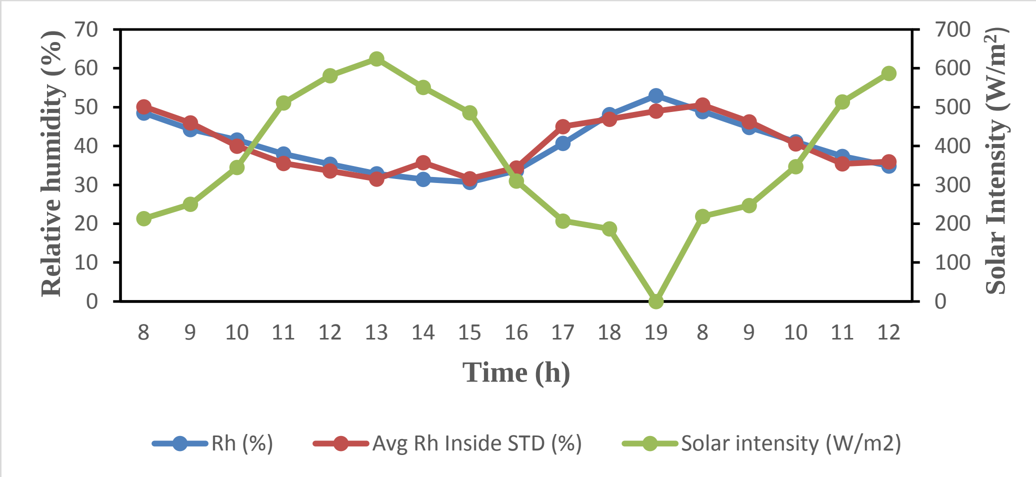

Fig 4.10 Variation of relative humidity with solar intensity and time inside dryer

From fig 4.10 it was noted that relative humidity developed inside the solar tunnel dryer with steam assisted hot air generation system at load test was discussed here. The minimum relative humidity inside the solar tunnel dryer on day one of drying was 31.50 % achieved at 1:00 pm with ambient temperature of 35.53 ^{o}C and ambient relative humidity of 32.87 % at the solar intensity of 624 W/m^2. The average relative humidity inside the solar tunnel was found to be 40.47 %.

4.8 Drying characteristics of mango pulp dried in solar tunnel dryer with steam assisted hot air generation system

The drying characteristics of mango pulp dried in solar tunnel dryer with steam assisted hot air generation system were studied and compared to without steam assisted hot air generation system. The different drying characteristics in terms of moisture content (per cent, db), drying rate (gm 100 g-^{1} min-^{1}) and moisture ratio were studied. The variation of moisture content, drying rate and moisture ratio with respect to drying time is presented in Fig. 4.11 to 4.12.

4.8.1 Variation of moisture content of mango pulp in STD with steam assisted hot air generation system

The fig.4.11 revealed that the average moisture content percent (d.b.) of mango pulp inside the solar tunnel dryer reduced from 488.235% (83 w.b.) to 32.53% (24.4 w.b.) in 15 h in solar tunnel dryer due to steam assisted hot air generation system. Similarly it was observed that maximum moisture removal had taken place from 488.235% to 130.098 % (d.b.) in 10 h during first day of drying in solar tunnel dryer.

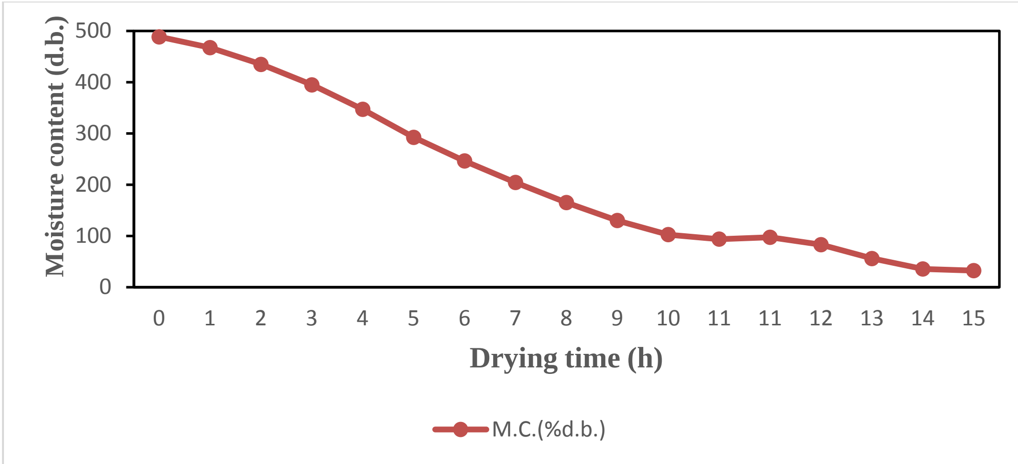

Fig 4.11 Variation of M. C. of mango pulp in STD with steam assisted system

4.8.2 Variation of moisture ratio & drying rate against drying time of mango pulp in STD with steam assisted system

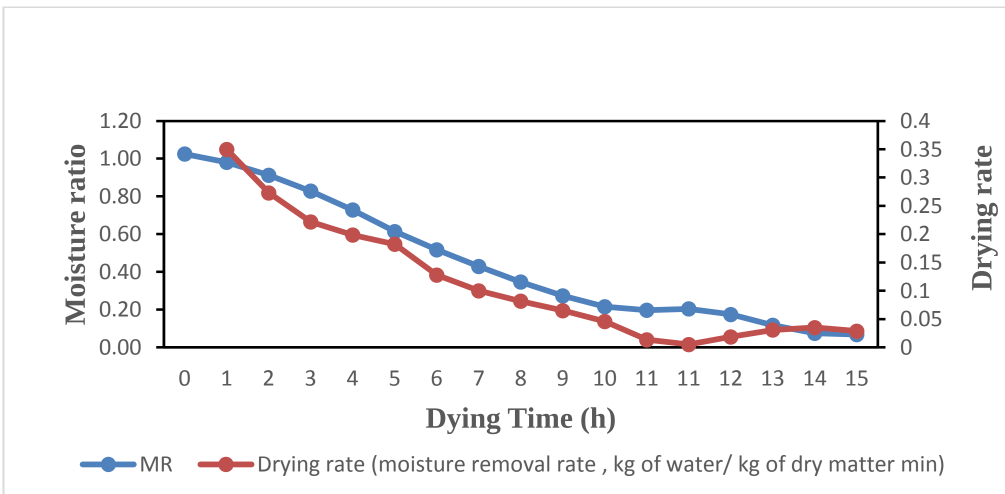

Fig 4.12 Variation of moisture ratio & drying rate of mango pulp in STD with steam assisted hot air generation system

From fig 4.12, it was revealed that the moisture ratio varied from 1.025 to 0.068 for drying of mango pulp in solar tunnel dryer. The drying rate varied from 0.350 to 0.029 gm/100gm bdm-min. for drying of mango pulp in solar tunnel dryer. The average drying rate was found to be 0.111 gm/100 gm bdm-min. corresponding to average moisture ratio of 0.453 for mango pulp in solar tunnel dryer respectively

4.9 Drying characteristics of dried mango pulp with and without steam assisted hot air generation system for solar tunnel dryer

The drying characteristics of mango pulp dried in solar tunnel dryer with & without steam assisted hot air generation system were studied, compared and noted below. The different drying characteristics in terms of moisture content (% db), drying rate (gm 100 g^{-1} min^{-1}) and moisture ratio were studied. The variation of moisture content, drying rate and moisture ratio with respect to drying time of with and without steam assisted hot air generation system is presented in Fig. 4.13 to 4.15.

Table 4.7: Drying characteristics of mango pulp with and without steam assisted hot air generation system on the performance of load test on solar tunnel dryer

Drying time (h)	M.C.(%d.b.) with system	M.R. with system	Drying rate with system	M.C. (%d.b.) without system	M.R. without system	Drying rate without system
0	488.235	1.025		488.235	1	
1	468.431	0.984	0.350	470.392	0.988	0.297
2	436.863	0.917	0.273	441.275	0.927	0.243
3	398.431	0.837	0.222	403.431	0.847	0.210
4	352.353	0.740	0.199	357.451	0.751	0.192
5	299.020	0.628	0.182	304.608	0.640	0.176
6	253.922	0.533	0.128	261.373	0.549	0.120
7	213.725	0.449	0.100	227.843	0.478	0.080
8	175.294	0.368	0.082	199.608	0.419	0.059
9	141.569	0.297	0.065	179.314	0.377	0.038
10	114.902	0.241	0.046	166.275	0.349	0.022
11	106.863	0.224	0.013	165.098	0.347	0.002
11	110.392	0.232	0.005	168.725	0.354	0.005
12	96.471	0.203	0.018	157.843	0.331	0.014
13	70.784	0.149	0.031	138.431	0.291	0.023
14	39.412	0.083	0.035	115.294	0.242	0.026
15	32.353	0.068	0.029	88.529	0.186	0.028
16				60.784	0.128	0.027
17				45.490	0.096	0.014
18				37.157	0.078	0.007
19				32.353	0.068	0.004

4.9.1 Variation of moisture content of mango pulp in STD with & without steam assisted hot air generation system

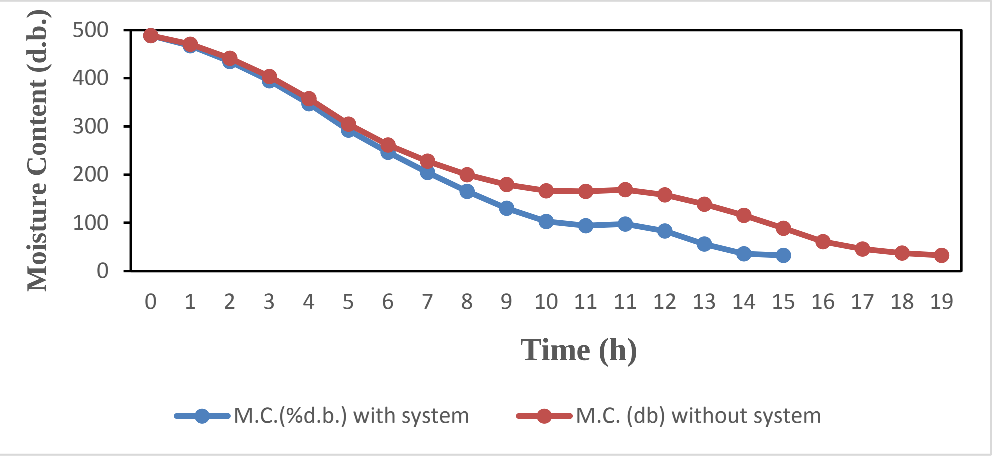

Fig 4.13 Variation of moisture content of mango pulp in STD with & without steam assisted hot air generation system

From fig 4.13 it was observed that the drying time required to dry the sample of mango pulp in solar tunnel dryer with steam assisted hot air generation system were 15 hours as compared to without steam assisted hot air generation system inn solar tunnel dryer (19 hrs.). Due to the steam assisted hot air generation system there was high reduction in moisture from 15 pm to 19 pm which was 204.314% (d.b.) to 93.824% (d.b.) compared to 199.608% (d.b.) to 168.705% (d.b.) without steam assisted hot air generation system. Saving of 4 hours of drying time was achieved in solar tunnel dryer due to steam assisted hot air generation system.

4.9.2 Variation of moisture ratio of mango pulp in STD with & without steam assisted hot air generation system

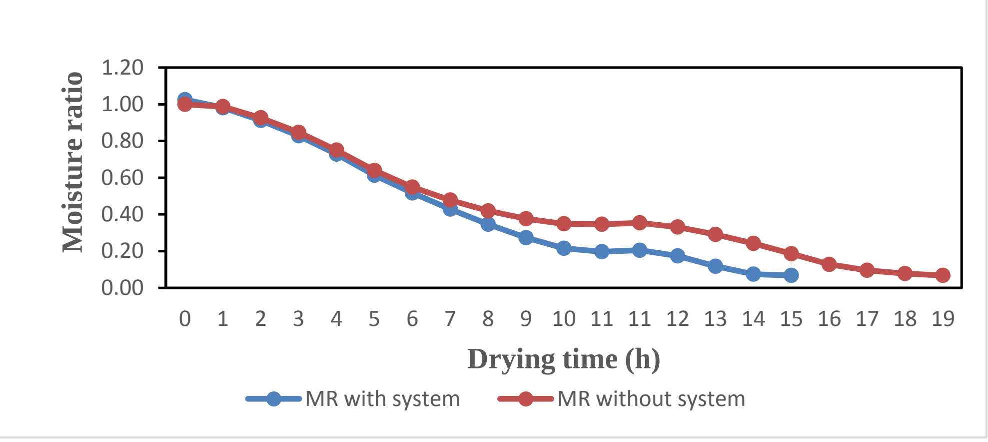

Fig 4.14 Variation of moisture ratio of mango pulp in STD with & without steam assisted hot air generation system

From fig 4.14 it was revealed that the moisture ratio varied from 1 to 0.068 and 1.025 to 0.068 for drying of mango pulp in solar tunnel dryer without and with steam assisted hot air generation system, respectively. The average moisture ratio for drying of mango pulp in solar tunnel dryer without steam assisted hot air generation system was found to be 0.450 and 0.453 with steam assisted hot air generation system for mango pulp drying, respectively.

4.9.3 Variation of drying rate of mango pulp in STD with & without steam assisted system

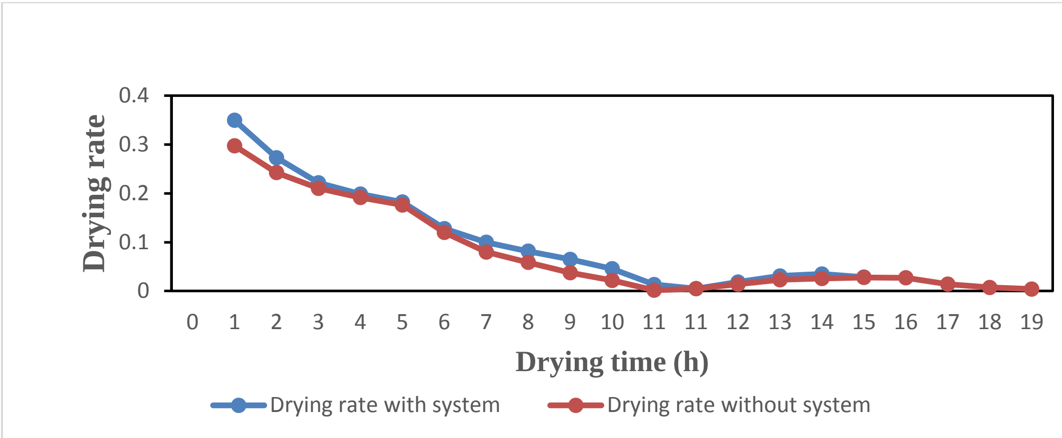

Fig 4.15 Variation of drying rate of mango pulp in STD with & without steam assisted hot air generation system

From fig 4.15, it was revealed that the drying rate varied from 0.297 to 0.004 gm/100 gm bdm-min. and 0.350 to 0.029 gm/100 gm bdm-min. for drying of mango pulp in solar tunnel dryer without and with steam assisted hot air generation system, respectively. The average drying rate for drying of mango pulp in solar tunnel dryer without steam assisted hot air generation system was found to be 0.079 gm/100 gm bdm-min. and 0.111 gm/100 gm bdm-min. with steam assisted hot air generation system for mango pulp drying, respectively.

4.10 Drying efficiency of solar tunnel dryer (ŋ)

Overall efficiency for drying of mango pulp drying was determined by considering the heat gained and heat utilized by the product in dryer. The overall drying efficiency of solar tunnel dryer based on experimental data was calculated by considering the total moisture evaporated with heat gain by product. The results obtained from overall efficiency of mango pulp dried in solar tunnel dryer is depicted in Table 4.8. It was revealed that the overall efficiency of mango pulp dried in solar tunnel dryer without and with steam assisted hot air generation system were found to be 16.81% and 22.30% respectively for laboratory test in summer season. (Appendix-XII)

Table 4.8: Overall efficiency of solar tunnel dryer with and without steam assisted hot air generation system

Sr. No.	Sample	Total drying time, (hr.)	Avg. moisture removed, (kg)	Avg. Solar Radiation, (W/m^2)	Efficiency, (%)
1	Mango Pulp (Without steam assisted hot air generation system)	20	77.5	385.78	16.81
2	Mango Pulp (With steam assisted hot air generation system)	16	77.5	363.49	22.30

4.11 Economics of steam assisted hot air generation system for tunnel shape solar dryer

The economic feasibility of the steam assisted hot air generation system for tunnel shape solar dryer for mango pulp drying was calculated by considering the initial investment of the dryer, initial investment on the components, average repair and maintenance cost, cost of raw material, electricity charges and selling price of the material after drying. Based on the study, average parameter were calculated for economics analysis depicted in Table 4.9 and 4.10.

4.11.1 Net present worth

Net present worth for mango pulp drying is presented in Table 4.10. The net present worth of total cash inflow and outflow for drying of mango pulp under tunnel shape solar dryer was found to be Rs. 311767.9. Based on the NPW it could be concluded that the drying of mango pulp in steam assisted hot air generation system for tunnel shape solar dryer is an economical and there is substantial increase in the income of the above products processing. (Appendix XIII)

4.11.2 Benefit cost ratio

The BC ratio of the system was calculated by dividing present worth of benefit stream and present worth of cost stream. Table 4.10 revealed benefits cost ratio for drying of mango pulp found to be 1.08. Thus, it is concluded that investment of mango pulp drying in steam assisted hot air generation system for tunnel shape solar dryer is justified and economically viable. (Appendix XIII)

4.11.3 Payback period

Payback period for drying of mango pulp in steam assisted hot air generation system for tunnel shape solar dryer was found to be 1 year 4 month and 13 days for recovery of the initial investment of steam assisted hot air generation system for tunnel shape solar dryer. Thus, it could be concluded that the drying of mango pulp seems to be economical in steam assisted hot air generation system for tunnel shape solar dryer.

Table 4.9: Calculation of operation cost for mango pulp drying in steam assisted hot air generation system for tunnel shape solar dryer

Sr. No.	Description	Cost (Rs./year)
I	**Fixed cost**	
i	Steam assisted hot air generation system for tunnel shape solar dryer	64,480
II	**Operating cost**	
i	Raw material cost	4,50,000
ii	Labour cost	4500
iii	Repair and maintenance cost per year (10% for every 5 yr)	2760
iv	Electricity charges (11.5/unit)	1934.4
	Sub-total (II)	459194.4
	Total operating cost	523674.4

Table 4.10: Cost analysis of steam assisted hot air generation system for tunnel shape solar dryer

Sr. No.	Description	Particulars
1	Initial investment (Rs)	64,480
2	Annual use (no. of batches)	30
3	Cost of raw material (Rs/yr) @150Rs/Kg	4,50,000
4	Cost of labour for drying (Rs /yr) @150Rs/batch	4,500
5	Operation and maintenance cost (10% for every 5 yr)	2760
6	Total dried product (kg)	675
7	Total cost of finished product @Rs 750/kg	5,06,250
	Economic indicators	
a	Net present worth, Rs	311767.9
b	Benefit- cost ratio	1.08
c	Payback period	1.37 yrs

V. SUMMARY AND CONCLUSIONS

This chapter deals with the summary and conclusion of the results obtained in the development and evaluation of steam assisted hot air generation system for solar tunnel dryer.

5.1 Summary

Drying depends upon the quality of air (temperature, humidity and quantity of air used), materials properties which are used for drying (size of the pieces being dried and physical, structure and composition) and airflow patterns within the drying system. Solar dryers use solar energy to dry the material by raising the temperature of the air surrounding it. After the sunshine period is over the drying cannot be completed which leads to an increase in overnight moisture leads to an increase in drying time. To overcome these processing losses during the drying and to retain the superior quality of the dried product, it is necessary to have a backup heating option which can provide the hot air inside the dryer during an evening period such that product can be completely dried up to its desired moisture content without an increase in its drying time and processing cost required for it. The steam-assisted hot air generation system consists of boiler, heat exchanger, fan and solar tunnel dryer. The indirect type of steam boiler was used for steam formation. The steam flow rate was 2 kg/h. The radiator was removed from the old AC ducts which were available at Energy Park. The axial fan with 6 blades and 1350 rpm was selected. The diameter of the blade was 30 cm. The semi-cylindrical shaped solar tunnel dryer consist of a drying chamber of 10 m x 3.75 m was selected for drying of mango pulp per batch. The tunnel dryer was made up of pipe frame structure covered with UV stabilized semi-transparent polythene of 200 microns. The capacity of the solar tunnel dryer was 100 kg per batch. The experiments were conducted without and with steam-assisted hot air generation system of the solar tunnel in the view to find out the temperature inside the solar tunnel dryer at different locations inside the dryer. The maximum temperature inside the solar tunnel dryer without steam-assisted system was 64.28 ^{o}C achieved at 1 pm with an ambient temperature of 36.2 ^{o}C, relative humidity inside the dryer was 20.33 % and ambient relative humidity was 27.83 % at the solar intensity of 617.67 W/m^2. The minimum temperature required to dry the product is 50 ^{o}C, so that to maintain the 50 ^{o}C temperature inside the solar tunnel dryer, the steam-assisted hot air generation system was started at 3:00 pm up to 7:00 pm. The boiler efficiency, rise in temperature due to steam assisted system, energy consumption and effectiveness of heat exchanger was determined.

The samples of the mango pulp were loaded in stainless steel trays inside the solar tunnel dryer. The drying of these samples was continued until the moisture content reached 25 %of the selected samples on a wet basis. The time required for drying mango pulp without steam-assisted hot air generation system was compared with steam-assisted hot air generation system in the solar tunnel dryer. The avg. moisture ratio for drying mango pulp without steam-assisted hot air generation system was compared with steam-assisted hot air generation system in the solar tunnel dryer. The avg. drying rate for drying mango pulp without steam-assisted hot air generation system was compared with steam-assisted hot air generation system in the solar tunnel dryer. The avg. drying efficiency for drying mango pulp without steam-assisted hot air generation system and with steam-assisted hot air generation system in the solar tunnel dryer were determined. The Net Present Worth of steam-assisted hot air generation system for mango pulp drying, Benefit-Cost ratio of steam-assisted hot air generation system for mango pulp drying and the Payback period of steam-assisted hot air generation system for mango pulp drying were found. The results obtained are as follows.

1. The steam flow rate of baby boiler was 2 kg/h. The boiler efficiency was found to be 90%.
2. The avg. rise in inside temperature of solar tunnel dryer was 5.22 ^{o}C with steam-assisted hot air generation system compared to the without steam-assisted hot air generation system.
3. The total energy consumption by steam-assisted hot air generation system was 8 kWh for 4 hours.
4. The fan blade diameter was 30 cm, the airflow rate and rpm of the fan was found to be 14.70 m^3/min and 1182, respectively.
5. The effectiveness and capacity ratio of the heat exchanger was found to be 0.265 and 1.342, respectively.
6. The corrected LMTD, COP and Heat utilisation factor of the heat exchanger was calculated to be 58.84 ^{o}C, 0.643 and 0.356, respectively.
7. The sample of mango pulp was dried from the initial moisture of 83.40 % w.b. (488.235 % d.b.) to 24.5 % w.b. (32.253 % d.b.).
8. The time required for drying mango pulp without steam-assisted hot air generation system was 19 h compared to 14 h with steam-assisted hot air generation system in the solar tunnel dryer.

9. The avg. moisture ratio for drying mango pulp without steam-assisted hot air generation system was 0.450 compared to 0.453 with steam-assisted hot air generation system in the solar tunnel dryer.
10. The avg. drying rate for drying mango pulp without steam-assisted hot air generation system was 0.079 gm/100 gm bdm-min compared to 0.111 gm/100 gm bdm-min with steam-assisted hot air generation system in the solar tunnel dryer.
11. The avg. drying efficiency for drying mango pulp without steam-assisted hot air generation system was 16.8 % compared to 22.30 % with steam-assisted hot air generation system in the solar tunnel dryer.
12. The Net Present Value of steam-assisted hot air generation system for mango pulp drying was Rs 3,11,767.9.
13. The Benefit-Cost ratio of steam-assisted hot air generation system for mango pulp drying was 1.08.
14. The Payback period of steam-assisted hot air generation system for mango pulp drying was 1 year 4 months and 13 days.

5.2 Conclusions

From the above study, it was concluded that the steam assisted hot air generation system was found to be economical and feasible for extended period of mango pulp drying in solar tunnel dryer.

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