

PERFORMANCE STUDY OF SOLAR TUNNEL DRYER FOR MEDICINAL PLANTS

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**PERFORMANCE STUDY OF SOLAR TUNNEL
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OCTOBER - 2022

Dedicated With Love and Veneration

*To my beloved parents, Mr. Sunil Pradhan and
Mrs. I. K, Pradhan.*

*Thank you for your great support and continuous
care.*

To my true friends

I am really grateful for your help.

To my respected Guide, Dr. P. M. Chauhan

*Who is the continuous source of
Inspiration and constant encouragement for me.*

Anisha.

ABSTRACT

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MEDICINAL PLANTS**

ABSTRACT

Keywords: solar tunnel dryer; *Adhatoda vasica*; *Moringa oleifera oleifera*; micro-climate; techno-economics; biochemical analysis.

Drying of agricultural products is still the most widespread preservation technique. Open sun drying is the most commonly used method to preserve agricultural products in most developing countries. Such drying under hostile conditions leads to severe losses in the quantity and quality of the dried product. Mechanical drying is an energy consuming operation in the post harvesting technology of agricultural products, so more emphasis is given on using solar energy sources due to the high prices and shortages of fossil fuel. A solar tunnel dryer is a poly house framed structure covered with UV-stabilized polythene sheet, where agricultural and industrial products on large scale could be dried under at least partially controlled environment. A solar tunnel dryer accelerates and improves the drying process, it protects the product from insects and other pests-infestation thereby, reducing the contamination or product loss. As a result, the solar tunnel dryer lowers post-harvest losses compared to traditional sun drying. In this study, *Adhatoda vasica* and *Moringa oleifera* leaves were dried using a simple, low-cost solar tunnel drier and then it was compared with the open sun-dried products. The mean carbohydrate content, ascorbic acid, ash, fat, fibre and protein content in solar-tunnel dried *Adhatoda vasica* leaves was found to be 39.05%, 3.76%, 54.77%, 3.48%, 15.91% and 10.71%, respectively. The mean carbohydrate content, ascorbic acid, ash, fat, fibre and protein content in in solar-tunnel dried *Moringa oleifera* leaves was found to be 38.78%, 3.06%, 43.52%, 6.88%, 18.33% and 8.44%, respectively. The mean value of bulk density was observed to be 303.00 kg/m³ and 451.67 kg/m³ for *Adhatoda vasica* and *Moringa oleifera* leaves, respectively. The mean value of recovery rate for *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 22.53% and 24.71%, respectively. The mean value of WAI for *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 344.88% and 259.68%, respectively, whereas the mean value of WSI for *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 57.75% and 57.31%, respectively. The final moisture content of *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 5.77% (db) and 4.93% (db), respectively. The drying efficiency and the pick-up efficiency of the solar tunnel dryer for the drying of medicinal plant leaves was found to be 12.14% and 26.45%, respectively. The total profit of *Adhatoda vasica* and *Moringa oleifera* leaves was calculated as ₹20.00/- and ₹30.00/- per kg, respectively as compared to the cost of sun drying which was ₹6.21/- and ₹16.30/- per kg, respectively. The payback period of the dryer was found to be 1 year and 20 days. The total cost of the dryer was ₹2,44,737/-.

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CERTIFICATE – I

This is to certify that the thesis entitled “**PERFORMANCE STUDY OF SOLAR TUNNEL DRYER FOR MEDICINAL PLANTS**” submitted by **Ms. ANISHA PRADHAN (Reg. No. 2050220003)** in partial fulfilment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in the subject of **RENEWABLE ENERGY ENGINEERING** to the Junagadh Agricultural University is a record of bonafide research work carried out by her under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. She has successfully completed the comprehensive/preliminary examination held on **May 04, 2022** as required under the regulation for post-graduate studies. She has submitted kachcha bound thesis on **July 30, 2022**.

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Date: 3/10/2022

This is to certify that the thesis entitled “**PERFORMANCE STUDY OF SOLAR TUNNEL DRYER FOR MEDICINAL PLANTS**” submitted by **Ms. ANISHA PRADHAN (Reg. No. 2050220003)** to Junagadh Agricultural University, Junagadh in partial fulfilment of the requirements for award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in the subject of **RENEWABLE ENERGY ENGINEERING** after recommendation by the external examiners were defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, forward with recommendation.

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(Anisha Pradhan)

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NOMENCLATURE

| | |
|-------------------------|--|
| A | Area, m ² |
| C | Specific heat, J/kg°C |
| h | Heat transfer coefficient, W/m ² °C |
| h _{df} | Mass transfer coefficient |
| h _{fg} | Latent heat of vapourization |
| I | Solar radiation, W/m ² |
| k | Thermal conductivity, W/m ² °C |
| L | Length of solar tunnel dryer, m |
| M | Mass, kg |
| Nu | Nusselt number |
| Pr | Prandtl number |
| Re | Reynold's number |
| T | Temperature, °C |
| t | Time, s, h |
| v | Velocity, m/s |
| <i>et al.</i> | et alia (and other) |
| kg/m ³ | Kilogram per meter cube |
| kWh | Kilowatt-hours |
| kWh/m ² | Kilowatt-hours per square meter |
| kWh/m ² /day | Kilowatt-hours per square meter per day |
| °C | Degree Celsius |
| SS | Stainless steel |
| % | Per Cent |
| ρ | Density |
| ₹ | Rupees |
| Subscripts | |
| a | ambient |
| atm | atmosphere |
| co | cover |
| coa | Cover-ambient |
| cogh | Cover-greenhouse air |
| cosky | Cover-sky |
| td | Tunnel dryer |
| tds (1) | Tunnel dryer air-ground |
| pco | Product-cover |
| ptd | Product- tunnel dryer air |
| r | radiative |
| s(1) | ground |
| s(1)co | Ground-cover |
| s(1)p | Ground-product |
| vent | ventilation |
| Greek letters | |
| ϵ | emissivity |
| σ | Stefan boltzman constnat |
| α | absorptivity |
| ρ | Density, kg/m ³ |
| \bar{C} | transmissivity |
| λ | Latent heat of vaporization, J/kg |

INTRODUCTION

CHAPTER I

INTRODUCTION

Renewable energy sources are available in various forms such as solar energy, wind energy, biomass, etc. Solar energy is the cheapest, inexhaustible and ample source which is a direct form of energy. Solar energy is one of the most abundant renewable energy sources and emits energy at a rate of 3.8×10^{23} kW, of which, approximately 1.8×10^{14} kW is intercepted by the earth which is about 10 times larger than current annual world consumption (Tyagi *et al.*, 2012). In principle, solar energy could supply all the present and future energy needs of the world on a continuous basis. Solar energy is environmentally clean and free source of energy and available in adequate quantities in almost all parts of the world.

For a country like India with its geographical location and plenty of sunshine available in most parts during the year. Solar energy can be one of the most important alternative energies to meet energy needs. India lies between 8°N and 38°S of the equator and therefore has a greater chance of utilizing this freely available source of energy. There are more than 3300 to 3700 hours of bright sunshine per year available in North-West and West coastal regions of the country and 2900 hour over central part of India except Kerala, Kashmir and Assam. In brief, there are nearly 250-300 days per year available to get useful sunshine (Mani, 1992).

Gujarat state is the western most part of India. Gujarat is situated on the western coast of the country having longest coastline of 1600 km. It lies between latitude 20°07' to 24°43'N and longitude 68°10' to 74°29' E. Summers in Gujarat is extremely hot and dry with daytime temperatures reaching around 41°C and night not lower than 29°C. The state is desert-like in the north-west and wet in the southern districts due to a heavy monsoon season. In its latest “Energy Statistics 2011” published by National Statistical Organisation has termed Gujarat as the second-best state of India in the availability of renewable energy sources and termed it as geographically eminently suited for developing solar and wind energy. Gujarat has well above average irradiance (5.5 to 6.5 Kwh/m²) in the country. Higher the insolation, higher is the thermal efficiency of solar power generation (Anon., 2022).

1.1 IMPORTANCE OF MEDICINAL PLANTS

The term, medicinal plants, represents all those plants, which are used for medicinal purposes. All medicinal plants are rich in secondary metabolites which act as potential source of drugs. India and China are the two major producers of medicinal plants, sharing more than 40 per cent of the global production. India is one of the world's 12 biodiversity centres with the presence of over 45,000 different plant species.

India's diversity is unmatched due to the presence of 126 different agro-climatic zones, 10 vegetation zones, 25 biotic provinces and 426 biomes. Global estimates indicate that 80% of about 4 billion population cannot afford the products of the Western Pharmaceutical Industry and have to rely upon the use of traditional medicines which are mainly derived from plant material. As a part of strategy to reduce the financial burden on developing countries, it is obvious that an increased use of plant drugs will be followed in the future. Among ancient civilizations, India has been known to be rich repository of medicinal plants.

Therefore, there is an urgent need to promote and product these fragile knowledge systems and the tribal wisdom. Further, these need to revive, update and link this wisdom with modern science in order to get value added products like medicine, nutraceuticals, cosmeceuticals, etc. for human welfare.

1.1.1 *Moringa oleifera* (Moringa)

Moringa oleifera is a perennial softwood medicinal plant belongs to family *Moringaceae*, consists of 13 species, widely distributed in northern India, Pakistan and Nepal. All the parts of the tree *viz.*, tender leaves, roots, flowers and fruits are consumable. The leaves of moringa are rich in minerals like calcium, potassium, zinc, magnesium, iron and copper. Vitamins like beta-carotene of vitamin A, vitamin B, such as folic acid, pyridoxine and nicotinic acid, vitamin C, D and E are also present in moringa. The leaves of moringa are a good source of calories and proteins as well as ascorbic acid (vitamin C), nicotinic acid and carotene-precursor of vitamin A as well as calcium and iron (Gupta *et al.*, 2016).

Moringa leaves also have a low calorific value and can be used in the diet of obese. Its leaves are used as fresh in salads, cooked or stored as dried powder for long periods with minimum loss of nutrients. Leaves of moringa are also used for treatment of inflammatory conditions, paralysis, hypertension, athlete's foot and tinea.

1.1.2 *Adhatoda vasica* (Ardusi)

Adhatoda vasica is a small evergreen plant, of the *Acanthaceae* family, with broad, lanceolate (sharp and pointed like lance) leaves measuring 10 to 16 cm wide. It is a perennial shrub about 2-3 m tall. It responds well to tropical hot climate to sub-tropical.

Medicinally ardusi has innumerable uses. Ardusi is prescribed in treating bronchitis, tuberculosis, asthma, colds and coughs. It is anthelmintic. A decoction of the leaves of ardusi may be used to help with cough and other symptoms of colds. The soothing actions helps irritation in the throat and the expectorant will help loosen phlegm deposits in the airway.

Dried leaves are smoked and find application in dysentery (Singh and Sharma, 2013). Poultice of leaves is applied on tumours, rheumatism, gout, swellings, wounds, ulcers, urticaria, neuralgia and sciatica. Leaves are also used as antispasmodic in chest diseases. Leaves contain oil and are also rich in vitamin C (Gupta *et al.*, 2016).

1.2 DRYING OF AGRICULTURAL PRODUCE

To ensure food security, major changes are needed to transform current practices of food production, storage, distribution and consumption. As an essential processing operation for safe storage of agricultural products and food, drying plays a critically important role in enhancing global food security. By removing the moisture to a safe level, drying can prevent the growth and reproduction of microbial proliferation, mitigate moisture-mediated deteriorative biochemical reactions, reduce the cost of packaging, transportation, storage and processing, so as to reduce postharvest losses, extend shelf life and increase added value. Inadequate and improper drying may lead to serious losses.

1.2.1 Open Sun Drying

Drying of agriculture products is still the most widespread preservation technique and it is increasingly becoming an alternative to marketing fresh fruits since demand of high-quality dried fruits is increasing all over the world.

Open sun drying is the most commonly used method to preserve agricultural products like grains, fruits and vegetables in most developing countries. Such drying under hostile climate conditions leads to severe losses in the quantity and quality of the

dried product. Mechanical drying is an energy consuming operation in the post harvesting technology of agricultural products, so more emphasis is given on using solar energy sources due to the high prices and shortages of fossil fuels.

In open sun drying, the crop is spread in a thin layer on the ground and exposed directly to solar radiation, wind and other ambient conditions. The working principle of open sun drying is that, the solar radiation falling on the crop surface is partly reflected and partly absorbed. The absorbed radiation and surrounding heated air heat up the crop surface. A part of this heat is utilized to evaporate the moisture from the crop surface to the surrounding air. The part of this heat is lost through radiation (long wavelength) to the atmosphere and through conduction to the ground surface.

Sun drying is the most common method for drying of medicinal crops followed by farmers or processors. Even though, sun drying is a cheap method, they have many disadvantages, viz., long time non-uniform drying, poor quality of final product needs large area, weather dependent, unhygienic drying conditions, losses due to insects, pests and animals. This leads to post harvest losses of the crop during drying.

1.2.2 Solar Drying

Man has used solar energy for drying for time immemorial. Drying of food grains, fruits and vegetables, dry fruits, meat and timber was common practice. In industries, dryers are used for drying of powder, seeds, cloths, paper and large number of agricultural products. Solar drying can be considered as an elaboration to sun drying and is an efficient system of utilizing solar energy. Solar energy is used for drying various industrial and agricultural products in open sun and in solar dryer (Zaman and Bala, 1989; Muhlbauer, 1986).

The purpose of solar drying is to reduce the moisture content of the product to safe level to minimise the deterioration of the quality of the product during storage and to increase the economic return. Drying is essentially simultaneous process of heat and mass transfer. The purpose of solar drying is to provide more heat to the product than is available under normal ambient conditions and maintaining an air flow either by natural convection or forced convection. This will step down the equilibrium moisture content and speed up the removal of the moisture from the product.

Solar drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. Further solar dryers can broadly be

categorized into direct, indirect and specialized solar dryers. The two modes of dryers are:

- a) Forced convection solar dryers
- b) Natural convection solar dryers

The working principle of these modes mainly depends upon the method of solar energy collection and its conversion to useful thermal energy.

1.2.2.1 Forced convection dryer

In a forced convection dryer, the crop is not directly exposed to solar radiation to minimize discolouration and cracking on the surface of the crop. The forced convection dryer air is heated in collector and is forced on to the drying material through external means like fans or pumps. These dryers are often known as active mode solar dryers.

A forced convection dryer has a solar air heater or collector placed at such an angle to optimize solar energy collection. Tilting the collectors is more effective than placing them horizontally because more solar energy can be collected when the collector surface is nearly perpendicular to the sun's rays and by tilting the collectors, the warmer, less dense air rises naturally into the drying chamber. In forced convection dryers, the solar-heated air flows through the solar drying chamber in such a manner as to contact as much surface area of the produce as possible. Leafy agriculture produces and thinly sliced food materials are placed on perforated drying trays. As heated air is forced into drying chamber through several layers of produce on trays, it becomes moisture laden. This moist air is vented out through the outlet port. Fresh air is then taken in to replace the exhaust air. Forced convection type solar dryers are known to be suitable for higher moisture content products such as papaya, kiwi fruits, brinjal, cabbage and cauliflower slices and such dryers are comparatively efficient, faster and can be used for drying large agricultural products.

1.2.2.2 Natural convection dryer

Natural convection type solar dryer essentially consists of an enclosure for keeping the products to be dried with a transparent cover placed over the enclosure. The internal surfaces of the enclosures are painted black. The evaporation of moisture from the product takes place due to direct absorption of solar radiation by the product as well

as transfer of heat by the internal surface, which get heated by the radiation incident on them. Here, ultimately removal of moisture takes place through naturally created draft. Some of the advantages of natural convection dryer is that, they require a smaller area of land in order to dry similar quantities of crop that would have been dried traditionally over large land areas in the open. They yield a relatively high quantity and quality of dry crops because fungi, insects and rodents are unlikely to infest the crop during drying. The drying period is shortened compared with open air drying, thus attaining higher rates of product throughput. They have relatively low capital and maintenance costs so it is commercially viable, moreover, the crop is protected from sudden down pours of rain.

1.2.2.2.1 Solar tunnel dryer

A solar tunnel dryer is a poly house framed structure covered with 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 solar radiation which is the propagation of energy come out of sun, travel as a short-wave radiation through the atmosphere falls on the transparent cover UV-stabilized polyethene sheets and enters into the dryer. It is absorbed by the materials which are present inside the tunnel dryer and in turns emits long-wave radiation which trapped inside the dryer. This results in trapping of radiation within the solar tunnel dryer and subsequent temperature rise. This particular effect is called greenhouse effect and this basic principle is utilized in all solar thermal collectors. The solar tunnel dryer is very useful in all types if climatic conditions (Shinde, 2009).

1.3 IMPORTANCE OF MATHEMATICAL MODELLING

Simulation models are needed in the design, construction and operation of drying systems (Gokhan *et al.*, 2008). The prediction of drying rate of specific crops under various conditions is of importance for the design of the drying systems. Fullscale experimentation for different products and systems configuration is sometimes costly and not possible. The use of a simulation model is a valuable tool for prediction of performance of solar drying systems (Steinfeild and Segal, 1986).

In the present study efforts were made to develop mathematical model to predict the hourly variation in solar tunnel dryer environment, i.e., temperature of cover, enclosed air inside the dryer, commodities namely, *Adhatoda vasica* and *Moringa Olifera*, tray temperature, floor temperature and relative humidity of enclosed air for different operating conditions.

1.4 PRACTICAL UTILITY

Post-harvest losses of leafy medicinal plant are about 30 to 40 % during various post-harvest operations. Drying is the most important post-harvest operation among all the post-harvest operations. Presently, traditional direct sun drying is used for drying of leafy medicinal plants. Traditional sun drying has many disadvantages, viz., weather dependent, require larger area, longer drying time, unhygienic, inferior quality of final product and damage by insects, pests, birds, animals, etc. It is estimated that postharvest losses during this traditional sun drying method was about 20 to 25 % in terms of qualitative and quantitative loss. Furthermore, the storability of sun-dried product is also poor and promotes microorganism growth due to uneven moisture of the stored product.

Blanching is one of the most promising pre-treatments prior to drying of leafy medicinal plants. Hot water blanching prior to drying has several benefits, viz., colour, texture, flavour, odour, taste, disease free and better retention of nutrients in final dried product. Blanching prior to drying increases the drying rates and reduces drying time. The solar tunnel dryer is one of the promising options for drying various medicinal plants on large scale. The drawbacks of traditional sun drying could be eliminated by adopting solar tunnel drying of leafy medicinal plants. The advantage of solar tunnel dryer is its relatively faster drying, better quality product, needs less area, hygienic product, least contamination and low operational cost. Furthermore, drying of medicinal product by solar tunnel drying minimizes the post-harvest losses as compared to traditional sun drying.

At present mechanical dryers available are of high capacity, costly and operated by fossil fuels, electric energy, etc. Hence, there is a need of simple, low cost on farm solar tunnel dryer for drying of freshly harvested medicinal plants, viz., *Adhatoda vasica* and *Moringa oleifera* leaves.

Objectives:

- 1) To study the diurnal variation of micro-climate of the dryer.
- 2) To evaluate the techno-economic performance of solar tunnel dryer.
- 3) To analyse the biochemical, physical and functional properties of dried products.
- 4) To carry out the thermal analysis of solar tunnel dryer and develop mathematical model.

REVIEW
OF
LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with a review of literature on medicinal plants, blanching, sun drying, solar tunnel dryer, drying of medicinal plants and techno-economic analysis and mathematical modelling of solar tunnel dryer. A brief review on the available information is presented in following subsection as mentioned hereunder.

2.1 CHEMICAL COMPOSITION OF MEDICINAL PLANTS

Medicinal plants naturally synthesize and accumulate biologically active secondary metabolites, like alkaloids, sterols, terpenes, flavonoids, saponins, anthraquinones, glycosides, volatile oils, etc. that have been extracted and used in different forms such as infusions, syrups, concoctions, decoctions, infused oils, essential oils, ointments and creams for the well-being of human life (Sharma *et al.*, 2018).

2.1.1 *Adhatoda vasica* (Ardusi)

The leaves of the plant contain the alkaloid vasicine ($C_{11}H_{12}N_2O$), which is responsible for the small but persistent bronchodilatation and an essential oil which is chiefly responsible for the expectorant action (Sarker *et al.*, 2011).

The phytochemical analysis shows that phenols, tanins, alkaloids, anthraquinone, saponins flavonoids and reducing sugars were found in the leaves of ardusi. But the pharmacologically most studied chemical component in *Adhatoda vasica* is bitter quinazoline alkaloid, vasicine (1,2,3, 9-tetrahydropyrrole [2, 1-b] quinozolin-3ol, $C_{11}H_{12}N_2O$) which is present in the leaves, roots and flowers. Besides vasicine, the leaves contain several alkaloids, betaine, steroids and alkanes (Dhankhar *et al.*, 2011).

This study evaluated that ardusi leaves contains an appreciable amount of phytol (3,7,11,15- tetramethylhexadec-2-en-1-ol) which is a diterpene and thus the essential oil may find extensive applications for antimicrobial activity (Shukla *et al.*, 2016).

The chemical compounds found in *Adhatoda vasica* plant includes essential oils, fats, resins, sugar, gum, amino acids, protein and vitamin C. the phytochemical analysis show that phenols, tanins, alkaloids, anthraquinone, saponins, flavonoids and

reducing sugars were found in the leaves of the plant. The leaves contain two major alkaloids called vasicine and vasicinone (Sharma *et al.*, 2018).

2.1.2 *Moringa oleifera*

In the study, Lutein was identified as the major constituents of leaves and fruits accounting for 53.6 and 52.0% of the total carotenoids. Furthermore, the β -sitosterol, total phenolic and flavonoid compounds in the leaves of moringa were reported as 90 mg/g, 8 μ g/mL and 27 μ g/mL respectively. The leaves of moringa were also reported to contain chlorophyll a, chlorophyll b, vitamin C, carotenoids, proteins, amino acids and minerals (Ragasa *et al.*, 2015).

Moringa contain various phytoconstituents such as alkaloids, saponins, tanins, steroids, phenolic acids, glucosinolates, flavonoids and terpenes (Rani *et al.*, 2018).

The leaves of moringa are rich in minerals like calcium, potassium, zinc, magnesium, iron and copper. Vitamins like beta-carotene of vitamin A, vitamin B such as folic acid, pyridoxine and nicotinic acid, vitamin C, D and E also present in moringa. Moringa leaves have low calorific value and can be used in diet of the obese. Moringa leaves contain fibre, fat, fat proteins and minerals like calcium, magnesium, phosphorous, potassium, copper, iron and sulphur. Vitamins like vitamin A (betacarotene), vitamin B-choline, vitamin B1- thiamine, riboflavin, nicotinic acid and ascorbic acid are present (Gopalakrishnan *et al.*, 2016).

The *M. oleifera* leaves are rich source of omega-3 and omega-6 polyunsaturated fatty acids (PUFAs), in the form of α -linolenic acid (49-59%) and linoleic (6-13%) and unsaturated fatty acid in the form of palmitic acid (16-18% of the total fatty acids) (Saini *et al.*, 2016).

2.2 IMPORTANCE OF MEDICINAL PLANTS

The medicinal plants selected for this project are *Adhatoda vasica* (Ardusi) and *Moringa oleifera* (Moringa).

2.2.1 *Adhatoda vasica* (Ardusi)

Adhatoda vasica belonging to the family Acanthaceae is found throughout the plains of India and in the sub-Himalayan tracts upto 4,000 feet (Chopra, 1956). It is popularly known as *vasaka* and is one of the most important Indian medicinal plants used in ayurvedic system of medicine, especially for respiratory ailments.

Chopra (1956) recorded medicinal values of leaves and roots of *A. vasica* in cough, chronic bronchitis and asthma. The authors also mentioned antiseptic property of its flowers, leaves and roots and insecticidal value of its leaves. The leaves were slated to contain an alkaloid vasicine.

Chakraborty and Brantner (2001) investigated the anti-inflammatory activity of methanol extract, the non-alkaloidal fraction, alkaloids and saponins of *A. vasica* leaves by the modified hen's egg chorioallantoic membrane test. They observed potent anti-inflammatory equivalent to that of hydrocortisone by the alkaloidal fraction as compared to methanol extract and other fractions, which showed less anti-inflammatory activity.

Kumar *et al.* (2007) studied the leaf extract *Adhatoda vasica* which showed radio modulatory influence against radiation-induced haematological alterations in peripheral blood of swiss albino mice. Significant increase in serum alkaline phosphatase activity was observed in leaf extract pretreated irradiated animals during the entire period of study.

Jahangir *et al.* (2006) investigated antimutagenic and antioxidant potential of *Adhatoda vasica* leaves extract. The extract produced antioxidant effect against lipid peroxidase and xanthine oxidase-induced oxidation.

Shrivastava *et al.* (2006) studied *Adhatoda* for its anti-ulcerogenic activity against ulcers induced ethanol, pylorus and aspirin. *Adhatoda* leaf powder showed considerable degree of anti-ulcer activity in experimental rats when compared with controls. The highest degree of activity was observed in ethanol-induced ulceration model, thus suggesting that *Adhatoda* has immense potential as an anti-ulcer agent. *Adhatoda vasica* has been used for the treatment of respiratory disorders namely acute and chronic cough, bronchitis and asthma. It is also used as an expectorant in the treatment of acute and chronic bronchial catarrh and pulmonary diseases.

Singh and Sharma (2013) found that the leaves, as well as, the flowers, fruits and roots are extensively used for the treatment of cold, whooping cough, asthma and as anthelmintic and the leaf extract is known to cure diarrhoea, dysentery and glandular tumour. The different parts of the plant are used in the Indian traditional medicine for the treatment of various diseases like asthma, joint pain, lumbar pain and sprains, cough, eczema, malaria, rheumatism, swellings, venereal diseases. In homeopathy, *A.*

vasica has been used in the treatment of cold, cough, pneumonia, spitting of blood, fever, jaundice, catarrh, whooping cough and asthma.

Amber (2020) reported that, *Adhatoda vasica* commonly known as *vasaka* is a well-known medicinal plant widely used in Unani and Ayurvedic system of medicine. All the parts of the plant have been used for their therapeutic effects from ancient times, particularly in upper respiratory tract diseases such as bronchitis and asthma. The plant has been used in the indigenous system of medicine in India for over 2000 years. The leaves of *Justicia adhatoda* contains phytochemicals such as alkaloids, tannins, saponins, phenolics and flavonoids. The most important is vasicine, a quinazoline alkaloid. The vascine yield of the herbage has been measured as 0.541 to 1.1% by dry weight. It has a number of traditional medicinal uses in Siddha medicine, Ayurveda, Homeopathy and Unani medicine.

2.2.2 *Moringa oleifera*

Fahey (2005) reported that, *Moringa oleifera* is the sole genus in the flowering plant family *Moringaceae*. The genus *Moringa* is made up of 13 species. The species most common, and which is the main subject of this study is the species called “*Moringa oleifera*”. *Moringa oleifera* is found in many tropical and sub-tropical regions. All parts of moringa tree are edible and have long been consumed by humans.

Oral administration of aqueous and alcoholic extracts of *Moringa* root-wood on calcium oxalate urolithiasis was studied in male wistar albino rats. Ethylene glycol feeding resulted in hyper-oxalourea as well increased renal excretion of calcium and phosphate. Increased deposition of stone forming constituents in kidneys of calculogenic rats was also significantly lowered by curative and preventive treatment using aqueous and alcoholic extracts. The results clearly suggested that the root-wood of *Moringa oleifera* is endowed with anti-urolithiatic activity (Karadi *et al.*, 2006).

Moringa oleifera is an important food commodity which has enormous attention as the “natural nutrition of the tropics”. The leaves, fruits, flowers and immature pods of this tree are used as a highly nutritive vegetable in many countries, particularly in India, Pakistan and Philippines (Anwar and Rashid, 2007). People in India have been using it as item of their daily food for nearly 5000 years (Patel *et al.*, 2010). Almost every part of this plant including bark, root, gum, leaf, fruit (pods), flowers, seed and

seed oil have been used for the treatment of various ailments in the indigenous system of medicine (Farooq *et al.*, 2012).

Moringa has been found to contain many essential nutrients, such as vitamins, minerals, amino acids, beta-carotene, antioxidants and omega 3 and 6 fatty acids. Various aqueous and alcoholic extracts of moringa leaves have been found to show significant cholesterol lowering action, antiulcerogenic effects, hepatoprotective effects, anti-tumor activity, anticancer activity, anti-inflammatory effects, antioxidant activity, antimicrobial properties and anti-diabetic properties (Razis *et al.*, 2014).

It was found that various aqueous and alcoholic extracts of Moringa leaves have been found to show significant cholesterol lowering action, antiulcerogenic effects, hepatoprotective effects, anti-tumor activity, anti-cancer activity, anti-inflammatory effects, antioxidant activity, antimicrobial properties and antidiabetic activities (Tilakaratne *et al.*, 2015).

Every part of *Moringa oleifera* is a storehouse of important nutrients and antinutrients. *Moringa oleifera* leaves act as a good source of iron, calcium, phosphorous, copper, vitamins A, B and C, α -tocopherol, β -carotene, β -sitosterol, and essential amino acids (Gopalakrishnan *et al.*, 2016).

Moringa leaf powder is a good source of vitamin A, B and C, protein, calcium, magnesium, potassium, selenium, zinc and essential amino acids and it is recommended for infants and nursing mothers across the length and breadth of the continent. Besides rich nutritional value, it also has impressive curative and pharmacological properties like cardiac and circulatory stimulants, anti-tumour, anti-pyretic, anti-inflammatory, anti-spasmodic, diuretic, anti-hypertensive, anti-diabetic, hepato-protective, antibacterial and anti-fungal properties (Tamilselvi *et al.*, 2018).

2.3 BLANCHING

Presently, blanching of leafy medicinal plant is an important pre-treatment for the quality enhancement in terms of colour, texture, aroma, test, flavour as well as better retention of antioxidants, volatile compounds, water soluble vitamins, minerals, flavonoids, etc.

Rocha *et al.* (1993) and Singh *et al.* (1996) found that blanching treatments resulted in better retention of chlorophyll in basil, marjoram and rosemary. Kidmose and Martens (1999) reported that unblanched frozen carrots had an off-taste caused by

release of fatty acids due to esterase activity. Ramesh *et al.* (1999) observed that the carotenoid in blanched red chilli dramatically increased as compared to un-blanched red chilli. These showed that better retention of carotenoid in blanched red chillies.

The leaching or diffusion of ascorbic acid in hot water blanching process can be positively influenced by the solid content of water, therefore, the recycled water with a high content will lead to less loss (Arroqui *et al.*, 2001). This assertion has been confirmed by Arroqui *et al.* (2002) who observed that the retention of ascorbic acid was higher when potatoes were blanched in recycled hot water than when they were blanched in distilled water.

Hossain *et al.* (2007) observed a faster drying rate and high colour value in red chilli samples that have been blanched. Pimpaporn *et al.* (2007) found that hot water blanching as a pre-treatment had a more significant effect on reducing the red colour of the potato chips than the pre-treatment using freezing and the immersion in monoglyceride and glycerol.

Blanching process used temperature 85°C for 7.5 minutes can decrease saponins content of *Moringa* leaves to the lowest content amount 3.9%, but still preserve protein content amount 25.08%, vitamin C content amount 84.68 mg/100 g and increase vitamin A amount 3600 µg/100 g (Indriasari and Kumalaningsih, 2016).

2.4 DRYING OF MEDICINAL PLANTS

Drying is the most common and fundamental method for post-harvest preservation of medicinal plants because it allows for the quicker conservation of the medicinal qualities of the plant material in an uncomplicated manner. Quality distinction was already made some 4000 years ago in ancient Egypt between medicinal plants dried in the sun and those dried in the shade (Heeger, 1989).

Food drying is one of the oldest methods of preserving food for later use. It is a complex operation involving heat and mass transfer which may cause changes in product quality. Physical changes that may occur include shrinkage, puffing and crystallisation. In some cases, desirable or undesirable chemical or biochemical reactions may occur leading to changes in colour, texture, odour or other properties of the food product. Drying can either be an alternative to canning and freezing or complement these methods. Drying occurs by vaporisation of the liquid by supplying heat to the wet feedstock. Heat may be supplied by conduction (contact or indirect

dryers), by convection (direct dryers), by radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85% of industrial dryers are of convective type with hot air or direct combustion gases as the drying medium (Mujumdar and Devahastin, 2000).

Drying is one of the most antique, fundamental and critical unit operations in the post-harvest processing of medicinal plants. It basically aims at decreasing of plant moisture content, preventing enzymatic and microbial activity and subsequently preserving the product for extended the shelf life. Energy demand during the drying process is a significant factor due to a high moisture content in the fresh material. The drying method, velocity and temperature of drying air highly influence the quality of the active ingredients present in medicinal plants (Muller and Heindl, 2006).

2.4.1 Open Sun Drying

Natural drying, i.e., drying without auxiliary energy either in the field or in sheds, should only be considered for drying small quantities. In case of mass production, the use of technical drying applications is indispensable. For the preservation of active ingredients of medicinal plants materials, comparatively low drying temperatures are recommended and, as a result, the drying duration is comparably long. Drying represents 30-50% of the total cost in medicinal plant production and, therefore, it is crucial that factors determining high costs are identified. Currently energy demand of drying represents a significant cost factor, especially with increased price of fossil fuel. This is largely due to the high moisture content of flowers, leaves or roots to be dried (Qaas and Schiele, 2001).

2.4.2 Solar Drying

Rathore *et al.* (2004) designed and developed natural convection cabinet dryer for drying Di-basic Calcium Phosphate (DCP). This is an odourless mineral based inorganic compound widely used for supplementing phosphorous and calcium to animals along with their feed. A prototype of natural convection cabinet type solar dryer having floor area of 9.5×4.5 m for drying of 50 kg of wet DCP per batch from moisture content 35% to 15% (wb). It consisted of bricks and hollow cement sand block structure, flat plate solar collector and an electrically operated exhaust fan removing the moisture air from the drying cabinet.

Janjai and Tung (2005) developed a solar dryer for drying the herbs and spices using hot air from roof integrated solar collectors. The dryer is a bin type (1m × 2m × 0.7m) with a rectangular perforated floor. Hot air is supplied to the dryer from fibreglass covered solar collectors, which also function as the roof of a farmhouse. The total area of the solar collector is 72 m². The dryer can be used to dry 200 kg of rosella flowers and lemon-grasses within four and three days respectively. The products being dried in the dryer were completely protected from rains and insects and the dried products are of high quality. The solar air heater has an average daily efficiency of 35 per cent and it performs well both as a solar collector and as a roof of a farmhouse.

Singh *et al.* (2021) carried out experiments in the solar dryer for drying fenugreek leaves. The ascorbic acid, total chlorophyll content and colour of the dried samples were found to be better compared to open sun drying.

2.4.2.1 Solar tunnel dryer

Lutz *et al.* (1987) developed a multipurpose solar crop dryer for drying various agricultural products such as fruits, vegetables, medicinal plants, etc. the newly developed system made up of a small fan, a solar air heater and a tunnel dryer. The simple design was suitable for farmers as well as small scale industries, using cheap and locally available materials. Due to the low investment required, the solar dryer was predestined for application on small farms in developing countries. Depending upon the crop to be dried and the size of the dryer 100-1000 kg of fresh material could be dried within 1-7 days to safe storage conditions. Compared to traditional sun drying methods, the use of the solar dryer reduced drying time significantly and prevented mass losses. During drying, the crop was protected completely from rain, dust, insect and animals. All these features contributed to the desired high product quality. The energy cost required for operating the fans were negligible compared to the additional earnings from reduced mass losses and improved the quality.

Muller *et al.* (1989) developed a solar heated dryer for medicinal plants and herbs. To lower the expenses of the required building, the drying system was incorporated into a commercially available low-cost plastic film greenhouse structure. In contrast to conventional plastic film greenhouses, this greenhouse had vertical side walls and a saddle roof. The solar air heaters were incorporated into the roof and consisted of a black absorber tissue, which was placed between the transparent cover

of the greenhouse and an insulating air bubble foil. To obtain a modular design, the system was structured along the ridge into segment of 2 m width. Each segment formed an independent solar air heater or batch dryer unit and was operated by a fan with a power consumption of 500W. A prototype was tested in Yugoslavia, drying mint, sage and hops. The drying process from an initial moisture content of 80% (wb) to a final moisture content of 11% (wb) took 3-4 days. The loading capacity was 250-500 kg fresh material per segment. Maximum temperatures have been within a range of 40-60°C. Compared to conventionally dried crude drugs; the percentage of active ingredients was up to 40% higher. The low investment and operating cost and the high quality of the crude drugs permit the solar dryer to be used in agriculture.

Esper and Muhlbauer (1996) found that use of solar tunnel dryer leads to considerable reduction of drying time and significant improvement of product quality in terms of colour, texture and taste as compared to natural sun drying. The performance of the solar tunnel dryer was significantly dependent on the weather conditions. Both the heat required for removing the moisture as well as the electricity necessary for driving the fans were generated by solar energy only. The drying time was short under sunny conditions and accordingly extended during adverse weather conditions. The influence of the weather conditions on the quality of the dried product is under normal circumstances negligible.

Bala *et al.* (2003) carried out field level experiments on solar drying of pineapple using solar tunnel drier at Bangladesh Agricultural University, Mymensingh, Bangladesh. The drier made up of transparent plastic covered flat plate collector and a drying tunnel connected in a series to supply hot air directly into the drying tunnel using two dc fans operated by a solar module. The loading capacity of the dryer was 120-150 kg of pineapple. Total eight drying runs were conducted. In all the cases, they found that the use of solar tunnel drier leads to considerable reduction of drying time in comparison to sun drying. The pineapple being dried in the solar tunnel drier were completely protected from rain, insects and dust, and the quality of the pineapple dried in the tunnel drier was higher as compared to sun dried products. Proximate analysis also showed that the pineapple dried in the solar tunnel drier was a good quality dried product.

Joshi and Gewali (2007) determined the thermal efficiencies of different types of solar dryers installed at different parts of the Nepal. They evaluated the performance

of solar dryers by using simple basic energy balance equations. All mathematical expressions related to energy interactions were expressed in simple and separate forms. Data obtained from twenty laboratories as well as outdoor field tests have been used in the calculation of thermal efficiencies. Tests were carried out on 12 different solar dryers including 3 solar cabinet dryers, 6 solar rack dryers, 2 solar tunnel dryers and 1 hybrid/biomass rack dryer. The maximum value of thermal efficiency obtained from these tests was found as 22.1% for solar cabinet dryer, 21.4% for solar rack dryer and 21.7% for solar tunnel dryer.

Seveda and Rathore (2007) developed a walk in type semi-cylindrical poly house for drying Di- basic Calcium Phosphate for 1.5 tons capacity at the M/s Phosphate India Pvt. Limited, Udaipur. The dryer has been covered with UV stabilized semi-transparent polythene sheet of 200-micron thickness. Gradient of 5-7° has been provided along the length of the tunnel to induce natural convection airflow. The orientation of solar tunnel dryer was in east-west direction. During testing air temperature in the solar tunnel dryer was found higher than outside by 15-20°C during sunshine hours and the moisture content of wet Di-basic calcium phosphate was reduced from an initial value of 38-40% to around 10-12% in 18 hours or 16 hours depending upon solar insolation.

Arzoo and Yadav (2017) evaluated the performance of walk-in type solar tunnel dryer (10×3.75×1.98 m) for chili, garlic, fenugreek and aonla candy. A temperature of 15-30°C higher than the atmospheric temperature was recorded inside the dryer. The STD reduces the moisture content of chilli from 77% to 7% (wb) in 7 days, garlic from 65% to 8.5% (wb) in 8 days, fenugreek from 86% to 7.2% (wb) in 5 days and aonla candy from 44% to 16% (wb). STD dried products were of good quality, hygienic and highly acceptable as compared to direct sun drying. It was observed that compared to other modes of conventional drying process, the solar drying is the most significant one and offers the following merits such as less operational cost, non-polluting process, minimizes the physical and chemical reactions, improve qualities of dried product, temperature is controllable, it can be used for direct and indirect heating and thermal energy can be stored during no sunshine hours.

Mahesh (2016) observed that the initial mass of onion was 4000 gm and is reduced up to 600 gm within 11 hours in solar tunnel dryer as compared to open sun

drying, which required 18 hours and moisture content was reduced from 85% to 15% (wb).

Mehta *et al.* (2017), analysed the drying systems with the solar and open sun drying systems. The quality parameters of the various dried products like vitamin A, vitamin C, polyphenol and flavonoids were higher with the solar drying system.

Shalaby *et al.* (2020) investigated the solar drying process of sweet basil leaves and concluded that the volatile organic compounds were found higher than those in the open sun-dried samples. Hidar *et al.* (2020) carried an investigation for drying of stevia leaves in a solar dryer and found a decrement in the phenolic, chlorophyll content of the dried samples with increased drying temperature.

2.5 TECHNO-ECONOMICS OF SOLAR TUNNEL DRYER

Mumba (1995) carried out an economic analysis on a drier with a passive drying-air temperature control for use on farms was observed and found that, drier has a pay-back period of less than one year and is cost-effective for a photovoltaic to solar air-heater area ratio of about 0.22.

Sevada and Rathore (2004) evaluated techno-economics of solar tunnel dryer installed at an industry. The net present worth for commercial solar tunnel dryer was Rs. 78,74,500/- whereas for diesel fired electrical drier it was Rs. 36,52,500/-. The benefit cost ratio for solar tunnel dryer and diesel fired electrical dryer was found to be 7.08 and 2.56 respectively. The payback period of solar tunnel dryer and diesel fired electrical dryer was 10 months and 2.9 years, respectively.

Jain *et al.* (2004) worked out the techno-economic evaluation of a forced convection solar dryer. A forced convection type solar dryer consisting of a flat plate collector panel, a drying chamber and two blowers was used for drying of groundnut, ginger and garlic in comparison to an electrically operated tray type mechanical dryer. The experiment and economic analysis of solar dryer has revealed that the solar dryer could be used effectively for drying of ginger, garlic and groundnut and had better economics than mechanical drying system. It is recommended that construction and use of solar drying system be encouraged for obtaining high value dried products and for generating additional income for the farmers/entrepreneurs. The benefit cost ratio for the solar dryer and mechanical dryer were found to be 1.56 and 1.18, respectively.

2.6 MATHEMATICAL MODELLING OF SOLAR TUNNEL DRYER

The prediction of drying rate of specific crops under various conditions is of importance for the design of the drying systems. Full-scale experimentation for different products and systems configurations is sometimes costly and not possible. The use of a simulation model is a valuable tool for prediction of performance of solar drying systems (Steinfeild and Segal, 1986).

Gaur (1993) conducted microclimatic studies in plastic greenhouse during winter season for an unventilated uncontrolled greenhouse of semi-circular shape using ultra violet stabilized sheet as cladding material. It was found that on an average 17°C higher maximum temperature from the outside conditions could be achieved during winter season. The difference in soil temperature between inside and outside the greenhouse at 5 cm depth (4.5°C) was higher than the difference in soil temperature at 10 cm depth (1.85°C) recorded at 7.35 hours while the soil temperature recorded at 14.35 hours showed the reverse trend. The minimum relative humidity under greenhouse conditions was always higher as compared to the corresponding values for outside conditions. No significant relationship was observed between maximum relative humidity inside and outside the greenhouse. Both the minimum and maximum solar radiation flux densities were around 33 per cent higher in outside conditions as compared to greenhouse conditions.

Jolliet (1994) developed the HORTITRANS model, predicting greenhouse relative humidity, crop transpiration rates and energy cost based on exterior climatic conditions. This model predicted the humidity and transpiration directly as a function of the outside climate, with the particular objectives of developing optimal control strategies for humidity in greenhouse. The developed model includes the processes of transpiration, condensation, ventilation and humidification and dehumidification. The model allows the inside vapour pressure to be directly calculated as a function of the outside conditions and the greenhouse characteristics.

Vollebregt and Braak (1995) developed a calculation method to analyse the heat flows of a greenhouse wall by combining steady state heat balance calculations and a simulation model of the airflow near the wall and the adjacent heating system. Heat exchanger by radiation between the wall heating pipes, interior and exterior of the greenhouse were taken into account by deriving radiation absorption factors from the

geometry and optical properties of the surfaces. Convective heat transfer coefficients at the wall were determined with an airflow simulation program. Comparing simulation results of detailed problems with data from literature valid the accuracy of the simulation modelling technique used. The analysis showed that about 20 per cent of the heat released by the heating pipes near the wall, is radiated towards and absorbed by the wall and about 30 per cent of the total heat loss through the wall is compensated by radiative exchange from the greenhouse interior.

Lee *et al.* (2002) developed a Computational Fluid Dynamics (CFD) model to investigate the effect of roof vent opening on natural ventilation of fully open-roof multi-span greenhouses. Using the Particle Image Velocimetry (PIV) data, the CFD validity was preferentially investigated. The results showed that the internal airflow of the CFD were very similar with the PIV computed airflow patterns. Considering the averaged air velocity vertically under the middle gutter of 2-span greenhouse, the errors of the CFD computed results were 33.6, 18.2 and 13.5% respectively for the external wind speeds of 3.5, 4.4 and 6.3 m/s at gutter height. It was assumed that the 2-dimensional input of the wind profile in the CFD model might cause the positive error compared to the PIV computed results. As the external wind speed increased, the strong incoming airflow stream moved from right to left at the second roof vent. As the number of the span increased over six, the error became mostly less than 10%.

Kumar and Tiwari (2006) dried jaggery in a natural convection greenhouse drying system and modelled the system thermally. With the created model, they tried to estimate the temperature of the dried product, air temperature of the greenhouse, amount of vaporized moisture and thermal performance of the greenhouse depending on the intensity of the radiation and the ambient temperature; and validated the results obtained with the experimental results. They found that the obtained model offered good results.

Goyal *et al.* (2007) conducted experiment on mathematical modelling of thin layer drying kinetics of plum in a tunnel dryer. Drying kinetics of plum in a tunnel dryer was studied at 55, 60 and 65°C air temperatures. Drying of plum slices followed falling rate period. It was found that treated plum slices dried faster. Six thin layer drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of plum slices with high R^2 values. The effective moisture diffusivity of plum

increased as the drying air temperature increased. The moisture diffusivity values were higher for treated samples than the control.

Prakash and Kumar (2014) created an Adaptive Neural Fuzzy Inference System (ANFIS) model, which is a neural fuzzy system, to estimate product temperature, greenhouse air temperature and amount of vaporized moisture during the drying of the same product in a natural convection greenhouse drying system. In order to ascertain the suitability of the model, they obtained its validity and observed that the ANFIS model predicted different drying parameters for the experimentally dried jaggery product.

MATERIALS
AND
METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the methodology adopted for experiment, viz., details of solar tunnel dryer, instrumentation, experimental details, micro-climate variations under no load and full load condition, performance evaluation of solar tunnel dryer, development of a mathematical model for thermal analysis and economic analysis of solar tunnel dryer. The details of materials, procedures and methodology adopted are discussed hereunder in the following sub-sections.

3.1 DETAILS OF SOLAR TUNNEL DRYER

A solar tunnel dryer constructed at the Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh was used for the drying experiments. The drying of medicinal plants, namely, *Adhaoda vasica* (Ardusi) and *Moringa oleifera* (Moringa) was carried out using the constructed solar tunnel dryer. The techno-economic analysis was done along with its thermal analysis by developing a mathematical modelling. The different components of the developed solar tunnel dryer along with its materials and constructional details are mentioned hereunder. The specifications of different components of dryer are also mentioned in Table 3.1.

Table 3.1 Details of solar tunnel dryer

| Sl. No. | Components | Details |
|---------|------------------------------|--|
| 1. | Type of dryer | Natural convection type solar tunnel dryer |
| 2. | Dryer dimension | 10 m x 5 m x 2.5 m |
| 3. | Shape | Hemi-cylindrical |
| 4. | Size of tray | 0.70 m x 0.70 m x 0.05 m |
| 5. | Number of trays | 64 (16 trays per stand arranged in two tier) |
| 6. | Total number of trays stands | 4 |

| | | |
|-----|--------------------------------------|--|
| 7. | Total volume of 64 trays | 1.57 m ³ |
| 8. | Number of air vents | 5 |
| 9. | Air vent dimension | 16.5 cm x 16.5 cm |
| 10. | Number of turbo fan | 2 (size:16.5 cm x 16.5 cm) |
| 11. | Number of exhaust fan | 2 (0.557 hp, 1400 rpm) |
| 12. | Solar tunnel dryer covering material | UV stabilized 200 μ polyethylene sheet |

3.1.1 Major Components of Solar Tunnel Dryer

3.1.1.1 RCC platform

RCC platform of size 10.80 m (L) x 5.80 m (W) x 0.70 m (H) was provided as a robust base for solar tunnel dryer of size – 10 m x 5 m x 2.5 m. The height of RCC platform was 0.70 m to protect the entire solar tunnel dryer structure during heavy rainfall. A layer of thermocol (polystyrene) sheets of 40 mm thickness was laid 6 inches below the top of solar tunnel dryer platform for insulation purpose. Top of platform was plastered by 15 cm thick cement mortar plaster. 12 no. of square GI pipes of size 50 mm x 50 mm x 2 mm having length of 15 inches (6 on each side, placed 2 m in length wise and 5 m in width wise on RCC platform) were reinforced to hold the six arcs of GI square pipes (40 mm x 40 mm x 1.2 mm) (Plate 3.1).

3.1.1.2 Solar tunnel dryer structure

The constructed solar tunnel dryer had six arcs made of GI pipe (40 mm x 40 mm x 1.2 mm), which was inserted, riveted and welded in square GI pipes (50 mm x 50 mm x 2 mm), i.e., foundation reinforced pipes. All the sides of STD structures were supported with square GI pipes of (35 mm x 35 mm x 2 mm). On the north side of the STD structure, a north wall of 3.5 feet made of GI sheet (22 gauge) was provided, which was painted with black colour to minimize heat losses. Back side of the north wall was insulated with 40 mm thick polystyrene sheet throughout the entire length (i.e., 10 m) of tunnel dryer. The entire structure was covered with a UV stabilized thermic clear plastic cladding film of 200 μ thickness to get the maximum advantage of incident solar radiation. The floor of solar tunnel dryer was painted black to absorb incident solar radiation more efficiently (Plate 3.2 (a) and (b)).

3.1.1.3 Drying tray with stand

The size of drying tray was 0.70 m (L) x 0.70 m (B) x 0.05 m (H) with net volume of 0.0245 m³. Total number of 64 trays were used for the drying experiments. The side support in the form of angle (size: 50 mm x 20 mm x 0.8 mm) of the drying tray was provided (SS 202), whereas wire mesh (700 mm x 700 mm) was of SS 304 grade with 10 to 11 perforations per inch. The wire mesh was fit in the angle frame with spot welding. Additional strip of SS 202 material was also spot welded at the four corners of drying tray to give more strength. The drying tray stand main frames were made of 35 mm x 35 mm x 2 mm square GI pipes, whereas side of the main frame was supported with by 25 mm x 25 mm x 1.2 mm square GI pipes. Total 4 stands were used to accommodate 64 drying trays, i.e., each stand accommodates 16 numbers of drying tray (700 mm x 700 mm x 50 mm) in two tiers (8 no. in upper tier and 8 no. in lower tier) (Plate 3.3).

3.1.1.4 Turbo fan and air vents

Total 5 square air vents facing towards south side of the STD of size 16.5 cm x 16.5 cm were provided to allow ambient air inside the STD. Turbo fans were also provided at the top of the solar tunnel dryer to exhaust the inside air (Plate 3.4).

3.1.1.5 Exhaust fan

Two exhaust fan (0.557 hp, 1400 rpm) were provided to maintain temperature and humidity level inside the tunnel dryer. In addition to this, two turbo fan were mounted on the top of solar tunnel dryer to exhaust the air inside the tunnel dryer (Plate 3.5).

3.1.1.6 Electric supply

All the electric fittings and their extension cables were installed for the power supply inside and outside STD for analytical instruments. Protecting cabinet was installed for the protection of the electric board (Plate 3.6).



Plate 3.1 Construction, insulation and plastering of RCC platform of solar tunnel dryer



Plate 3.2 (a) Inside frame structure of solar tunnel dryer



Plate 3.2 (b) Solar tunnel dryer covered with 200 μ UV stabilized polyethylene sheet

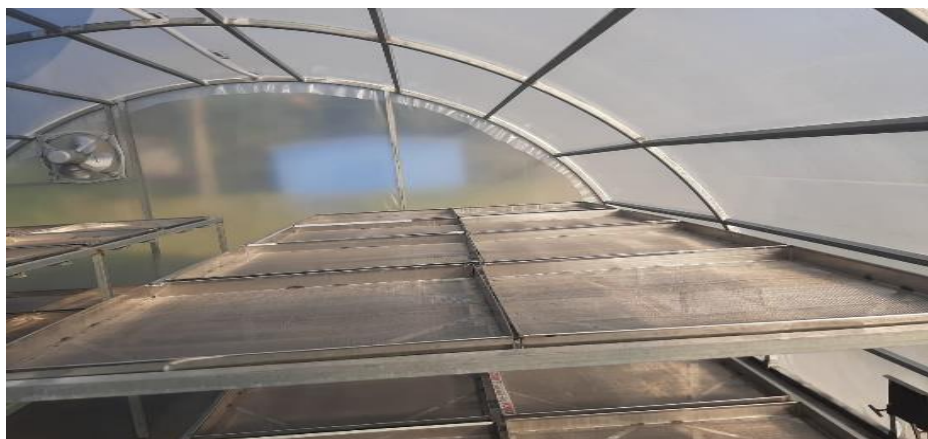


Plate 3.3 Arrangement of drying trays in drying stand



Plate 3.4 Turbo fan



Plate 3.5 Exhaust fan



Plate 3.6 Electric supply

3.2 INSTRUMENTATION

The different analytical instruments used for experimental work are mentioned in Table 3.2.

Table 3.2 Details of instruments used experimental work.

| Sl. No. | Name of the instrument | Specification |
|---------|---------------------------------|--|
| 1. | K-type thermocouple sensors | Model - COM1706. Range: 200 to 1260°C, least count: 0.75°C. It was used to measure temperature, relative humidity, etc. (Plate 3.7). |
| 2. | Humidity cum temperature sensor | Model - Hygro Clip 2, Range: 0 - 100 % (rh) or 0-100°C Made in Switzerland by Rotronics. It was used to measure relative humidity inside and outside the dryer. (Plate 3.8) |
| 3. | Pyranometer | Model - LSI Class II (ISO 9060), Range: 0-4000 W/m ² . It was used to measure the global radiation inside the solar tunnel dryer. (Plate 3.9) |
| 4. | Data logger | Model - DT80 and DT600. Manufactured by Data Logger Co. It was used to record the data of air temperature, relative humidity, plate temperature and solar insolation. (Plate 3.10) |
| 5. | Digital Anemometer | Model - AVM -03, Manufactured by Work Zone. Range: 0-45 m/s, Resolution: 0.01 m/s Hand-held digital anemometer was used to record the wind velocity. (Plate 3.11) |
| 6. | Digital weight balance | Model - VSP-100. Manufactured by Voda Ltd. Range: 1 – 200 kg. It was used to record the weight of the product being loaded in the dryer. (Plate 3.12) |
| 7. | Analytical weighing balance | Model - DWAI-314C. Manufactured by Danwer scales Range: 0.1 mg – 310 g. It was used to measure the weight precisely. |



Plate 3.7 K-type sensors for temperature measurement



Plate 3.8 Humidity cum temperature sensor



Plate 3.9 Pyranometer for measurement of global solar radiation



Plate 3.10 Data logger to record the microclimate data



Plate 3.11 Anemometer for wind velocity measurement



Plate 3.12 Digital weight balance

3.3 EXPERIMENTAL DETAILS

3.3.1 Procurement of Medicinal Plant Leaves

The medicinal plants namely, *Adhatoda vasica* and *Moringa oleifera* leaves, was procured from Botanical Nursery, Junagadh Agricultural University. The harvesting of *Adhatoda vasica* leaves was done manually by hand picking, whereas harvesting of *Moringa oleifera* was carried out by a wooden rod having a sharp stainless-steel knife at the top for cutting the branches of tree. Then after, damaged and discoloured leaves were separated manually by hand picking.

3.3.2 Physio-chemical Parameters of Freshly Harvested Leaves

Good quality leaves of *Adhatoda vasica* and *Moringa oleifera* were used to determine the different Physio-chemical parameters, viz., carbohydrate content, ascorbic acid content, total ash content, fat content, protein content, crude fibre content, bulk density, recovery rate, WSI and WAI content as per the standard methods described in 3.5.8.1, 3.5.8.2, 3.5.8.3, 3.5.8.4, 3.5.8.5, 3.5.8.6, 3.5.8.7, 3.5.8.8, 3.5.8.9 and 3.5.8.10, respectively in this Chapter.

3.3.3 Pre-treatments

The freshly harvested medicinal plant leaves were subjected to different levels of pre-treatment (i.e., steam blanching for 3 and 5 minutes) prior to solar tunnel drying and sun-drying. Many researchers have suggested that steam blanching prior to drying will improve sensory qualities (colour, flavour, taste, fragrance, aroma, etc), permits longer storability as well as reduces the drying time.

Drying trays were loaded with the both *Adhatoda vasica* and *Moringa oleifera* leaves in a uniform manner. A SS vessel of 30 L capacity was filled with 15 L of water and boiled in gas stove until steam was generated. After steam generation, the SS drying tray loaded with the leaves of *Adhatoda vasica* and *Moringa oleifera* were kept at the top of the vessel and the leaves were subjected to steam blanching for 3 minutes (Plate 3.13 and 3.14). The same process was carried out for steam blanching for 5 minutes. In addition to this, drying trays with leaves for without steam blanching were also placed inside the solar tunnel dryer. Then after, the trays were loaded in the solar tunnel dryer as per different treatment combinations. Each tray was capable to hold 0.50 kg of *Adhatoda vasica* leaves and 0.445 kg of *Moringa oleifera* leaves. A total of 32 kg of *Adhatoda vasica* leaves and 44.8 kg of *Moringa oleifera* leaves were loaded in the solar

tunnel dryer in each trial. However, samples of *Adhatoda vasica* leaves and *Moringa oleifera* leaves were dried in open sun as per the method followed by local pharmaceuticals for drying (Plate 3.15 (a), (b), (c), (d)). The medicinal leaves were dried in the solar tunnel dryer through natural convection mode to evaluate the performance of the developed solar tunnel dryer. Statistical analysis was carried out by Factorial Completely Randomized Design method, in which the effect of various treatments on various parameters were analysed. The treatment details and the treatment combination details are provided in Table 3.3 and 3.4, respectively.

Table 3.3 Treatment details

| SI. No. | Type of Variable | Levels | Details |
|----------------------|----------------------|--|--|
| Independent Variable | | | |
| 01 | Crop leaves | 2 levels | <i>C₁ - Moringa oleifera</i> |
| | | | <i>C₂ - Adhatoda vasica</i> |
| 02 | Steam blanching time | 3 levels | <i>S₁ – 0 min</i> |
| | | | <i>S₂ – 3 min</i> |
| | | | <i>S₃ – 5 min</i> |
| 03 | Drying method | 2 levels | <i>D₁ – Solar Tunnel Drying</i> |
| | | | <i>D₂ – Sun Drying</i> |
| Dependent Variable | | | |
| 04 | Parameters | 1. Physical parameter: Bulk density. 2. Biochemical parameter: Moisture content, carbohydrate, ascorbic acid, total ash, fat, fibre and protein content. 3. Functional parameter: W.S.I, W.A.I, Recovery rate. | |
| Treatment Details | | | |
| 05 | Treatments | 12 | |
| 06 | Repetitions | 3 | |
| 07 | Statistical design | 3 - Factor Completely Randomised Design | |

Table 3.4 Treatment combination details

| Treatment No. | Treatment Details | Combinations |
|----------------------|---|--|
| 1 | Moringa Leaves (C ₁) + 0 min Steam blanching(S ₁) + Solar Tunnel Drying (D ₁) | C ₁ S ₁ D ₁ |
| 2 | Moringa Leaves (C ₁) + 3 min Steam blanching(S ₂) + Solar Tunnel Drying (D ₁) | C ₁ S ₂ D ₁ |
| 3 | Moringa Leaves (C ₁) + 5 min Steam blanching(S ₃) + Solar Tunnel Drying (D ₁) | C ₁ S ₃ D ₁ |
| 4 | Moringa Leaves (C ₁) + 0 min Steam blanching(S ₁) + Sun Drying (D ₂) | C ₁ S ₁ D ₂ |
| 5 | Moringa Leaves (C ₁) + 3 min Steam blanching(S ₂) + Sun Drying (D ₂) | C ₁ S ₂ D ₂ |
| 6 | Moringa Leaves (C ₁) + 5 min Steam blanching(S ₃) + Sun Drying (D ₂) | C ₁ S ₃ D ₂ |
| 7 | Ardusi Leaves (C ₂) + 0 min Steam blanching(S ₁) + Solar Tunnel Drying (D ₁) | C ₂ S ₁ D ₁ |
| 8 | Ardusi Leaves (C ₂) + 3 min Steam blanching(S ₂) + Solar Tunnel Drying (D ₁) | C ₂ S ₂ D ₁ |
| 9 | Ardusi Leaves (C ₂) + 5 min Steam blanching(S ₃) + Solar Tunnel Drying (D ₁) | C ₂ S ₃ D ₁ |
| 10 | Ardusi Leaves (C ₂) + 0 min Steam blanching(S ₁) + Sun Drying (D ₂) | C ₂ S ₁ D ₂ |
| 11 | Ardusi Leaves (C ₂) + 3 min Steam blanching(S ₂) + Sun Drying (D ₂) | C ₂ S ₂ D ₂ |
| 12 | Ardusi Leaves (C ₂) + 5 min Steam blanching(S ₃) + Sun Drying (D ₂) | C ₂ S ₃ D ₂ |



Plate 3.13 Steam blanching of *Moringa oleifera*



Plate 3.14 Steam blanching of *Adhatoda vasica*



Plate 3.15 (a) Loading of samples in SS drying tray



Plate 3.15 (b) Loading of SS trays in solar tunnel dryer



Plate 3.15 (c) Sun drying of fresh leaves



Plate 3.15 (d) Sun dried leaves

3.4 MICRO-CLIMATIC VARIATIONS

The micro-climatic variations have been studied inside a solar tunnel dryer. This variation includes the measurement of the natural rise of temperature, due to reduced air movement and greenhouse effect, which helps to maintain the desirable thermal conditions for drying and relative humidity inside the tunnel. The environmental parameters, viz., solar radiation, temperature and relative humidity, inside and outside solar tunnel dryer were measured under no load as well as full load condition.

3.4.1. No Load Condition

This experiment was made to know maximum temperature attended inside the solar tunnel dryer and finally to conclude for stagnant temperature assessment. Here the useful heat was assessed in terms of maximum temperature attended, but not effectively utilized for drying purpose.

The observations were recorded with the view to find out the temperature profile at the different places inside the solar tunnel dryer, five sensors inside (3 sensors at the centre, at the top, middle and bottom and one each at the entrance and the end of the solar tunnel dryer) and one sensor outside the solar tunnel dryer were kept for recording. The inside environmental parameters like temperature, relative humidity and solar radiation for the duration 14th January to 5th February 2022 were recorded with different instruments and sensors like data taker DT600 and DT80 series data logger, pyranometer, k-type sensors, humidity cum temperature sensor and anemometer. The specifications of the instruments are given in Table 3.2. The instruments were kept at appropriate locations inside the solar tunnel dryer for recording the data. The data recorded with each instrument were at an interval of one hour. The hourly data were used to calculate and obtain weekly average data.

3.4.2 Full Load Condition

Full load testing of solar tunnel dryer was conducted for evaluating the performance in actual loaded condition. Under these conditions the useful heat was extracted and utilized to remove the moisture from material. *Adhatoda vasica* and *Moringa oleifera* leaves with known initial moisture content was taken for study and loaded in the trays of solar tunnel dryer. Material was spread in thin layers in trays. The data on moisture content, weight reduction, drying time, air temperature, etc., was

analysed for calculating drying rate and drying efficiency. The microclimate of inside environmental parameters of the solar tunnel dryer during the full loading of the medicinal plant leaves, namely, *Adhatoda vasica* and *Moringa oleifera*, were recorded by the same instruments and methods as under no load condition.

3.5 PERFORMANCE EVALUATION OF SOLAR TUNNEL DRYER

The performance evaluation of the solar tunnel dryer was evaluated at no load and full load condition by observing the micro-climatic variation and determining the moisture content, moisture ratio as well as the drying rate of the leaves with the help of standardised formulae, and drying characteristic curves, viz., moisture content vs. drying time, drying rate vs. drying time and moisture ratio vs. drying time. The physical and biochemical characteristics of the freshly harvested raw leaves as well as that of the dried leaves powder was determined, so that any changes in any one of these parameters after drying could be highlighted.

3.5.1 Moisture Content

The initial and the final moisture content were determined by the hot air oven method as reported by Ranganna (2000). The leaves of the freshly harvested medicinal plants as well as solar tunnel dried and sun-dried leaves were kept in a pre-weighed petri dish and dried in a hot air oven at 70°C for 16 hours. After oven drying, the weight of the petri dish along with the samples was measured, the difference in weight determines the amount of moisture lost from the sample. This amount of moisture when divided by the total weight or the dry weight determines the moisture content of the sample in wet as well as dry basis.

Amount of initial water content can be found out by the following equation:

$$M = \frac{M_1 - M_2}{\text{total weight of the sample or dry weight of the sample}} \times 100 \quad \dots (3.1)$$

Where, M = Initial water content in the product, kg

M_1 = Weight of the sample before drying, kg

M_2 = Weight of the sample after drying, kg

3.5.2 Moisture Ratio

Moisture ratio was computed as per the method suggested by Singh *et al.* (1996):

$$MR = \frac{M - M_e}{M_o - M_e} = e^{-k\theta} \quad \dots (3.2)$$

Where, MR = Moisture ratio

M = Moisture content at any time θ , % (db)

M_e = Equilibrium moisture content, % (db)

M_o = Initial moisture content, % (db)

k = Drying constant,

θ = Time, h

3.5.3 Drying Rate

The moisture content data recorded during experiments was analysed to determine the moisture lost by dried arduci and moringa leaves at an interval of 1 h. The drying rate of the samples was calculated using the following equation,

$$\text{Drying rate} = \frac{dm}{dt} \quad \dots (3.3)$$

Where, dm = Moisture removed per hour, % (wb)

dt = Drying time, h

3.5.4 Total Energy Required Q, kcal

$$Q = M_d \times C_d \times (T_2 - T_1) + M \times C_p \times (T_2 - T_1) + M_w \times \lambda \quad \dots (3.4)$$

(Dulawat, 2012)

Where, M_d = Mass of bone-dry product, kg

M = Initial moisture content of mass, kg

M_w = Weight of water removed, kg

T_1 = Ambient air temperature, °C

T_2 = Temperature inside the solar tunnel dryer, °C

C_p = Specific heat of water, kJ/kg °C

C_d = Specific heat of product, kJ/kg °C

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

3.5.5 Energy Required Per Hour Q_t , kcal/h

$$Q_t = \frac{Q}{t} \quad \dots (3.5)$$

Where, t = Total drying time, h

3.5.6 Dryer Thermal Efficiency

Thermal efficiency of the solar tunnel dryer was estimated using the formula as given by Dulawat (2012).

$$\eta_{th} = \frac{Q_t}{A \times I} \quad \dots (3.6)$$

Where, η_{th} = Dryer thermal efficiency

Q_t = Energy required per hour

A = The area of solar tunnel dryer in m^2

I = The solar intensity in W/m^2

3.5.7 Pick-up Efficiency

This parameter is useful for evaluating the actual evaporation of moisture from the commodity inside the solar tunnel dryer. The pick-up efficiency is defined as the ratio of moisture picked up by the air in the drying chamber to the theoretical capacity of the air to absorb moisture. The pick-up efficiency can also be calculated from the following equation (Dulawat, 2012).

$$\eta_p = \frac{w}{V} \times \rho \times t \times (h_{as} - h_i) \quad \dots (3.7)$$

Where, w = Moisture evaporated, kg

V = Air flow rate, m^3/s

ρ = Air density, kg/m^3

t = Drying time, s

h_i = Absolute humidity of air entering the drying chamber,

h_{as} = Adiabatic saturation humidity of the air

3.5.8 Physio-chemical Analysis of Raw and Dried Products

The physio-chemical analysis of the raw leaves, i.e., freshly harvested leaves and that of the dried leaves powder was carried out in the Food Testing Laboratory, College of Agriculture, JAU, Junagadh. The parameters determined were carbohydrate content, ascorbic acid content, total ash content, fat content, protein content, crude fibre content, bulk density, recovery rate, WSI and WAI. The methodology for determination of moisture content is already mentioned in the subsection 3.5.1 and for the rest of the analysis, the methodology is described in the following subsections.

3.5.8.1 Carbohydrate content determination

To determine carbohydrate content, phenol sulphuric acid method was used (Plate 3.16). A standard solution was prepared by mixing 1 ml of working stock solution and 9 ml of distilled water. 1 ml of phenol was added to all the test tubes and kept for 10 minutes. 5 ml of H₂SO₄ was also added and kept for it to cool down, until yellow colour appears. The solutions were read at 490nm in spectroscopy.

In this study, 0.1 gm each of sample was taken and 10 ml of 80% Hcl was added to it. It was then kept in water bath for 3 hours and afterwards kept overnight to form the aliquat. 0.1 ml of aliquat was mixed with 0.9 ml of distilled water to make 1 ml volume. Similarly, 0.2, 0.4, 0.6, 0.8, and 1ml of aliquat was mixed with distilled water to make 1 ml volume. 1 ml of 0.5% phenol was added to all the test tubes and mixed well. After resting for 10 minutes, 5 ml of 96% H₂SO₄ was added and mixed well, after which it was left to cool down. The reading was taken at 490 nm in spectroscopy. The percentage of carbohydrate content was determined by the following formula:

$$\text{Carbohydrate \%} = \frac{\text{total volume of graph factor}}{\text{aliquat sample}} \times \frac{\text{total volume of extract}}{\text{weight of sample}} \times \frac{1}{100} \quad \dots (3.8)$$

3.5.8.2 Ascorbic acid content determination

To determine the ascorbic acid content in the sample, DNPH method was used as recommended by Roe (1961). In this study, 0.1 g of each of the sample was taken and extracted with 6% trichloro acetic acid (TCA) in 10 ml of 80% H₂SO₄. Aliquot of 0.2, 0.4, 0.6, 0.8 and 1.0 concentration were formed. In it, 2 ml of 2% 2,4-Dinitrophenylhydrazine (DNPH) and 10% thiourea was added and the whole set up was kept in water bath of 80°C for 15 minutes (Plate 3.18). After the time had elapsed, 5 ml

of 80% H₂SO₄ was added to all the test tubes, mixed well and kept it for cooling. The reading was taken at 490nm in spectroscopy.

3.5.8.3 Ash content determination

Ash or mineral content is the portion of the food or any organic material that remains after it is burned at very high temperatures. The ash constituents include potassium, sodium, calcium and magnesium, which are present in larger amounts as well as smaller quantities of aluminium, iron, copper, manganese or zinc, arsenic, iodine, fluorine and other elements present in traces. Ash content represents the total mineral content in food, although less than 7% of the total dry matters, they play an important role from a physiochemical, technological and nutritional point of view.

Total ash content was determined by combustion method as described in AOAC (2005). About 2 g of leaf powder from each sample was taken. Dried and powdered samples were incinerated in a muffle furnace at 550°C for 4 hours, cooled in desiccators and weighed until the weight is constant (Plate 3.19).

$$\text{Total ash \%} = \frac{\text{weight of ash}}{\text{initial weight of sample}} \times 100 \quad \dots (3.9)$$

3.5.8.4 Crude fat content determination

Crude fat is the term used to refer to the crude mixture of fat-soluble material present in a sample. Crude fat also known as the ether extract or the free lipid content, is the traditional measure of fat in food products. The lipid materials may include triglycerides, diglycerides, monoglycerides, phospholipids, steroids, free fatty acids, fat soluble vitamins, carotene pigments, chlorophylls, etc. The common approach for total crude fat determination is based on the solubility of lipids in non-polar organic solvents such as hexanes, petroleum ether, or supercritical liquid carbon dioxide with or without a solvent modifier.

Crude fat content was determined as the weight change recorded after exhaustively extracting the leaf samples with a non-polar solvent (hexane) using soxlet method (Plate 3.20), according to AOAC (2005). The experimental setup has mainly three compartments: flask, extraction chamber and condenser. About 2g each of the sample is placed in a thimble, once the flask is heated, the solvent (hexane) is evaporated and moved up to the condenser, where it is converted into liquid and collected into the extraction chamber containing the sample. When the solvent passes through the sample, it extracts the fats and carries them into the flask (Plate 3.21). This

process generally lasts 6-8 hours. After completion of the extraction, the solvent is evaporated and the mass of lipid remaining is measured and used to analyse.

$$\text{Fat \%} = \frac{\text{weight of the oil extracted}}{\text{weight of the sample taken}} \times 100 \quad \dots (3.10)$$

3.5.8.5 Protein content determination

To determine the protein content of *Moringa oleifera* and *Adhatoda vasica*, Follin Lowry method was adopted, recommended by Waterborg (2009). Reagents used for the extraction were:

1. 0.1 N NaOH: 0.4 g of Sodium hydroxide (NaOH) was dissolved in 100 ml of distilled water.
2. Solution A: 2% Sodium carbonate (Na_2CO_3) (2 g of Na_2CO_3 dissolved in the 100 ml of 0.1 N NaOH).
3. Solution B: 0.5% Copper sulphate (CuSO_4) was mixed with 0.1 g of sodium potassium tartarate and 10 ml distilled water.
4. Solution C: 50 ml of solution A was mixed with 1ml of solution B.
5. Follin reagent (FCR): 1 ml of FCR was added to 1 ml of distilled water to dilute it to 1:1.

To extract the protein content of the samples, 0.1 ml of sample extraction was mixed with 0.9 ml of distilled water, to it, 5 ml of solution C was added and then left to rest for 10 minutes. After the time had elapsed, 0.5 ml of FCR was mixed with it and kept in a dark place to rest it for 30 minutes (Plate 3.22). Solutions were read at 660 nm on spectrometer.

3.5.8.6 Crude fibre content determination

Crude fibre is a measure of the quantity of indigestible cellulose, pentosans, lignin and other components. It is the residue of plant materials remaining after solvent extraction followed by digestion with dilute acid and alkali.

Crude fibre percentage was determined by extraction method with the help of fibretherm (Plate 3.23), according to AOAC (2005). About 2 g each of sample powder was taken and introduced into the extraction unit (Plate 3.24), 150 ml of hot 0.2 N H_2SO_4 and Hcl was added and digested for 30 minutes. Then, the acids were drained and the sample was washed with hot deionized water for 1 h. The crucible was removed

and oven dried overnight at 105°C for 2.3 hours, cooled, weighed and heated at 600°C in a muffle furnace for 30 minutes and reweighed after cooling (Plate 3.25). Percentage extracted fibre was calculated as:

$$\text{Crude fibre \%} = \frac{\text{weight of digested sample} - \text{weight of ashed sample}}{\text{weight of samples}} \times 100 \quad \dots (3.11)$$

3.5.8.7 Bulk density

Bulk density is defined as ratio of weight of an untapped material to its volume including the contribution of the inter-particulate void volume. The total volume includes particle volume, inter-particle void volume and internal pore volume. Weight of the material is determined with the help of weighing balance (Plate 3.27) and the volume can be determined by using a container of a known volume (Plate 3.26). The bulk density can be determined by the formula, as given by Anderson (1969):

$$\text{bulk density} = \frac{\text{weight}}{\text{volume}} \quad \dots (3.12)$$

3.5.8.8 Percentage recovery

The dried leaves of *Moringa oleifera* and *Adhatoda vasica* was powdered in a grinder and sieved through a sieve. The percentage recovery of *Moringa oleifera* and *Adhatoda vasica* powder was determined according to the formula given by Anderson (1982) (Plate 3.28 (a), (b), (c) and (d))

$$\text{Recovery\%} = \frac{\text{weight of powder}}{\text{weight of fresh leaves}} \times 100 \quad \dots (3.13)$$

3.5.8.9 Water Solubility Index (WSI)

The solubility of *Moringa oleifera* and *Adhatoda vasica* was determined according to the method suggested by Anderson (1982). Water solubility index (WSI) is defined as the weight of dissolved solids in supernatant per weight of dry solid powder and expressed in per cent. It indicates the rate for dispersing or rehydration ability in a liquid medium. The method involves adding 2.5 g of moringa and vasaka powder in 25 g of distilled water at 30°C. A glass rod was used to break up any lumps. After stirring for 30 minutes, the dispersion was rinsed into tarred centrifuge tubes. The solution was then centrifuged at 3000 rpm for 10 minutes. The supernatant liquid was

poured carefully into a tarred evaporating dish (Plate 3.29 (a)). The amount of dried solid was recovered by evaporating supernatant dish (Plate 3.29 (b)). The water solubility index was calculated using the following equation,

$$\text{WSI, \%} = \frac{\text{weight of dissolved solid in supernatant}}{\text{weight of dry solid powder}} \times 100 \quad \dots (3.14)$$

3.5.8.10 Water Absorption Index (WAI)

Water absorption index is the ratio of the weight of sediments to weight of dry solid powder and expressed in per cent. The sediment obtained in the estimation of water solubility index was used for determination of water absorption index and calculated using the following equation, (Plate 3.30 (a) and (b)).

$$\text{WAI, \%} = \frac{\text{weight of sediments}}{\text{weight of dry solid powder}} \times 100 \quad \dots (3.15)$$



Plate 3.16 Carbohydrate extraction of the samples



Plate 3.17 Hot air oven for determination of moisture content



Plate 3.18 Water bath used for determination of ascorbic acid



Plate 3.19 Total ash content of the samples



Plate 3.20 Soxlet apparatus for determination of fat content



Plate 3.21 Fat extraction process for the samples

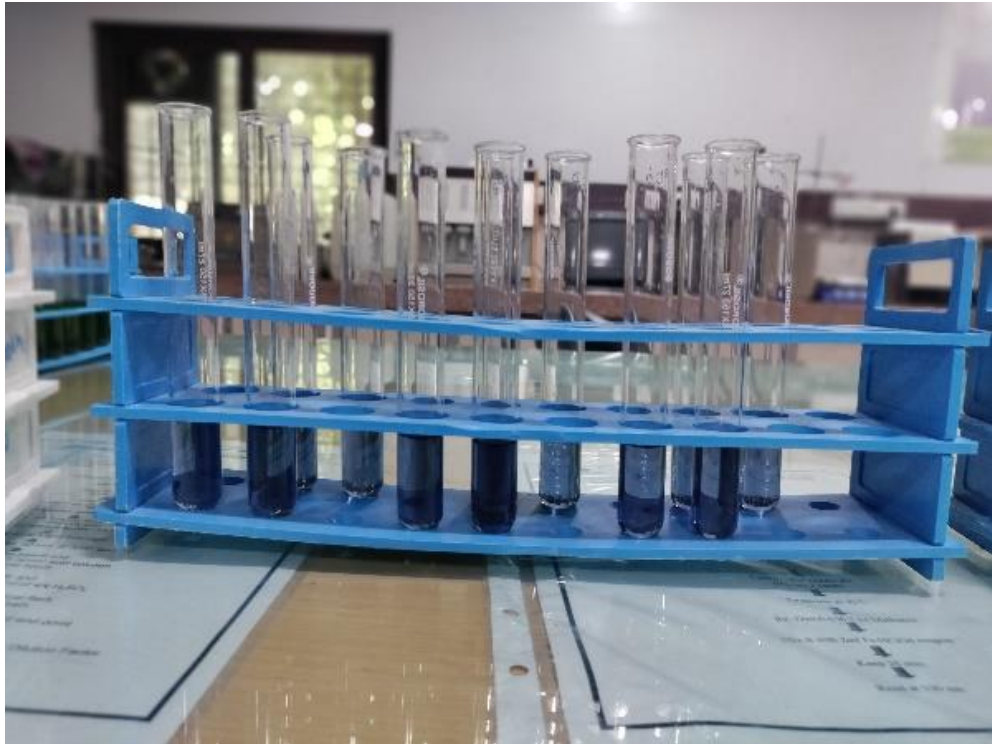


Plate 3.22 Protein extraction of the samples



Plate 3.23 Fibretherm used for determination of fibre content



Plate 3.24 Fibre extraction process of the samples



Plate 3.25 Extracted fibre of the samples



Plate 3.26 Container used for determination of bulk density



Plate 3.27 Analytical weighing balance used for physio-chemical analysis



Plate 3.28 (a) Grinding of *Adhatoda vasica* leaves



Plate 3.28 (b) Grounded powder of *Adhatoda vasica*



Plate 3.28 (c) Pouring of *Adhatoda vasica* leaf powder into the sieve (300 μ)



Plate 3.28 (d) Sieving of *Adhatoda vasica* leaf powder



Plate 3.29 (a) Supernatant for WSI determination of the samples

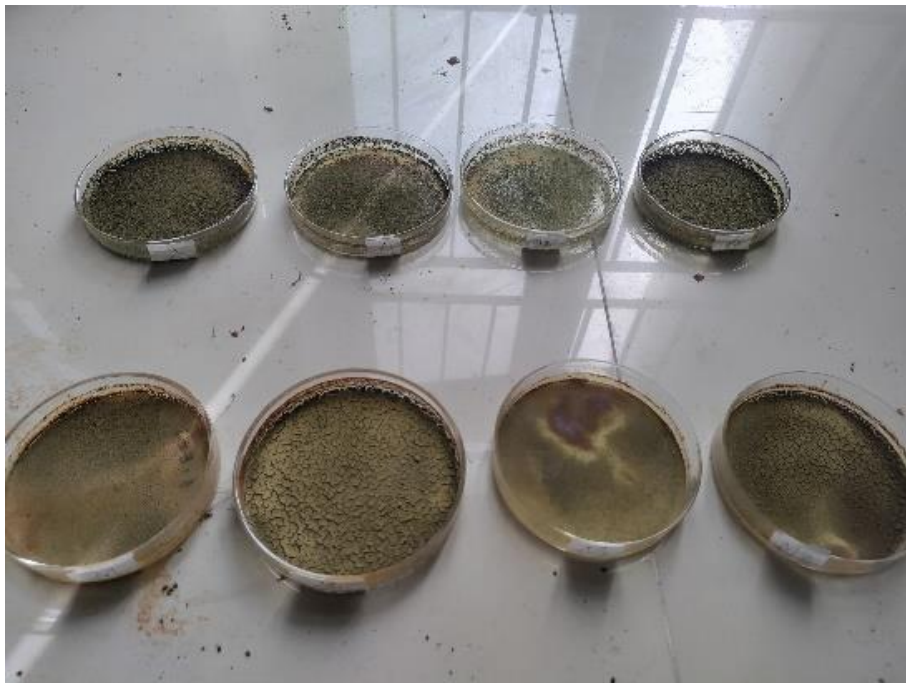


Plate 3.29 (b) Dried supernatant for WSI determination of the samples



Plate 3.30 (a) Centrifuge machine for WAI determination

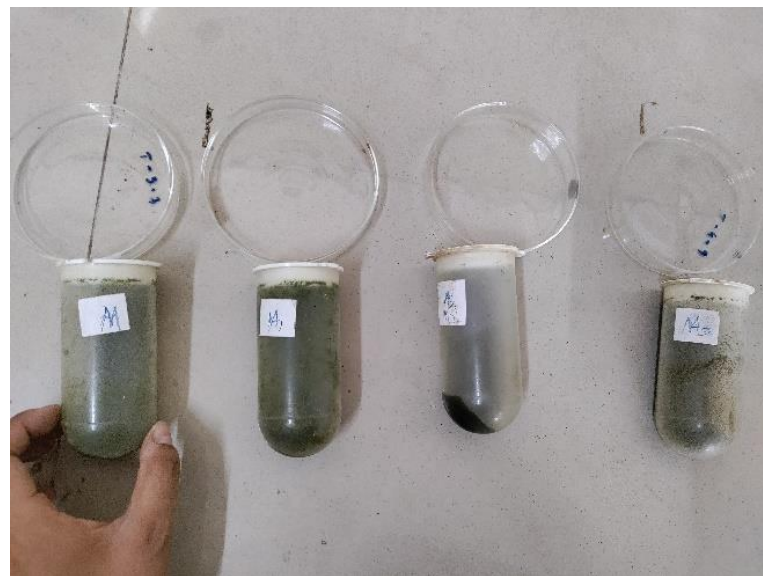


Plate 3.30 (b) Sediments of *Moringa oleifera* during WAI determination

3.6 MATHEMATICAL MODELLING OF SOLAR TUNNEL DRYER FOR THERMAL ANALYSIS

In the present study, efforts were made to develop mathematical model by adopting thermal analysis of the solar tunnel dryer. Study includes average hourly variation in temperatures of solar tunnel dryer cover, dryer air, the medicinal plants, viz., *Adhatoda vasica* and *Moringa oleifera*, ground surface and relative humidity of the dryer air for natural convection conditions at Junagadh (21.52°N, 70.45°E).

The mathematical model was developed to predict the hourly variation in solar tunnel dryer environment, i.e., temperature of cover, enclosed air inside the dryer, commodities namely, *Adhatoda vasica* and *Moringa oleifera*, tray temperature, floor temperature and relative humidity of enclosed air for different operating conditions.

The input environmental data for the model was considered for measured data of the environment. The energy balance equation was solved by using finite difference technique and the results was obtained by using computer program. The program was run on computational machine (computer) available at the Renewable Energy Engineering department.

3.6.1 Assumptions

In order to write an energy balance equation for each component of the solar tunnel dryer, the following assumptions was made:

1. The solar tunnel dryer is oriented in the E-W direction and the air flow is in one-dimensional.
2. No co-efficient has been included to account for shading due to structural members.
3. The moisture is freely available at the surface of drying tray.
4. The temperature of top surface of drying tray is assumed to respond instantaneously to energy transfer mechanism. Edges loss are considered to be negligible compared with those through the surface of the tray.
5. The temperature of inlet air is assumed as ambient temperature.
6. The solar tunnel dryer air is well mixed at all times so that no temperature or moisture gradient exists in the structure.
7. Heat loss from the tray to the ground surface will be considered in a steady state mode.

3.6.2 Development of Mathematical Models

The energy balance equations for developing the mathematical model for solar tunnel dryer environment prediction were written for different components of solar tunnel dryer, such as the cover, solar tunnel dryer inside air, floor and product to be dried. The energy balance equations are given in next sub-sections. The computer programs were prepared in FROTRAN language by incorporating these equations and using finite difference technique. The input and operational conditions were incorporated to obtain predicted data.

3.6.2.1 Cover

The energy received by the cover is the amount of solar radiation absorbed by the cover, convection heat transfer between cover and the solar tunnel dryer air. Also, the cover receives heat by radiative heat transfer between the cover and the floor and also between the cover and the product. The energy lost by the cover is due to the convection and radiation heat transfer between cover and ambient. The energy balance equation at cover can be written as:

Energy stored by the cover = energy received by the cover – energy lost by cover

$$M_{co}C_{pco} \partial T_{co}/dt = \alpha_{co}A_{co}I + A_{co} h_{ctdco} (T_{td} - T_{co}) + A_s h_{rcos(1)} (T_{s(1)} - T_{co}) + A_p h_{rpto} (T_p - T_{co}) - A_{co} h_{rcos} (T_{co} - T_{sky}) - A_{co} h_{cco} (T_{co} - T_a) \quad \dots (3.16)$$

3.6.2.2 Inside air

The energy received by the air inside the solar tunnel dryer is because of the heat transfer between the cover, product and floor due to convection and radiation. Heat lost by the air is the energy lost through natural ventilation. The energy balance equation for the inside air can be written as:

Energy stored in the solar tunnel dryer air = energy received by the solar tunnel dryer air – energy lost by the solar tunnel dryer air

$$M_{td}C_{ptd} \partial T_{td}/dt = A_p h_{ctdp} (T_p - T_{td}) + A_{s(1)} h_{ctds(1)} (T_{s(1)} - T_{td}) + A_{co} h_{ctdco} (T_{co} - T_{td}) + A_p f h_{td} (W_p - W_{td}) - E_{nv} \quad \dots (3.17)$$

3.6.2.3 Product

Energy received by the product is the amount of solar radiation absorbed by the product. Energy lost by the product is the heat transfer by convection from the product to the solar tunnel dryer air and by radiation from the product to the cover of the solar tunnel dryer. The energy balance equation at product can be expressed as:

$$M_p C_{pp} \partial T_p / dt = A_p C_{co} \alpha_p I + A_p h_{r_{pco}} (T_p - T_{co}) + A_p h_{ctdp} (T_p - T_{td}) \quad \dots (3.18)$$

3.6.2.4 Floor

Energy received by the floor is the amount of solar radiation absorbed by the floor. The energy lost from the floor include the heat transfer due to convection from the floor to the solar tunnel dryer air and heat transfer due to radiation from the floor to the solar tunnel dryer cover. The energy balance equation at floor can be written as:

$$M_{s(1)} C_{ps(1)} \partial T_{s(1)} / dt = A_{s(1)} C_{co} \alpha_{s(1)} I + A_{s(1)} h_{rs(1)co} (T_{s(1)} - T_{co}) - A_{s(1)} h_{ctds(1)} (T_{s(1)} - T_{td}) \quad \dots (3.19)$$

3.6.2.5 Mass balance equation

Air temperature inside the solar tunnel dryer is higher than corresponding ambient temperature. It increases the ability to pick up moisture from the product and product gets dried. The mass balance inside the tunnel dryer can be written as:

$$\rho_a V \frac{dH}{dt} = A_{in} \rho_a H_{in} V_{in} - A_{out} \rho_a H_{out} V_{out} + D_p A_p \rho_p \frac{dM_p}{dt} \quad \dots (3.20)$$

3.6.3 Solution of Equation

The temperatures of the different components of the solar tunnel dryer like cover, inside air, product and floor with respect to operating time were obtained by solving the above equations using finite difference technique as given below.

3.6.3.1 Cover

$$T_{co} = T_{coOLD} + R_1 \Delta T [\alpha_{co} A_{co} I + A_{co} h_{ctdco} (T_{td} - T_{co}) + A_s h_{rcos(1)} (T_{s(1)} - T_{co}) + A_p h_{r_{pco}} (T_p - T_{co}) - A_{co} h_{rcos} (T_{co} - T_{sky}) - A_{co} h_{cco} (T_{co} - T_a)] \quad \dots (3.21)$$

Where, $R_1 = 1 / (M_{co} C_{pco})$

3.6.3.2 Inside air

$$T_{td} = T_{tdOLD} + R_2 \Delta T [A_p h_{ctdp} (T_p - T_{td}) + A_{s(1)} h_{ctds(1)} (T_{s(1)} - T_{td}) + A_{co} h_{ctdco} (T_{co} - T_{td}) + A_p f h_{td} (W_p - W_{td}) - E_{nv}] \quad \dots (3.22)$$

Where, $R_2 = 1 / (M_{td} C_{ptd})$

3.6.3.3 Product

$$T_p = T_{pOLD} + R_3 \Delta T [A_p C_{co} \alpha_p I + A_p h_{rpco} (T_p - T_{co}) + A_p h_{ctdp} (T_p - T_{td})] \quad \dots (3.23)$$

Where, $R_3 = 1 / (M_p C_{pp})$

3.6.3.4 Floor

$$T_{s(1)} = T_{sOLD(1)} + R_5 \Delta T [A_{s(1)} C_{co} \alpha_{s(1)} I + A_{s(1)} h_{rs(1)co} (T_{s(1)} - T_{co}) - A_{s(1)} h_{ctds(1)} (T_{s(1)} - T_{td})] \quad \dots (3.24)$$

Where, $R_5 = 1 / (M_{s(1)} C_{ps(1)})$

3.6.4 Heat Transfer Coefficients

The convective heat transfer between (h_{cotd}) cover and inside air, ($h_{tds(1)}$) floor and inside air, (h_{ptd}) product and inside air, (h_{coa}) cover and ambient air. The radiative heat transfer coefficient between (h_{rpco}) product and cover, (h_{rcosky}) cover and sky.

3.6.4.1 Convective heat transfer coefficients

1. Natural convective heat transfer between cover and ambient

$$h_{coa} = 2.8 + 3.8W \quad \dots (3.25)$$

2. Natural ventilation

$$E_{nv} = Q \rho_a (W_{td} - W_a) \quad \dots (3.26)$$

3.6.4.2 Radiative heat transfer coefficients

1. Cover and sky

$$h_{rcosky} = \sigma (T_{sky}^2 + T_{co}^2) (T_{sky} + T_{co}) / ((1/\epsilon_{co}) - 1) \quad \dots (3.27)$$

Where, $T_{sky} = 0.0552 (T_a)^{1.5}$

2. Product and cover

$$h_{r_{pco}} = \sigma (T_p^2 + T_{co}^2) (T_p + T_{co}) / ((1/\epsilon_p) + (1/\epsilon_{co}) - 1) \quad \dots (3.28)$$

3. Floor and cover

$$h_{r_{s(1)co}} = \sigma (T_{s(1)}^2 + T_{co}^2) (T_{s(1)} + T_{co}) / ((1/\epsilon_g) + (1/\epsilon_{co}) - 1) \quad \dots (3.29)$$

3.6.5 Input Parameters

1. The hourly ambient air temperatures, solar radiation, relative humidity and wind velocity for natural convection conditions at Junagadh (21.52°N, 70.45°E).
2. Specifications and properties of the solar tunnel dryer system:

Table 3.5 Specifications and Properties of the solar tunnel dryer

| Sl.No. | Parameters | Value | Unit |
|--------|---|-------------------------|----------------------------------|
| 1. | Length of STD (L) | 10 | meter |
| 2. | Breadth of STD (B) | 5 | meter |
| 3. | Height of STD (H) | 2.5 | meter |
| 4. | Thickness of polyethylene (Th _{pe}) | 200 | micron |
| 5. | Absorptivity of cover (α _{co}) | 0.25 | dimensionless |
| 6. | Transmissivity of cover (C _{co}) | 0.75 | dimensionless |
| 7. | Density of polyethylene (ρ _{pe}) | 1150 | kg/m ³ |
| 8. | Specific heat of cover (C _{co}) | 2302 | J/kg °C |
| 9. | Emissivity of cover (ε _{co}) | 0.9 | dimensionless |
| 10. | Specific heat of air (C _a) | 1005 | J/kg °C |
| 11. | Thermal conductivity of air (K _a) | 0.028 | W/m °C |
| 12. | Density of air (ρ _a) | 1.2 | kg/m ³ |
| 13. | Wind velocity (W) | 1.5 | m/s |
| 14. | Area of ventilation (A _{vent}) | 0.165×0.165 | meter ² |
| 15. | Stefan-Boltsman constant (σ) | 5.67 × 10 ⁻⁸ | W/m ² °K ⁴ |
| 16. | Prandlt number (Pr) | 0.7 | dimensionless |
| 17. | Atmospheric Pressure (P _{atm}) | 101325 | kg/m ² |

3.7 TECHNO-ECONOMIC ANALYSIS

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or not. Therefore, an attempt was made to determine economics of the solar tunnel dryer.

3.7.1 Assumptions

The following assumptions were made for carrying out economic analysis.

1. The life of GI pipe framed structure was taken as 20 years.
2. The maximum life of 200 micron UVS PE sheet as 3.0 years.
3. Interest rate on capital investment was considered as 10 % per annum.
4. In case open sun drying, the production loss as compared to solar tunnel dryer was considered as 15%
5. The quality of solar tunnel dried products were found superior than open sun dried products hence little higher revenue is considered for solar tunnel dried products.
6. The drying was considered as 9.0 hrs/day whereas for labour charges it was taken as 8.0 hrs/day and labour charges were considered as Rs. 300 per day.
7. The raw material cost of *Adhatoda vasica* leaves was considered assumed as Rs.7.80/ kg and *Moringa oleifera* leaves as 5.60 /kg.
8. For solar tunnel dried products, recovery of *Adhatoda vasica* powder was taken as 22% and for *Moringa oleifera* as 27% and for sun dried products 15% less recovery was considered ie 18.7% and 21.6% respectively.

3.7.2 Annual Production Cost (APC)

The production cost of the dried powdery products of *Adhatoda vasica* and *Moringa oleifera* using solar tunnel dryer and open sundrying were calculated. The cost parameters were calculated as given below

$$APC = AFC + AMC + AOC - ASV \quad \dots (3.30)$$

Where, APC = Annual production cost, Rs

AFC = Fixed cost, Rs.

AMC = Maintenance cost, Rs.

AOC = Operating cost, Rs.

ASV= Salvage value, Rs.

The different components of the Annual production cost were calculated using the following equations.

3.7.2.1 Annual Fixed cost (AFC)

$$AFC = CI \times CRF \quad \dots (3.31)$$

Where, $CRF = \frac{i(i+1)^n}{[(i+1)^n - 1]}$

Here, Life of structure (n) =20 years for pipe structure

Life of plastic covering = 3 years

Rate of interest (i) =10 per cent on capital investment

The capital investment i.e. cost of the dryer includes costs of structure, drying stand, drying trays and electric fittings etc. as reported in Table 4.29.

3.7.2.2 Annual maintenance cost (AMC)

The maintenance cost of the structure during the crop season was considered as 3% of the cost of the structure (CI)

3.7.2.3 Annual operational costs (AOC)

The labour cost required to handle the material, blanching material and operating the drying systems were considered to calculate the operational cost of drying. Here for solar tunnel it is considered as one and for open sun drying, two labourers per day assuming each labour can handle 50.0 kg material per day.

3.7.2.4 Annual salvage value (ASV)

$$SV = SFF \times CI \quad \dots (3.32)$$

$$SFF = \frac{1}{[(i+1)^n - 1]}$$

$$SV = 0.10 (CI) \quad \dots (3.33)$$

3.7.2.5 Gross revenue and profit

The gross revenue was calculated on the basis of prevailing average market price of the product and total production obtained per day/kg.

3.7.3 Payback period

The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.

The payback period of the project will be estimated by using the straight forward formula:

$$P = \frac{I}{E} \quad \dots (3.34)$$

Where, P = Payback period of the project in years,

I = Investment of the project in rupees and

E = Annual net cash revenue in rupees

3.7.4 Net present worth (NPW)

Net present worth is simply the present worth of the cash flow stream. The difference between the present value of all future returns and the present money required to make an investment is the net present worth or net present principal for the investment. The present values of the future returns are calculated through the use of discounting. Discounting is essentially a technique by which future benefits and cost streams can be reduced to their present worth. The process of finding the present worth of a future value is called discounting. The discounting rate is the interest rate assumed for discounting.

The most straight forward discounted cash flow measure of project worth is the Net Present Worth (NPW). The net present worth may be computed by subtracting the total discounted present worth of the cost stream from that of the benefit stream. To obtain the incremental net benefit, gross cost was subtracted from gross benefit or the investment cost from the net benefit. The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad \dots (3.35)$$

Where, C_t = Cost in each year,

B_t = Benefit in each year,

$t = 1, 2, 3, \dots, n$

i = Discount rate

3.7.5 Benefit cost ratio

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The formal selection criterion for the benefit-cost ratio for measure of project worth was to accept projects for a benefit-cost ratio of 1 or greater.

In practice, it is probably more common not to compute the benefit-cost ratio using gross cost and gross benefit, but rather to compare the present worth of the net benefit with the present worth of the investment cost plus the operation and maintenance cost. The ratio is computed by taking the present worth of the gross benefit less associated cost and then comparing it with the present worth of the project cost. The associated cost is the value of goods and services over and above those included in project costs needed to make the immediate products or services of the project available for use or sale. Project economic cost is the sum of installation cost, operation and maintenance cost and replacement costs.

The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit - cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \quad \dots (3.36)$$

Where, C_t = Cost in each year,

B_t = Benefit in each year,

$t = 1, 2, 3, \dots, n$ (year)

i = Discount rate

RESULTS
AND
DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

To study the performance of solar tunnel dryer for drying of medicinal plants, viz., *Adhatoda vasica* and *Moringa oleifera*, an experiment was conducted as per the methodology as described in chapter III. The observations of micro-climatic conditions of solar tunnel dryer during the no load condition as well as full load condition were recorded. Also, various physio-chemical and functional parameters of the solar tunnel dried and sun-dried medicinal plant leaf powder were taken.

Various observations were taken to identify the best method to prepare *Adhatoda vasica* and *Moringa oleifera* leaf powder in accordance with varying steam blanching time and appropriate drying method. In accordance with these variables, the physical, bio-chemical and functional parameters of the final solar tunnel dried and sun-dried *Adhatoda vasica* and *Moringa oleifera* leaf powder by different treatments were also considered for its quality evaluation. As described in chapter III, observations were analysed by using analysis of variance technique considering Factorial Completely Randomized Design (FCRD) with three factors. This chapter also deals with the evaluation of the techno-economic performance of the dryer as well as the thermal analysis of solar tunnel dryer with the help of a mathematical model.

4.1 DIURNAL VARIATION OF AMBIENT ENVIRONMENTAL DATA

The daily global radiation, ambient temperature, relative humidity and wind velocity data recorded on hourly basis with the help of all the analytical instruments, viz., k-type sensors, humidity cum temperature sensor, pyranometer and a datalogger. The data was analysed to obtain weekly average hourly data and discussed here under (Appendix-I) for different weeks of study.

4.1.1 Global Solar Radiation

The weekly average hourly global radiation data were computed from the daily obtained data and presented in Fig. 4.1, 4.2 and 4.3 for different weeks. It shows that the global radiation intensity during different weeks of the month was varied from 115.85 W/m² to 586.18 W/m², 137.82 W/m² to 595.84 W/m² and 145.68 W/m² to 538.02 W/m² for the duration of 14th January to 21st January, 22nd January to 29th

January and 30th January to 5th February 2022, respectively. The data shows that solar radiation intensity in above weeks is quite high, which is also responsible to increase inside air temperature in a natural convection type solar tunnel dryer.

4.1.2 Ambient Air Temperature

From Fig. 4.4, 4.5 and 4.6 it can be seen that in the first week, i.e., from 14th January to 21st January, ambient temperature was varied from 18.22°C (min.) to 29.42°C (max.) during sunshine hours. In second week, i.e., from 22nd January to 29th January, these temperatures were observed to be very close to the 1st week though slightly lower, i.e., 16.99°C (min.) to 27.92°C (max.). In 3rd week, i.e., from 30th January to 5th February, the ambient temperature increased to 19.58°C (min.) to 30.19°C (max.) during sunshine hours as compared to 1st week. The monthly average revealed that temperature varied from 18.26°C to 29.18°C which is quite suitable for natural ventilation.

4.1.3 Ambient Relative Humidity

From Fig. 4.7, 4.8 and 4.9 it can be seen that in the 1st week, i.e., 14th January to 21st January, the ambient relative humidity varied from 40.060% to 68.278%. Similarly for the second week (22nd January 2022 to 29th January 2022) and third week (30th January 2022 to 5th February 2022), the minimum and the maximum values for relative humidity were 26.63% and 55.76%, and 32.5% and 75.84%, respectively. It was derived that the value of relative humidity was higher in the morning when the temperature was low, then it decreased gradually till 16:00 h. The relative humidity increases after 17:00 h as temperature starts decreasing in the evening.

Thus, it could be observed that the relative humidity and temperature are inversely proportional to each other and the drying was better when relative humidity was lower, since the air was drier and the temperature was higher. Similarly, when the relative humidity was higher, the temperature was low and drying could not be done properly.

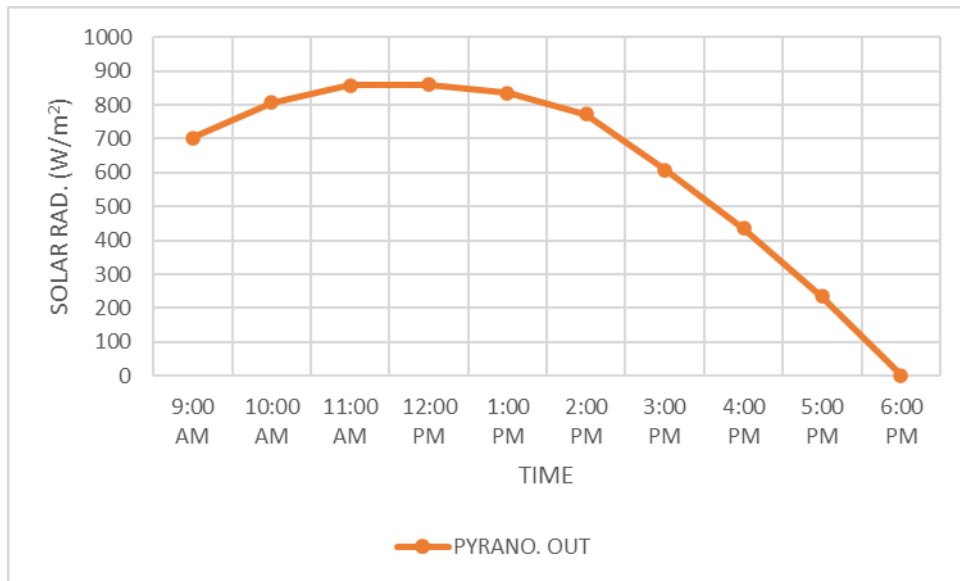


Fig. 4.1 Variation in global solar radiation during 14th January to 21st January outside the dryer.

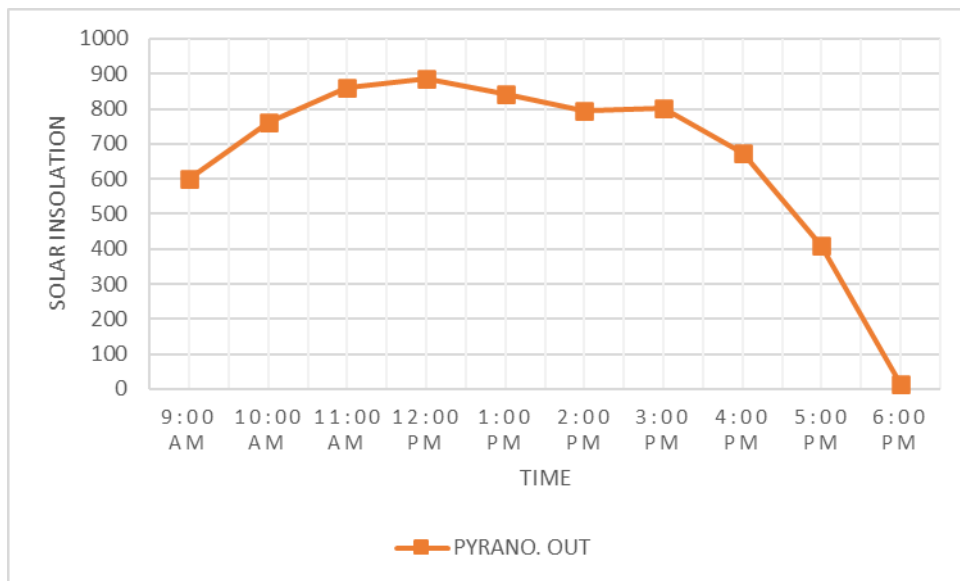


Fig. 4.2 Variation in global solar radiation during 22nd January to 29th January outside the dryer.

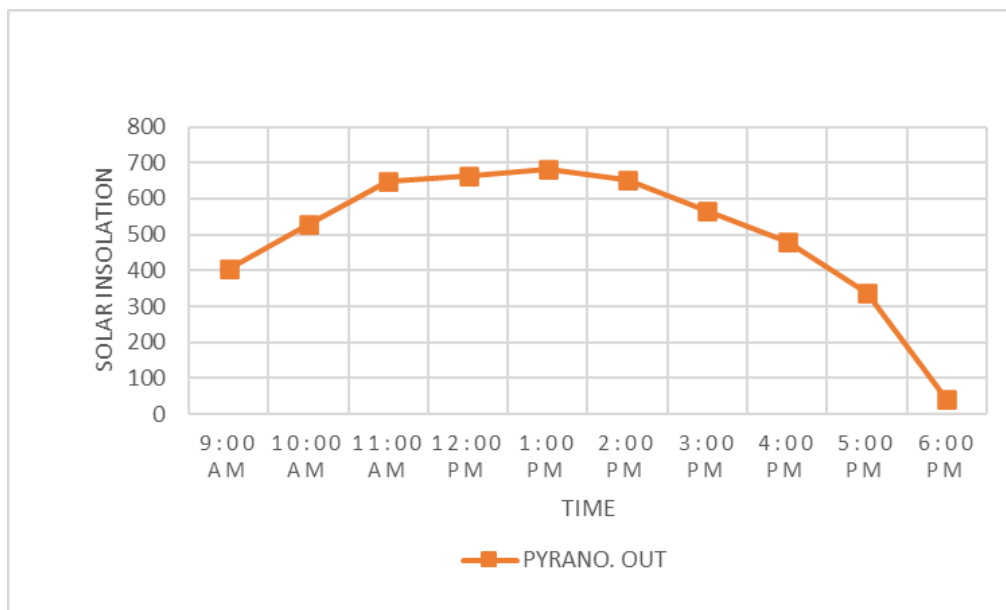


Fig. 4.3 Variation in global solar radiation during 29th January to 5th February outside the dryer.

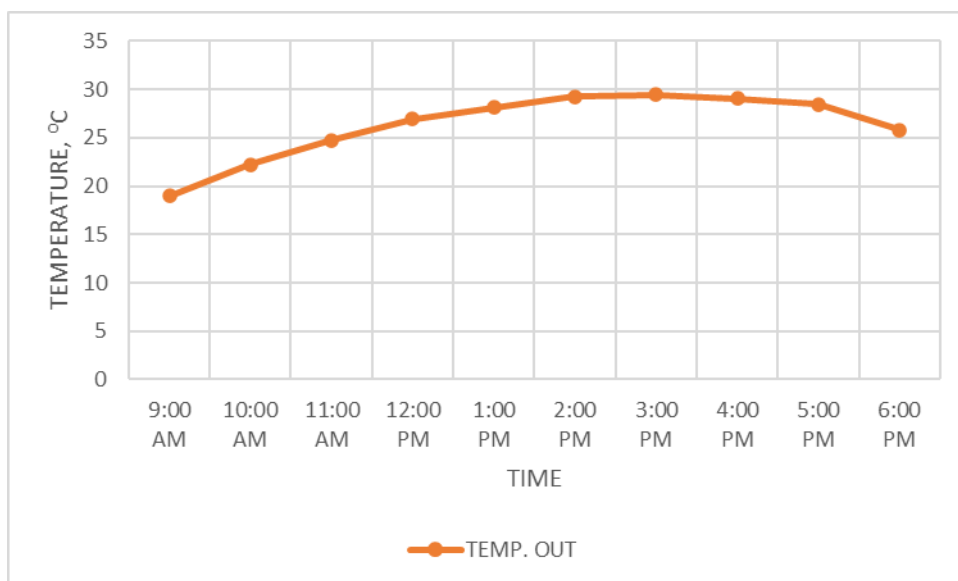


Fig. 4.4 Variation in temperature during 14th January to 21st January outside the dryer.

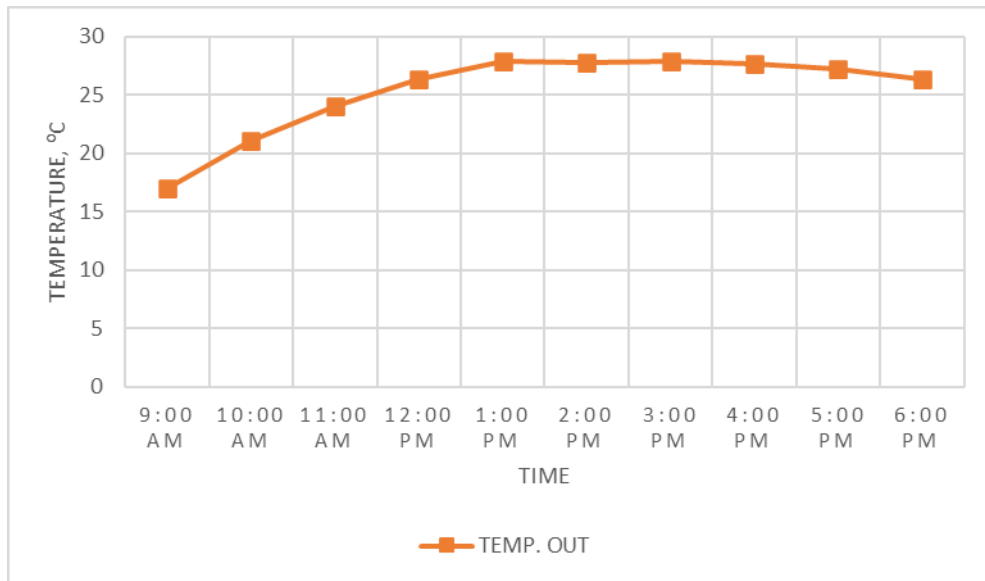


Fig. 4.5 Variation in temperature during 22nd January to 29th January outside the dryer.

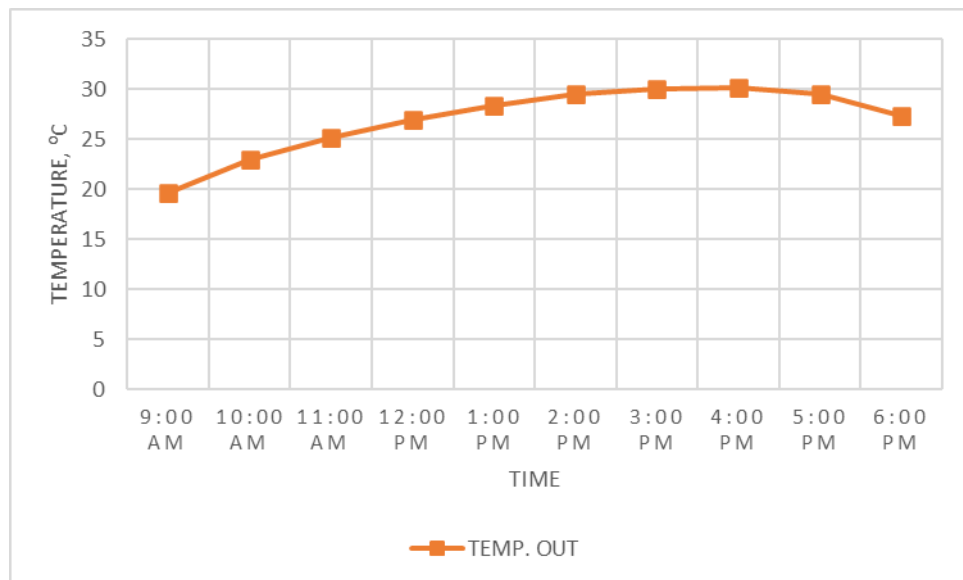


Fig. 4.6 Variation in temperature during 29th January to 5th February outside the dryer.

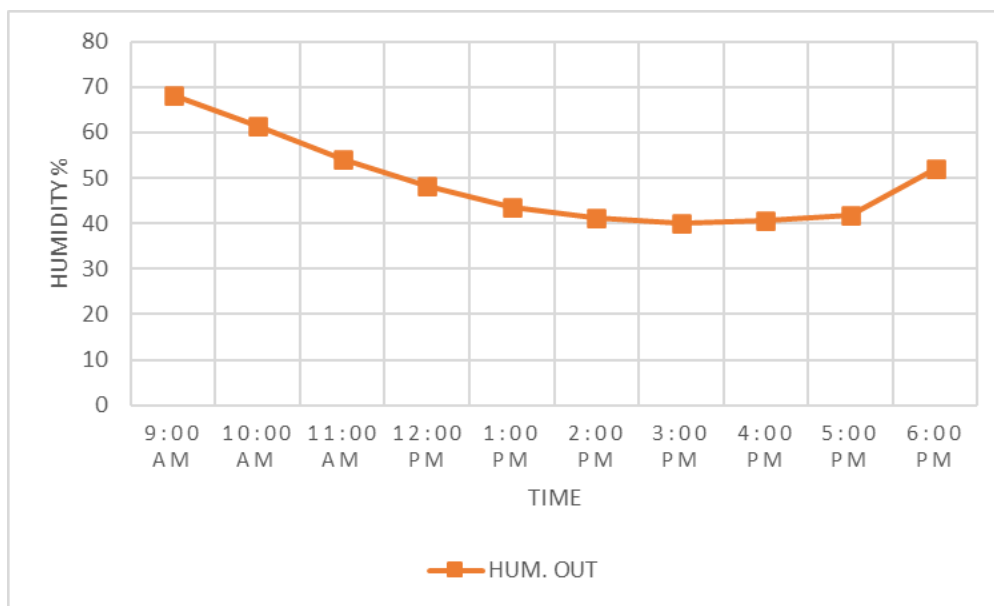


Fig. 4.7 Variation in relative humidity during 14th January to 21st January outside the dryer.

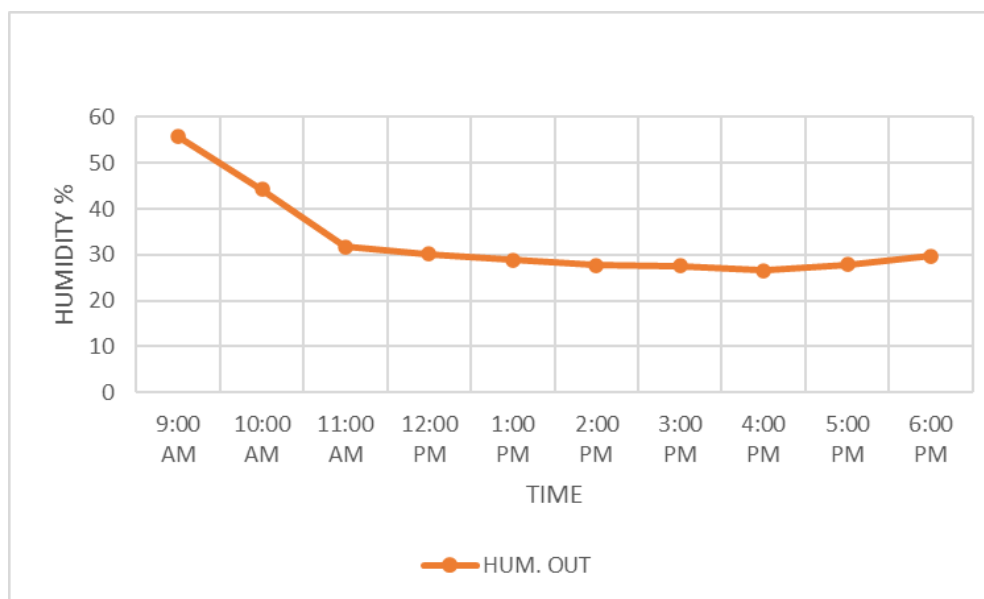


Fig. 4.8 Variation in relative humidity during 22nd January to 29th January outside the dryer.

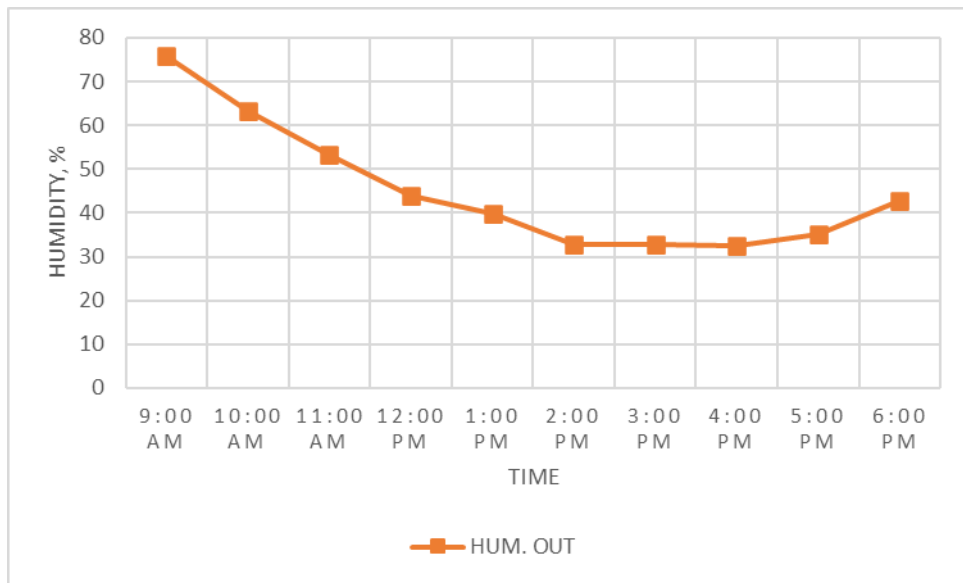


Fig. 4.9 Variation in relative humidity during 29th January to 5th February outside the dryer.

4.2 DIURNAL VARIATION OF SOLAR TUNNEL DRYER ENVIRONMENT

The solar tunnel dryer environment in terms of diurnal variation of inside air, temperature, relative humidity and solar radiation, were measured for the time interval of 1 h for the different days, starting from 14th January to 5th February 2022 and same were analysed to obtain weekly average data which are discussed here under.

4.2.1 Inside Solar Radiation

The diurnal variation in solar tunnel dryer solar radiation for different weeks of January and February are presented in Fig. 4.10, 4.11 and 4.12.

Fig. 4.10 shows the diurnal variation of inside solar radiation in 1st week, i.e., from 14th January to 21st January 2022. It shows that the minimum solar radiation inside the solar tunnel dryer was 84.02 W/m² at 18:00 h and its maximum was recorded as 586.82 W/m² at 13:00 h. Similarly, Fig. 4.11 shows that the solar radiation variation inside the solar tunnel dryer for the 2nd week, i.e., 22nd January 2022 to 29th January 2022. It can be determined from the graph that, the minimum and the maximum solar radiation values recorded were 10.63 W/m² and 595.84 W/m² at 18:00 h and 13:00 h, respectively. From Fig. 4.12, it can be observed that, for 3rd week, i.e., 30th January to 5th February 2022, the minimum and the maximum solar radiation values recorded were 16.71 W/m² and 538.02 W/m² at 18:00 h and 13:00 h, respectively.

4.2.2 Inside Air temperature

The weekly average hourly temperatures (T_{gh}) for the solar tunnel dryer during the study period were varied from 21.07°C to 53.23°C, 18.63°C to 50.76°C and 21.11°C to 55.09°C for 14th to 21st January, 22nd to 29th January and 30th January to 5th February 2022, respectively. From Fig. 4.13, 4.14 and 4.15, it was observed that, as compared to the ambient temperature, the air temperature of solar tunnel dryer remained relatively higher and the maximum temperature inside the solar tunnel dryer was found to be at 14:00 h, whereas the minimum temperature was determined at 9:00 h.

Inside the solar tunnel dryer, k-type sensors were placed in five locations, that is, at the centre with one at the top (T1), second one at the centre (T2) and the third sensor at the bottom (T3) of the dryer. Similarly, one sensor each was fitted at each end of the solar tunnel dryer (T4 and T5). The graphs demonstrating their temperature variations are represented in Fig. 4.16, 4.17 and 4.18.

From the Fig. 4.16 it may be observed that, the temperature of sensor T4 is the highest, which is then followed by sensor T2, T3 and then by sensor T1. T5 has the lowest temperature which may be due to frequent opening and closing of the solar tunnel dryer door. Similarly, from Fig. 4.17, it may be understood that, T2 has the highest temperature, which may be due to the heat radiated from the floor as well as their proximity to the drying stands. Sensor T2 is followed by sensor T3, as the black painted floor also radiates heat. Sensor T4 and T1 almost have the same temperature as both are near the cover and they receive heat from the cover and are at equidistant from the drying trays and the floor. Here also, sensor T5 has the lowest temperature due to the same reason as mentioned above.

Correspondingly, from Fig. 4.18, it may be observed that, sensor T2 and T3 have similar temperature curve as the 3rd week, i.e., from 30th January to 5th February had higher temperature compared to the previous two weeks, thus sensors T2 and T3 might have received surplus heat radiation from the black painted floor as well as the drying stands. These sensors were then followed by sensors T1 and T4 which also followed a similar trend due to the previously mentioned reasons. The sensor T5 still had the lowest temperature, due to the frequent influence of the door.

4.2.3 Inside Relative Humidity

The diurnal variation in solar tunnel dryer relative humidity for different weeks of January to February are presented in Fig. 4.19, 4.20 and 4.21.

The minimum relative humidity inside the solar tunnel dryer for the 1st week, (17th January 2022 to 21st January 2022), was recorded as 13.64% at 15:00 h and the maximum relative humidity was recorded to be 58.9% at 9:00 h. Similarly for the 2nd week (22nd January 2022 to 29th January 2022) the minimum relative humidity value was observed as 10.23% at 15:00 h and the maximum value was recorded as 52.17% at 15:00 h. Correspondingly, for the 3rd week (30th January 2022 to 5th February 2022), the minimum and the maximum relative humidity values were recorded as 10.73% at 9:00 h and 63.12%, respectively at 15:00 h, respectively.

Thus, it may be concluded that the observed relative humidity variations were in accordance with the variations of temperature inside the solar tunnel dryer as they are inversely proportional to each other, as mentioned earlier in the subsection 4.1.3.

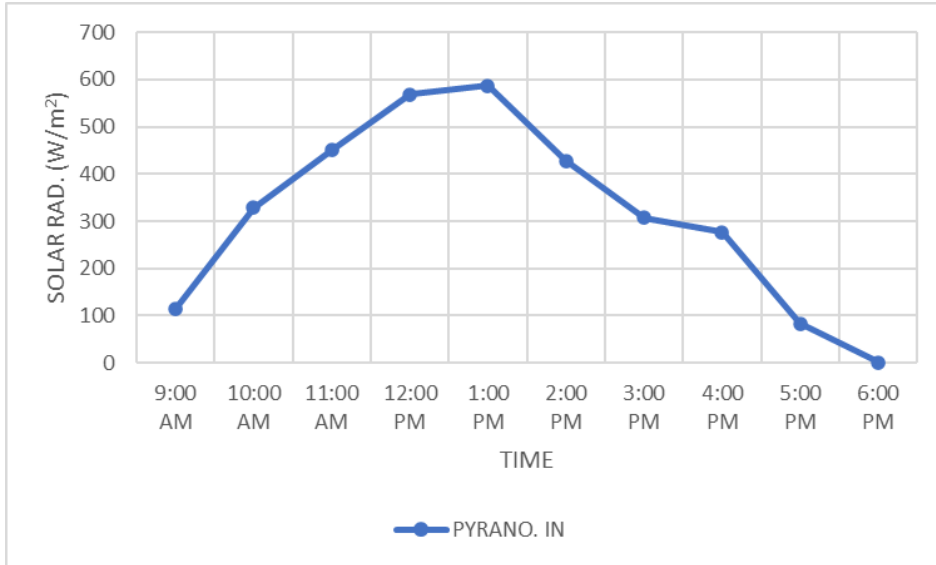


Fig. 4.10 Variation in global solar radiation during 14th January to 21st January inside the dryer.

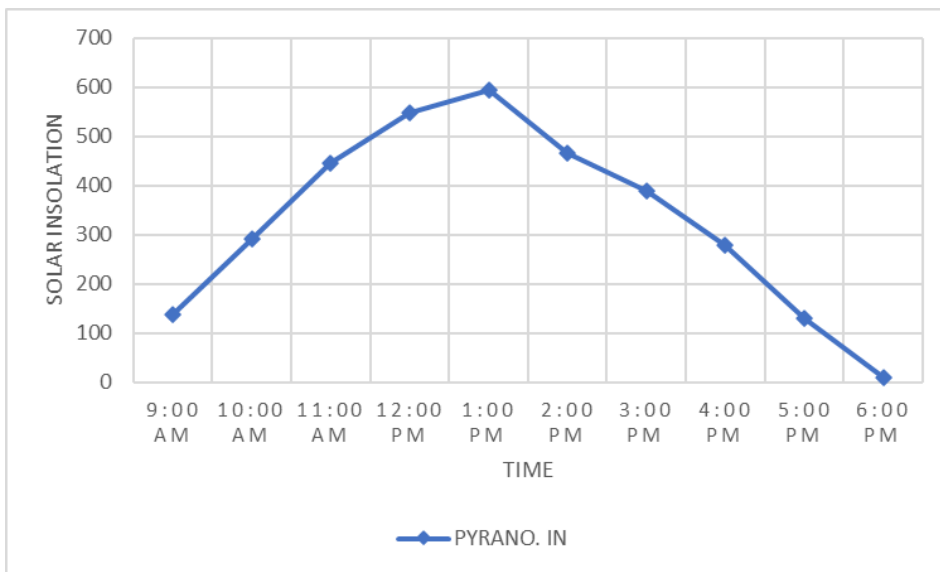


Fig. 4.11 Variation in global solar radiation during 22nd January to 29th January inside the dryer.

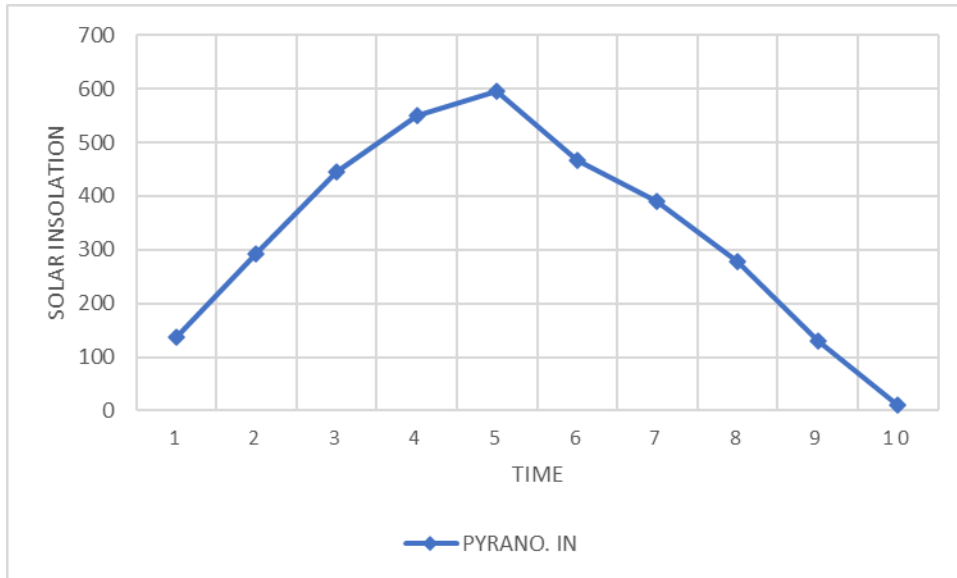


Fig. 4.12 Variation in global solar radiation during 29th January to 5th February inside the dryer.

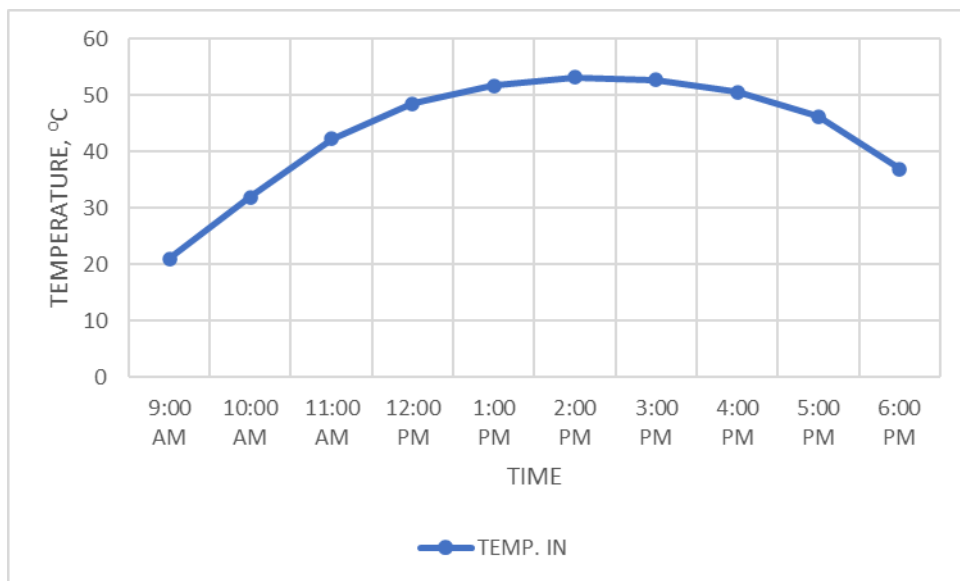


Fig. 4.13 Variation in temperature during 14th January to 21st January inside the dryer.

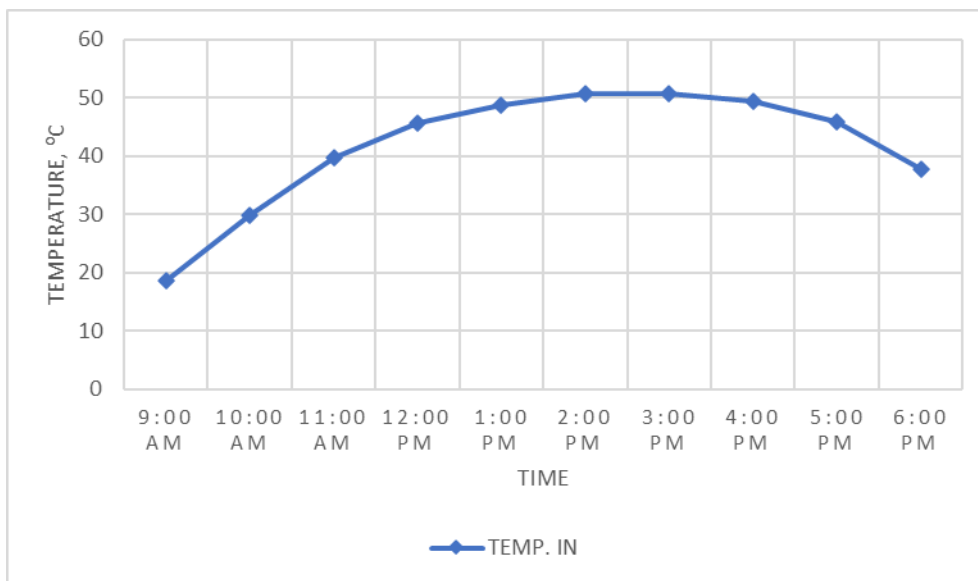


Fig. 4.14 Variation in temperature during 22nd January to 29th January inside the dryer.

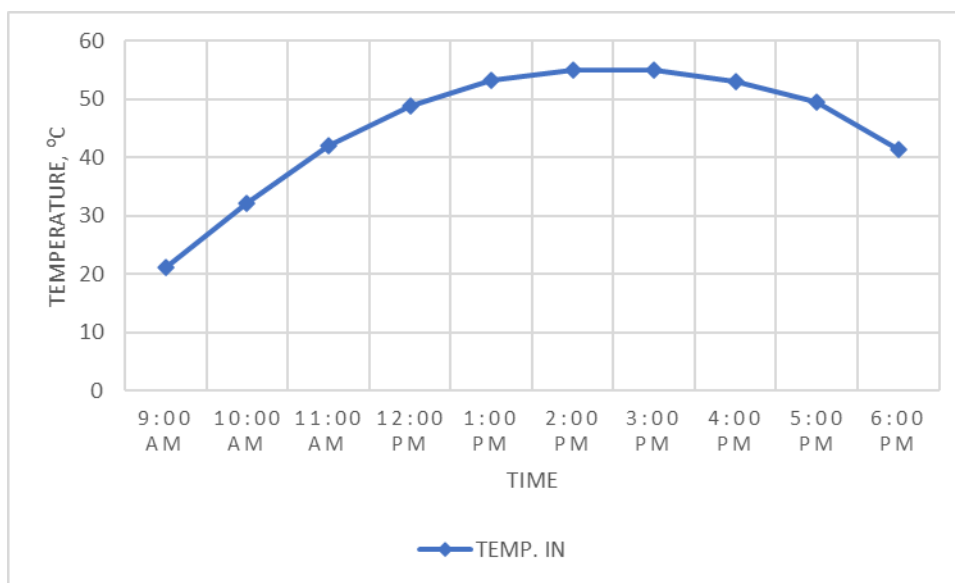


Fig. 4.15 Variation in temperature during 29th January to 5th February inside the dryer.

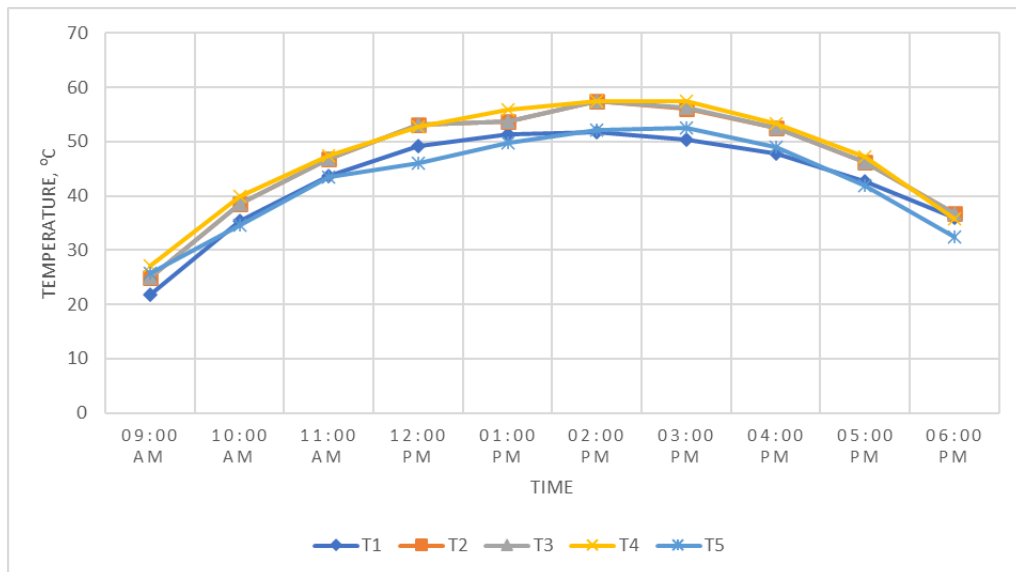


Fig. 4.16 Temperature variation at different location inside the dryer for the week of 14th January to 21st January.

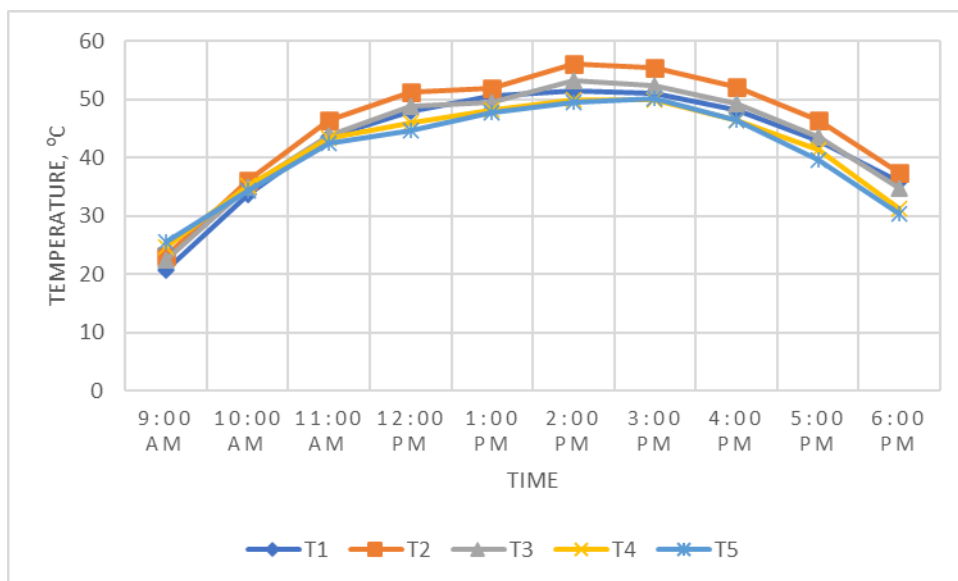


Fig. 4.17 Temperature variation at different location inside the dryer for the week of 22nd January to 29th January.

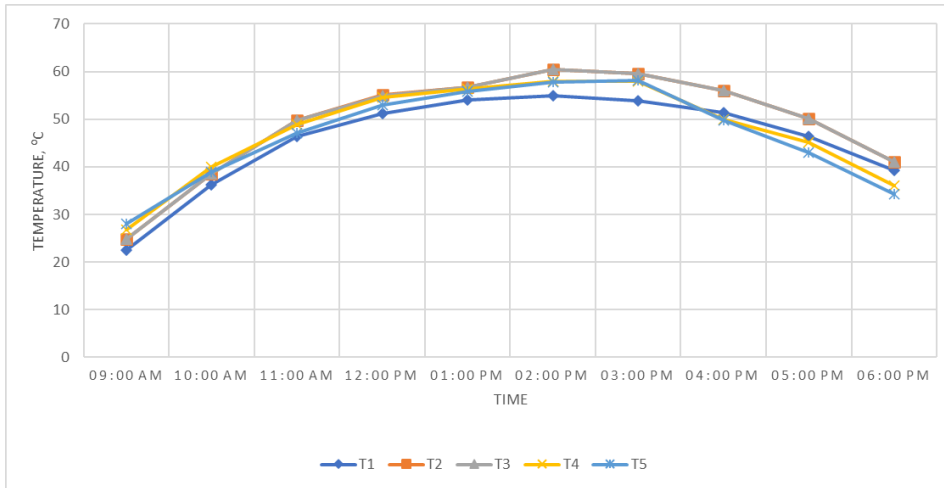


Fig. 4.18 Temperature variation at different location inside the dryer for the week of 29th January to 5th February.

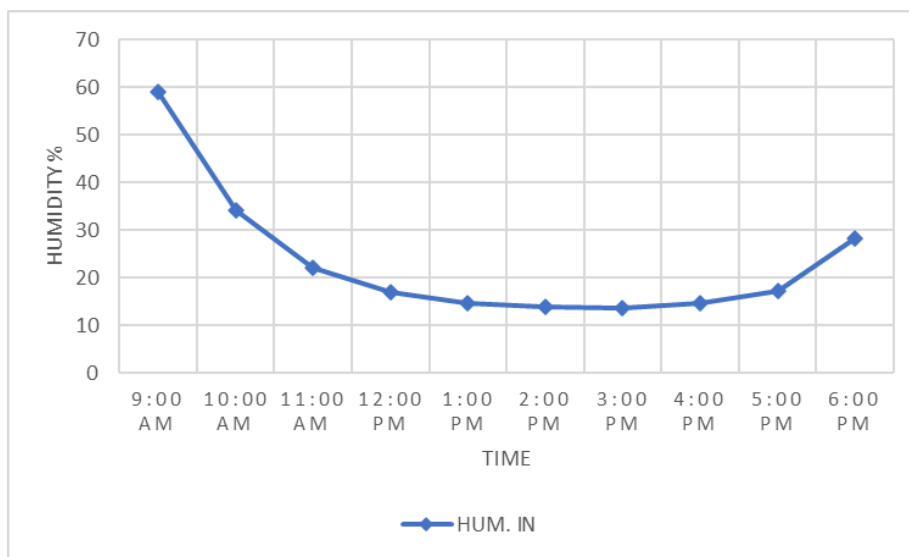


Fig. 4.19 Variation in relative humidity during 14th January to 21st January inside the dryer.

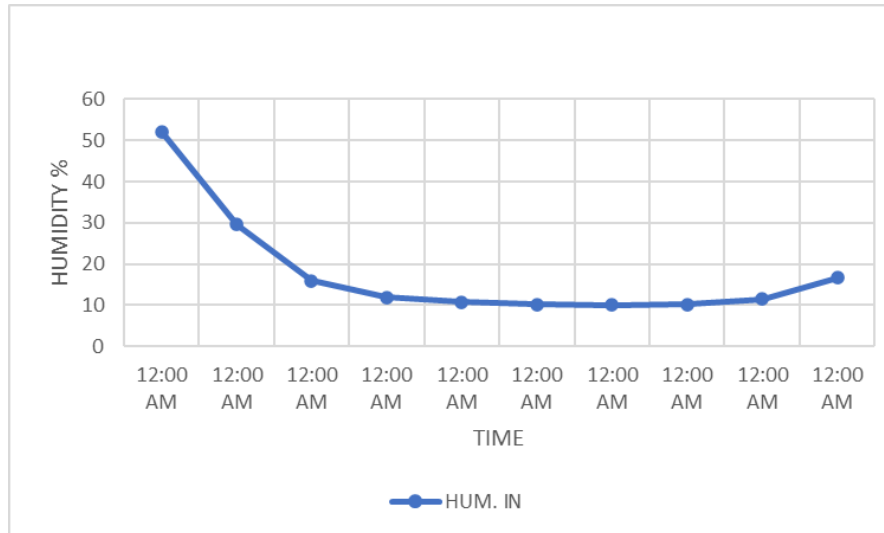


Fig. 4.20 Variation in relative humidity during 22nd January to 29th January inside the dryer.

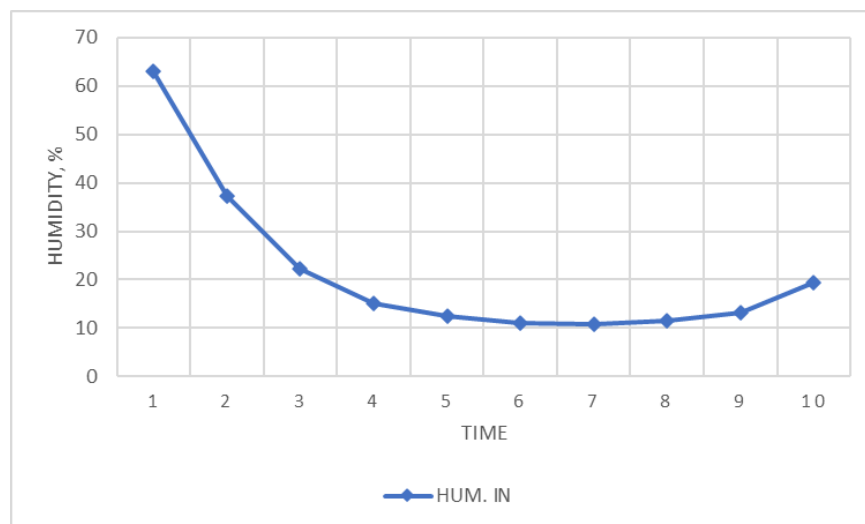


Fig. 4.21 Variation in relative humidity during 29th January to 5th February inside the dryer.

4.3 PERFORMANCE EVALUATION OF SOLAR TUNNEL DRYER

The performance evaluation of the solar tunnel dryer was carried out by determining the moisture content, moisture ratio, drying rate, drying characteristics and physio-chemical parameters of the freshly harvested leaves as well as dried leaves by the solar tunnel dryer as well as by sun drying. These parameters were then statistically analysed with the help of 3 factorial completely randomized design.

For the performance evaluation of the solar tunnel dryer, its thermal efficiency, the total energy required for drying as well as the energy required per hour were also calculated. The result for the different samples is presented here under. The details of drying of *Adhatoda vasica* and *Moringa oleifera* leaves are presented in Appendix II.

4.3.1 Moisture Content, Moisture Ratio and Drying Rate Determination

Table 4.1 demonstrates the values of moisture content, moisture ratio and drying rate of *Adhatoda vasica*. It can be observed from this Table that, for the 1st trial, the sun-dried sample has the drying constant as 0.31 h^{-1} and R^2 value as 0.82. Similarly, the unblanched sample dried in solar tunnel dryer has the drying constant and R^2 value as 0.57 h^{-1} and 0.95, respectively, but for 3-minute and 5-minute blanched sample, the drying constant and R^2 value were recorded to be 0.79 h^{-1} and 0.98, and 0.72 h^{-1} and 0.99, respectively.

Correspondingly, for the 2nd trial, the drying constant and R^2 value of the sun-dried sample was recorded as 0.47 h^{-1} and 0.85, respectively. For the solar tunnel dried unblanched sample the drying constant and R^2 value were 0.73 h^{-1} and 0.89, respectively, whereas for 3-minute and 5-minute blanched sample, the drying constant and R^2 value were observed as 1.12 h^{-1} and 0.90, and 0.91 h^{-1} and 0.96, respectively.

For the 3rd trial, the drying constant and R^2 value of the sun-dried sample was observed to be 0.59 h^{-1} and 0.93. Similarly, the drying constant and R^2 value of the unblanched sample were recorded as 0.60 h^{-1} and 0.93, respectively, whereas for 3-minute and 5-minute blanched sample, the drying constant and R^2 value was 1.02 h^{-1} and 0.95, and 0.80 h^{-1} and 0.99, respectively.

It can be observed from the Table 4.1 that, maximum drying rate was found to be between 3rd and 4th hour for sun dried samples. For the solar tunnel dried but unblanched samples drying rate peaked only after the 5th hour, whereas for the blanched samples, the drying rate started increasing from the 1st hour itself and decreased as the

drying time increased. This demonstrates that, in blanched samples which are dried in solar tunnel dryer, the drying rate is higher and faster as compared to other samples. These observations were similar to the findings of Hossain *et al.* (2007).

From the Table 4.1, it can also be understood that the R^2 value which shows the goodness of fit, is better for 5 minutes blanched samples which were dried in solar tunnel dryer, as compared to other samples. This was followed by the 3-minute blanched solar tunnel dried sample and then by the unblanched solar tunnel dried sample. The graphs representing the trends of drying rate vs drying time and moisture ratio vs drying time for *Adhatoda vasica* is represented in Fig. 4.26 and 4.28, respectively.

Table 4.1 Moisture content, moisture ratio and drying rate of *Adhatoda vasica***a) TRIAL 1**

| Sun dried sample | | | | | |
|-------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.31 | 0.82 |
| 1 | 277.68 | 9.01 | 0.96 | | |
| 2 | 256.66 | 21.02 | 0.89 | | |
| 3 | 166.55 | 90.10 | 0.56 | | |
| 4 | 85.46 | 81.09 | 0.27 | | |
| 5 | 46.41 | 39.04 | 0.13 | | |
| 6 | 14.88 | 31.53 | 0.32 | | |
| 7 | 10.37 | 4.50 | 0.00 | | |

| STD unblanched sample | | | | | |
|------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.57 | 0.95 |
| 1 | 205.40 | 6.88 | 0.71 | | |
| 2 | 148.64 | 7.47 | 0.50 | | |
| 3 | 102.70 | 9.11 | 0.34 | | |
| 4 | 73.87 | 8.18 | 0.23 | | |
| 5 | 33.33 | 17.48 | 0.09 | | |
| 6 | 16.21 | 11.0 | 0.03 | | |
| 7 | 9.00 | 5.68 | 0.00 | | |

| STD 3 min blanched sample | | | | | |
|----------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.79 | 0.98 |
| 1 | 147.48 | 17.76 | 0.50 | | |
| 2 | 102.48 | 7.90 | 0.33 | | |
| 3 | 65.92 | 15.55 | 0.20 | | |
| 4 | 39.21 | 14.65 | 0.11 | | |
| 5 | 19.52 | 6.05 | 0.04 | | |
| 6 | 9.68 | 3.37 | 0.00 | | |
| 7 | 8.27 | 1.18 | 0.00 | | |

| STD 5 min blanched sample | | | | | |
|----------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.72 | 0.98 |
| 1 | 125.88 | 15.49 | 0.42 | | |
| 2 | 87.82 | 6.56 | 0.28 | | |
| 3 | 58.36 | 13.79 | 0.18 | | |
| 4 | 36.26 | 11.67 | 0.10 | | |
| 5 | 20.30 | 9.73 | 0.04 | | |
| 6 | 9.25 | 8.40 | 0.00 | | |
| 7 | 6.80 | 2.10 | 0.00 | | |

b) TRIAL 2

| Sun dried sample | | | | | |
|------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.10 | | 1.00 | 0.46 | 0.848 |
| 1 | 222.45 | 5.11 | 0.77 | | |
| 2 | 170.48 | 5.95 | 0.58 | | |
| 3 | 167.30 | 0.44 | 0.57 | | |
| 4 | 138.66 | 4.48 | 0.47 | | |
| 5 | 108.96 | 5.95 | 0.36 | | |
| 6 | 85.62 | 6.01 | 0.28 | | |
| 7 | 51.68 | 12.05 | 0.16 | | |
| 8 | 18.80 | 18.24 | 0.04 | | |
| 9 | 11.37 | 5.61 | 0.02 | | |
| 10 | 9.25 | 1.74 | 0.01 | | |
| 11 | 7.13 | 1.81 | 0.00 | | |

| STD with unblanched sample | | | | | |
|----------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.73 | 0.89 |
| 1 | 218.45 | 5.54 | 0.75 | | |
| 2 | 138.08 | 10.60 | 0.46 | | |
| 3 | 94.10 | 9.51 | 0.30 | | |
| 4 | 50.13 | 15.09 | 0.02 | | |
| 5 | 18.28 | 17.93 | 0.03 | | |
| 6 | 15.25 | 2.22 | 0.02 | | |
| 7 | 10.70 | 3.56 | 0.00 | | |
| 8 | 8.42 | 1.89 | 0.00 | | |

| STD with 3 min blanched sample | | | | | |
|---------------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 1.12 | 0.90 |
| 1 | 190.67 | 8.03 | 0.65 | | |
| 2 | 64.97 | 23.67 | 0.20 | | |
| 3 | 23.08 | 18.30 | 0.05 | | |
| 4 | 12.60 | 12.93 | 0.01 | | |
| 5 | 9.11 | 2.84 | 0.00 | | |
| 6 | 7.80 | 1.11 | 0.00 | | |

| STD with 5 min blanched sample | | | | | |
|---------------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.91 | 0.956 |
| 1 | 170.27 | 8.23 | 0.58 | | |
| 2 | 61.25 | 25.77 | 0.19 | | |
| 3 | 26.05 | 19.42 | 0.06 | | |
| 4 | 6.74 | 14.34 | 0.00 | | |

c) TRIAL 3

| Sun dried sample | | | | | |
|-------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.698 | | 1.000 | 0.53 | 0.68 |
| 1 | 262.670 | 1.713 | 0.913 | | |
| 2 | 240.144 | 1.826 | 0.832 | | |
| 3 | 201.849 | 3.730 | 0.693 | | |
| 4 | 126.012 | 11.116 | 0.418 | | |
| 5 | 44.918 | 24.759 | 0.125 | | |
| 6 | 20.139 | 14.232 | 0.035 | | |
| 7 | 10.378 | 7.361 | 0.000 | | |

| STD with unblanched sample | | | | | |
|-----------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.59 | 0.93 |
| 1 | 219.20 | 7.22 | 0.75 | | |
| 2 | 161.54 | 7.56 | 0.551 | | |
| 3 | 88.42 | 3.26 | 0.28 | | |
| 4 | 42.02 | 5.48 | 0.12 | | |
| 5 | 25.14 | 20.33 | 0.06 | | |
| 6 | 18.11 | 0.69 | 0.03 | | |
| 7 | 13.90 | 6.88 | 0.02 | | |
| 8 | 8.27 | 15.05 | 0.00 | | |

| STD with 3 min blanched sample | | | | | |
|---------------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 1.02 | 0.95 |
| 1 | 174.78 | 10.53 | 0.59 | | |
| 2 | 72.87 | 21.45 | 0.23 | | |
| 3 | 41.94 | 12.60 | 0.12 | | |
| 4 | 18.28 | 14.09 | 0.03 | | |
| 5 | 9.18 | 7.04 | 0.00 | | |
| 6 | 7.82 | 1.15 | 0.00 | | |

| STD with 5 min blanched sample | | | | | |
|---------------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 286.69 | | 1.00 | 0.80 | 0.99 |
| 1 | 144.35 | 15.06 | 0.49 | | |
| 2 | 49.46 | 25.98 | 0.15 | | |
| 3 | 35.22 | 7.04 | 0.10 | | |
| 4 | 6.75 | 19.72 | 0.00 | | |

Table 4.2 demonstrates the values of moisture content, moisture ratio and drying rate of *Moringa oleifera*. It can be observed from this Table that, for the 1st trial, which is the sun-dried sample, the values of the drying constant and the R² were recorded to be 0.55 h⁻¹ and 0.95, respectively. For unblanched sample dried in solar tunnel dryer, the drying constant and R² value was observed to be 0.57 h⁻¹ and 0.98, respectively, but for 3-minute and 5-minute blanched sample, drying constant and R² value were obtained as 0.49 h⁻¹ and 0.99, and 0.52 h⁻¹ and 0.92, respectively.

Similarly, for the 2nd trial, the drying constant and R² value of the sun-dried sample were 0.33 h⁻¹ and 0.94, respectively. For the unblanched solar dried sample, the drying constant and R² value were observed to be 0.58 h⁻¹ and 0.95, respectively, whereas for 3-minute and 5-minute blanched sample, the drying constant and R² value were recorded as 0.71 h⁻¹ and 0.96, and 0.79 h⁻¹ and 1.00, respectively.

For the 3rd trial, the drying constant and R² value of the sun-dried sample was observed as 0.51 h⁻¹ and 0.78, respectively. For the solar tunnel dried unblanched sample, the drying constant and R² value were 0.68 h⁻¹ and 0.96, respectively, whereas for 3-minute and 5-minute blanched sample, the drying constant and R² value were recorded to be 0.64 h⁻¹ and 0.97, and 0.75 h⁻¹ and 0.98, respectively.

It can be observed from this Table 4.2 that, for the sun-dried sample the drying rate increased in the 4th and 5th hour, whereas for the blanched samples, which were dried in solar tunnel dryer, the drying rate was increased in the 1st hour itself, which proves that, blanching increases drying rate and thus reducing the drying time. This was in accordance with the findings of Hossain *et al.* (2007).

The graphs representing the trends of drying rate vs drying time and moisture ratio vs drying time for *Moringa oleifera* leaves is represented in Fig. 4.27 and 4.29, respectively.

Table 4.2 Moisture content, moisture ratio and drying rate of *Moringa oleifera***a) TRIAL 1**

| Sun dried sample | | | | | |
|-------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.22 | | 1.00 | 0.53 | 0.93 |
| 1 | 267.55 | 2.42 | 0.88 | | |
| 2 | 164.90 | 10.54 | 0.54 | | |
| 3 | 100.00 | 12.25 | 0.32 | | |
| 4 | 58.94 | 12.91 | 0.19 | | |
| 5 | 29.13 | 14.51 | 0.09 | | |
| 6 | 14.57 | 9.84 | 0.04 | | |
| 7 | 10.59 | 3.13 | 0.03 | | |

| STD unblanched sample | | | | | |
|------------------------------|----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.578 | 0.98 |
| 1 | 199.91 | 8.50 | 0.65 | | |
| 2 | 129.46 | 5.93 | 0.41 | | |
| 3 | 83.17 | 10.16 | 0.26 | | |
| 4 | 51.97 | 16.36 | 0.15 | | |
| 5 | 23.79 | 14.97 | 0.06 | | |
| 6 | 15.74 | 5.62 | 0.03 | | |
| 7 | 5.64 | 8.26 | 0.00 | | |

| STD 3 min blanched sample | | | | | |
|----------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.49 | 0.99 |
| 1 | 177.11 | 11.30 | 0.57 | | |
| 2 | 119.25 | 5.22 | 0.38 | | |
| 3 | 70.53 | 9.21 | 0.21 | | |
| 4 | 47.69 | 5.13 | 0.14 | | |
| 5 | 23.33 | 25.42 | 0.06 | | |
| 6 | 6.58 | 7.67 | 0.00 | | |
| 7 | 5.05 | 5.07 | 0.00 | | |

| STD 5 min blanched sample | | | | | |
|----------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.22 | | 1.00 | 0.53 | 0.93 |
| 1 | 267.55 | 2.42 | 0.88 | | |
| 2 | 164.90 | 10.54 | 0.54 | | |
| 3 | 100.00 | 12.25 | 0.32 | | |
| 4 | 58.94 | 12.91 | 0.193 | | |
| 5 | 29.13 | 14.51 | 0.09 | | |
| 6 | 14.57 | 9.84 | 0.04 | | |
| 7 | 10.59 | 3.13 | 0.03 | | |
| 8 | 5.06 | 0.00 | 0.00 | | |

b) TRIAL 2

| Sun dried sample | | | | | |
|------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.33 | 0.94 |
| 1 | 245.03 | 4.19 | 0.80 | | |
| 2 | 181.45 | 6.54 | 0.58 | | |
| 3 | 167.55 | 1.84 | 0.53 | | |
| 4 | 141.06 | 4.10 | 0.44 | | |
| 5 | 84.10 | 12.83 | 0.24 | | |
| 6 | 44.37 | 14.95 | 0.11 | | |
| 7 | 11.92 | 20.08 | 0.00 | | |

| STD unblanched sample | | | | | |
|-----------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.58 | 0.95 |
| 1 | 213.91 | 7.01 | 0.69 | | |
| 2 | 151.49 | 7.90 | 0.48 | | |
| 3 | 102.64 | 9.58 | 0.32 | | |
| 4 | 56.50 | 14.54 | 0.16 | | |
| 5 | 28.46 | 13.94 | 0.07 | | |
| 6 | 15.79 | 8.51 | 0.02 | | |
| 7 | 7.65 | 6.53 | 0.00 | | |

| STD 3 min blanched sample | | | | | |
|----------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.71 | 0.96 |
| 1 | 198.91 | 8.61 | 0.65 | | |
| 2 | 123.43 | 11.30 | 0.39 | | |
| 3 | 80.15 | 10.75 | 0.25 | | |
| 4 | 49.96 | 11.17 | 0.15 | | |
| 5 | 21.77 | 15.43 | 0.05 | | |
| 6 | 7.68 | 9.04 | 0.041 | | |
| 7 | 4.97 | 2.58 | 0.00 | | |

| STD 5 min blanched sample | | | | | |
|----------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.78 | 1.00 |
| 1 | 139.04 | 17.04 | 0.45 | | |
| 2 | 72.05 | 16.28 | 0.22 | | |
| 3 | 33.98 | 16.51 | 0.09 | | |
| 4 | 15.71 | 11.78 | 0.03 | | |
| 5 | 11.14 | 3.55 | 0.02 | | |
| 6 | 4.75 | 3.85 | 0.00 | | |

c) TRIAL 3

| Sun dried sample | | | | | |
|-------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.51 | 0.78 |
| 1 | 274.17 | 1.94 | 0.90 | | |
| 2 | 242.384 | 2.48 | 0.79 | | |
| 3 | 176.82 | 6.91 | 0.57 | | |
| 4 | 111.92 | 11.06 | 0.35 | | |
| 5 | 54.96 | 17.34 | 0.15 | | |
| 6 | 19.20 | 19.35 | 0.03 | | |
| 7 | 8.60 | 8.18 | 0.00 | | |

| STD unblanched sample | | | | | |
|------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.68 | 0.96 |
| 1 | 213.91 | 7.01 | 0.69 | | |
| 2 | 118.02 | 14.01 | 0.37 | | |
| 3 | 73.69 | 13.88 | 0.22 | | |
| 4 | 36.60 | 13.45 | 0.09 | | |
| 5 | 23.93 | 7.48 | 0.05 | | |
| 6 | 12.17 | 8.45 | 0.01 | | |
| 7 | 7.65 | 3.74 | 0.00 | | |

| STD 3 blanched sample | | | | | |
|------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.64 | 0.96 |
| 1 | 195.89 | 8.95 | 0.64 | | |
| 2 | 130.47 | 9.59 | 0.42 | | |
| 3 | 79.14 | 12.43 | 0.28 | | |
| 4 | 38.88 | 16.18 | 0.11 | | |
| 5 | 19.76 | 11.49 | 0.05 | | |
| 6 | 11.71 | 6.01 | 0.02 | | |
| 7 | 4.97 | 5.11 | 0.00 | | |

| STD 5 blanched sample | | | | | |
|------------------------------|-----------------|----------------------|------------------------|---------------------------------------|----------------|
| Time, h | M. C. (% db) | Drying Rate (%/h) | Moisture Ratio (MR) | Drying Constant (h ⁻¹) | R ² |
| 0 | 303.48 | | 1.00 | 0.74 | 0.97 |
| 1 | 178.63 | 11.10 | 0.58 | | |
| 2 | 113.16 | 11.02 | 0.36 | | |
| 3 | 56.82 | 16.85 | 0.17 | | |
| 4 | 29.42 | 13.50 | 0.08 | | |
| 5 | 11.14 | 8.02 | 0.02 | | |
| 6 | 5.05 | 8.53 | 0.00 | | |

4.3.2 Drying Characteristics of Dried Products

To study the drying characteristics of medicinal plants, drying characteristics curves are required which contains the following parameters:

1. Moisture content vs drying time
2. Drying rate vs drying time
3. Moisture ratio vs drying time

The moisture content, moisture ratio and the drying rate were determined as per the formulas given in the previous Chapter III in equation no.3.1, 3.2 and 3.3 under subsections 3.5.1, 3.5.2 and 3.5.3, respectively. The values of the same are also provided in the previous sub-section.

4.3.2.1 Moisture content vs drying time

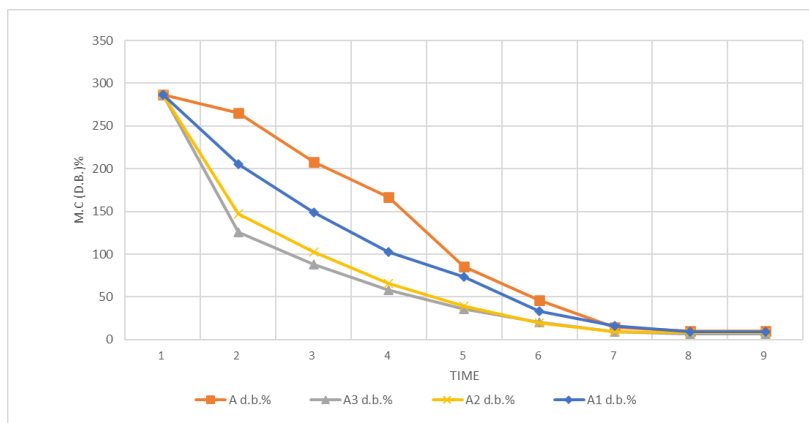
The resultant graphs for moisture content vs drying time for the samples and their trials are given in Fig. 4.22 for *Adhatoda vasica* and Fig. 4.23 for *Moringa oleifera*. It could be observed that almost similar drying curves were obtained for all the trials. Also, it indicated that the moisture content of the leaves of *Adhatoda vasica* and *Moringa oleifera* decreased with increase in drying time. The reduction in moisture content was faster in the first few hours of drying, which was subsequently slow with increase in drying period.

In the graphs represented in Fig. 4.22, A represents unblanched sample of *Adhatoda vasica* leaves dried in open sun, A1 represents unblanched sample of *Adhatoda vasica* leaves dried in solar tunnel dryer and A2 and A3 represents blanched sample of *Adhatoda vasica* leaves for 3-minutes and 5-minutes, respectively and dried in solar tunnel dryer. From the graph we can understand that, the unblanched sample which was kept in open sun for drying had uneven and slow drying, whereas for the samples kept in the solar tunnel dryer, they had even and fast drying. The unblanched sun dried samples took more than 9 hours to dry and the final moisture content was 10.38% (db), whereas the unblanched solar tunnel dried sample took 7 hours to dry and its moisture content was recorded as 9.00% (db). But the samples which were blanched for 3 and 5 minutes took only 5-6 hours to dry and the moisture content recorded for these samples were 8.27% (db) and 6.80% (db), respectively. The blanched samples took 3 hours less time to dry as compared to unblanched samples. Fig. 4.24 represents the average of all the trials for *Adhatoda vasica*. This was in accordance with the

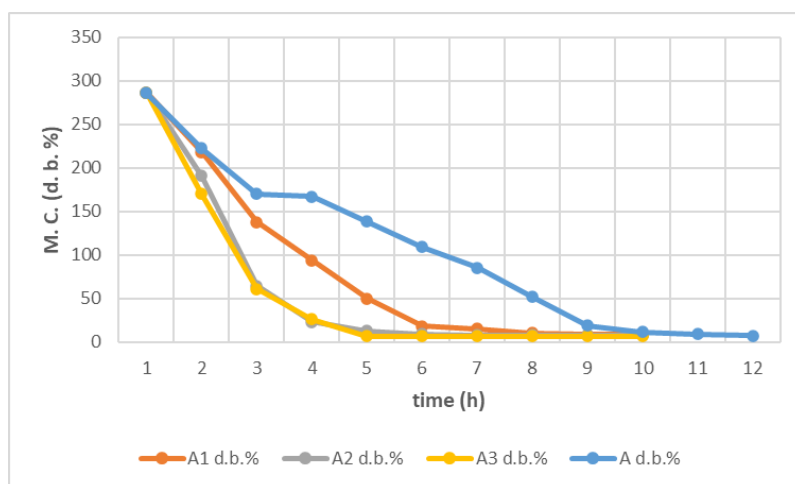
findings of Hossain *et al.* (2007), who had concluded that blanching helps in reducing drying time.

In the graphs represented in Fig. 4.23, M represents unblanched sample of *Moringa oleifera* leaves dried in open sun, M1 represents unblanched sample of *Moringa oleifera* leaves dried in solar tunnel dryer and M2 and M3 represents blanched sample of *Moringa oleifera* leaves for 3-minutes and 5-minutes, respectively and dried in solar tunnel dryer. The trends of the drying curves were similar to the curves obtained in drying of *Adhatoda vasica* leaves. Further, the 5-minute blanched leaves of *Moringa oleifera* showed the minimum moisture content of 5.09% (db) after drying as compared to all other treated leaves of *Moringa oleifera* at the end of 5 hours of drying. The moisture content of unblanched solar tunnel dried sample was found to be 7.65% (db) after 5 hours of drying, whereas for the sun-dried sample the moisture content was found to be 8.06% (db) even after 8 hours of drying. The effect of blanching on the drying time could be observed clearly. The drying of blanched samples in solar tunnel dryer took only 5 hours as compared to 9 hours by sun drying. It indicated that drying rate reduced with the increase in drying time. Further, all the trays in the solar tunnel dryer showed uniform drying pattern.

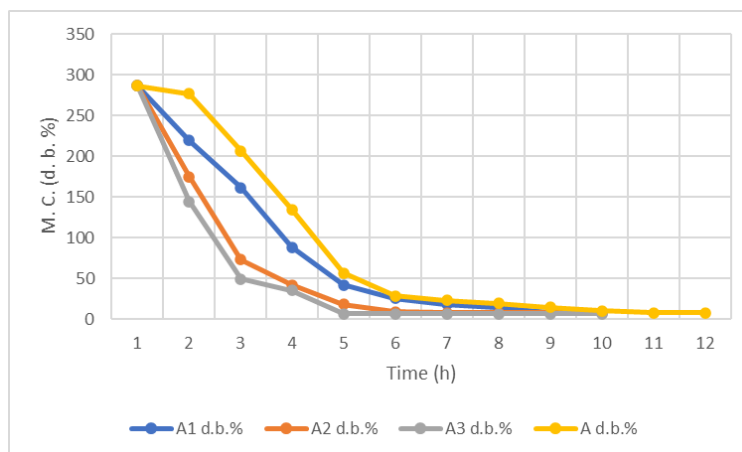
The average values graph is represented in Fig. 4.25. The drying curves obtained were similar in trends to those obtained by Nobosse *et al.* (2017) for drying of *Moringa oleifera* leaves.



(a) Trial 1 for *Adhatoda vasica*

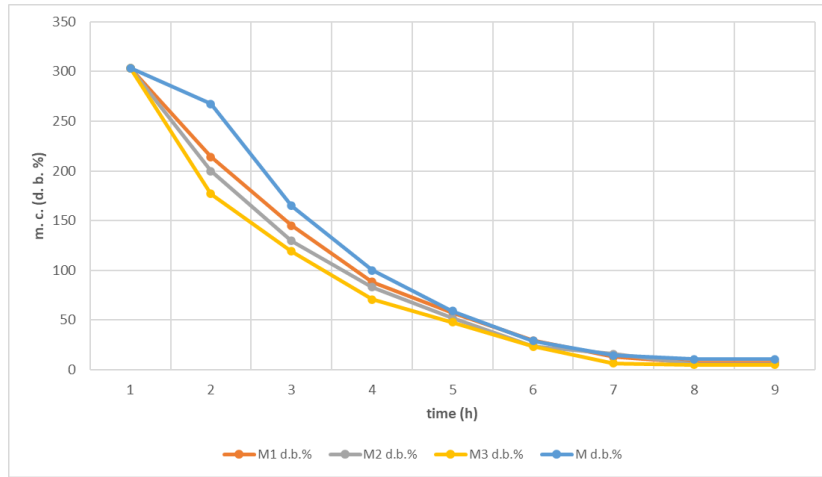


(b) Trial 2 for *Adhatoda vasica*

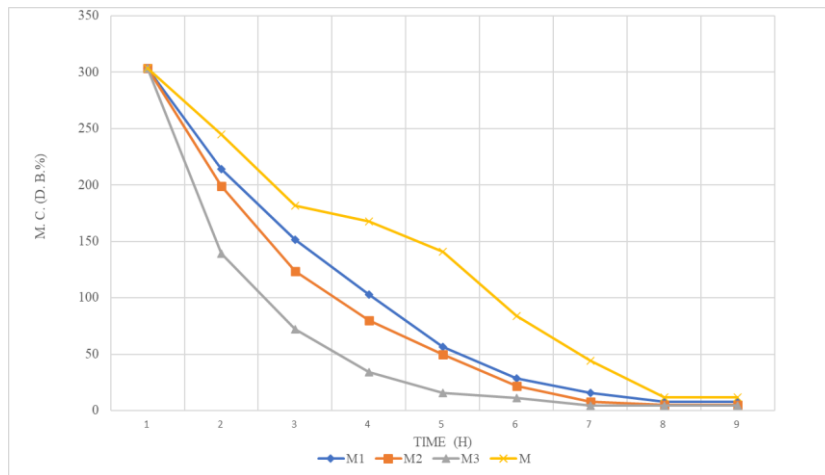


(c) Trial 3 for *Adhatoda vasica*

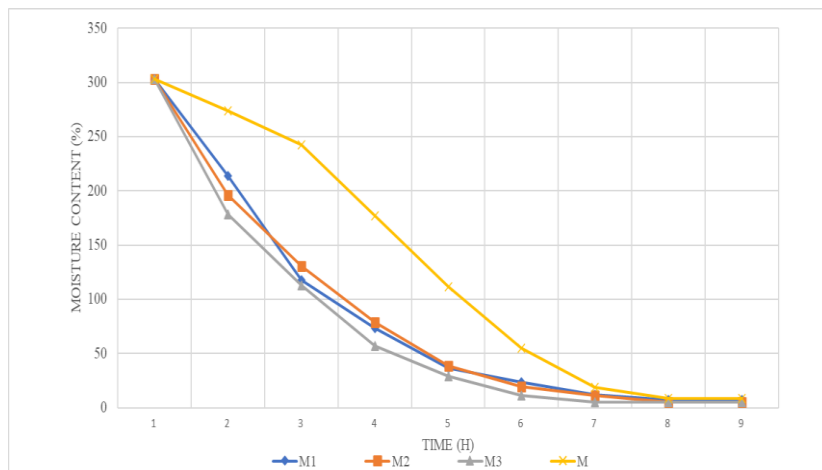
Fig. 4.22 (a), (b), (c) Moisture content vs drying time for *Adhatoda vasica* for different trials



(a) Trial 1 for *Moringa oleifera*



(b) Trial 2 for *Moringa oleifera*



(c) Trial 3 for *Moringa oleifera*

Fig. 4.23 (a), (b), (c)Moisture content vs drying time for *Moringa oleifera* for different trials

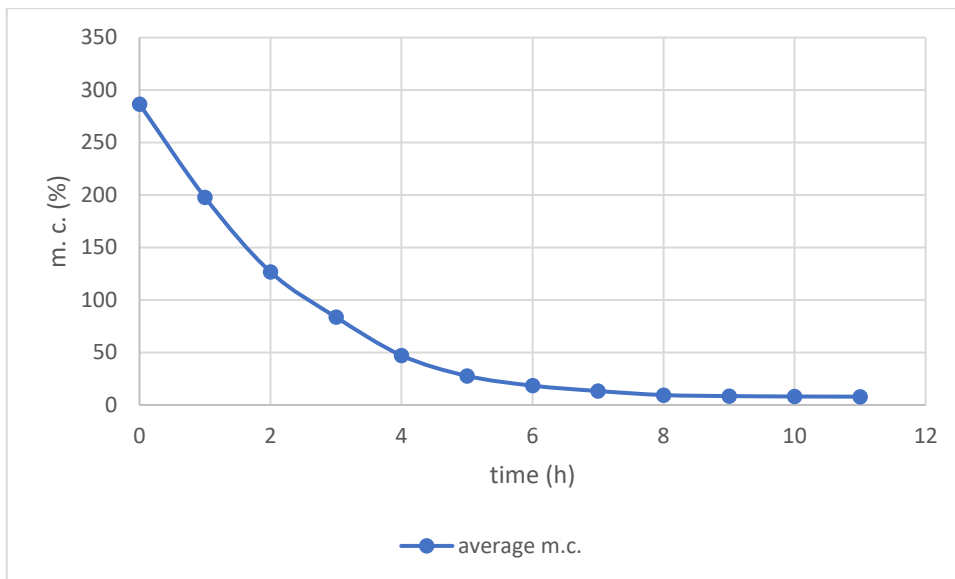


Fig. 4.24 Average moisture content vs drying time for *Adhatoda vasica*

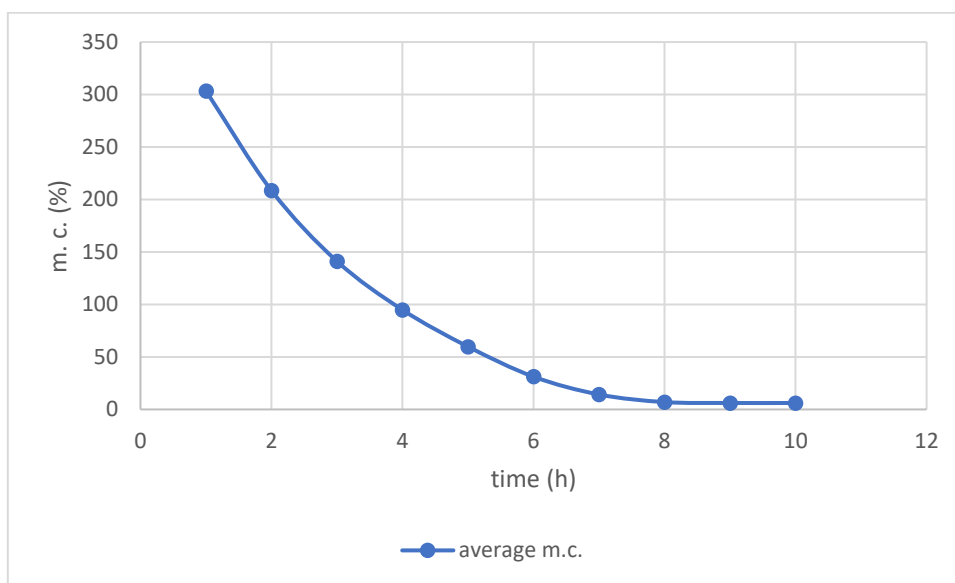


Fig. 4.25 Average moisture content vs drying time for *Moringa oleifera*

4.3.2.2 Drying rate vs drying time

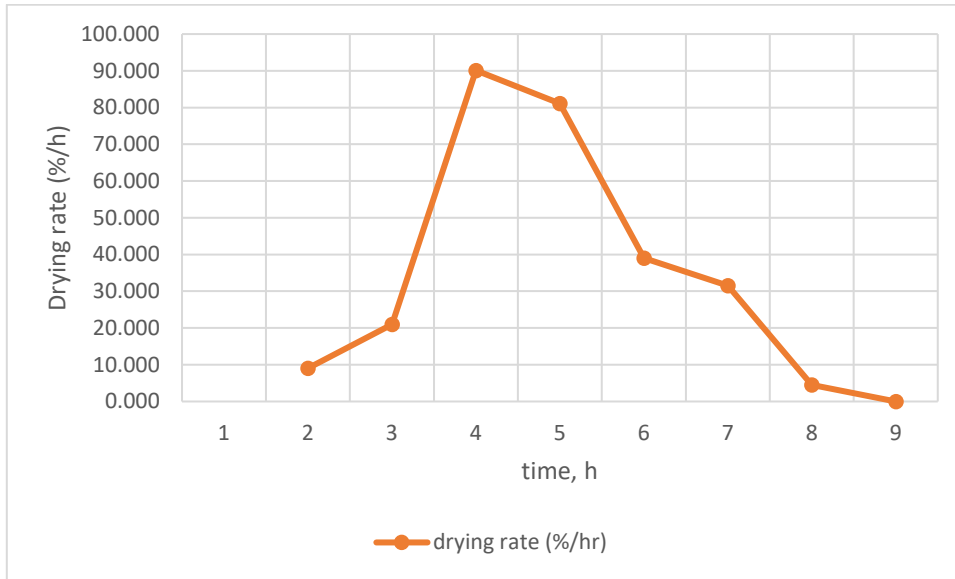
The drying rates at different drying time for the blanched and unblanched samples dried in open sun and in solar tunnel dryer were determined as given in subsection 4.3.1 and the mean graph for their trials are given in Fig. 4.24 for *Adhatoda vasica* and Fig. 4.25 for *Moringa oleifera*. It could be observed that the drying rates first increased for couples of hours due to high moisture content and then gradually started decreasing with the increase in drying time as the moisture content in the product was reduced significantly with the passage of time.

The Fig. 4.26 (a) shows that, for a sun-dried sample of *Adhatoda vasica* leaves, the drying rate increased in the 3rd and the 4th hour, which was recorded as 90.10 %/h and 81.09 %/h, respectively. In an unblanched solar tunnel dried sample (Fig. 4.26 (b)) the drying rate started increasing from the 2nd hour with 7.47 %/h and maximum drying rate was achieved in the 5th hour which was observed to be 17.48 %/h as the temperature inside the solar tunnel dryer is higher as compared to the outside temperature due to the greenhouse effect. For the 3-minute and 5-minute blanched samples which were dried in solar tunnel dryer, as shown in Fig. 4.26 (c) and (d), respectively, the maximum drying rate was achieved very quickly, that is in 2 hours of drying and gradually decreases after 4 hours of drying which demonstrates that moisture content of the leaves had reduced significantly after 4 hours of drying. The data for these graphs are presented in Table 4.1 in the subsection 4.3.1.

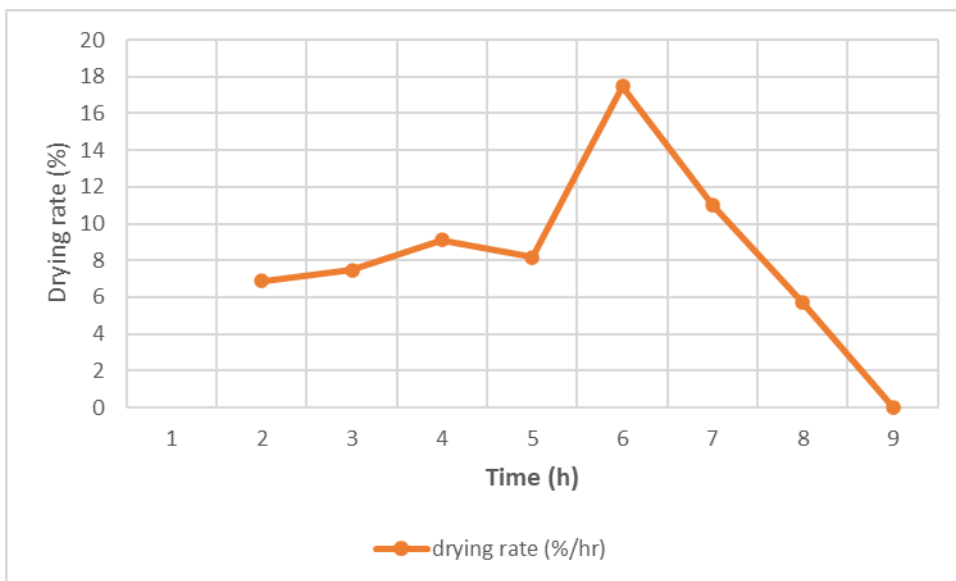
The Fig. 4.27 (a) shows the graph for drying rate vs drying time for sun-dried leaves of *Moringa oleifera*. It demonstrates that, the drying starts at the 2nd hour of drying with a drying rate of 10.54 %/h. This is due to the small size of the leaves of *Moringa oleifera*, since the leaves are small in size, their surface area is increased due to which drying takes place faster even in open sun drying. Fig. 4.27 (b) represents the drying rate vs drying time for the unblanched sample of *Moringa oleifera* leaves dried in solar tunnel dryer. From this graph it may be observed that, drying rate starts increasing from the 1st hour itself and was maximum at 3 hours with a drying rate of 11.95 %/h. For the 3-minute blanched sample which was dried in the solar tunnel dryer (Fig. 4.27 (c)), the drying rate was maximum at 4 hours which was recorded 16.37 %/h. Similarly for the 5-minute blanched solar tunnel dried sample (Fig. 4.27 (d)), the drying period started at 3 hours from the start of drying time but a rate of 11.30 %/h and

reached a maximum value at 4 hours of drying with the drying rate of 25.42 %/h. The data for the Fig. 4.27 is presented in Table 4.2 in the subsection 4.3.1.

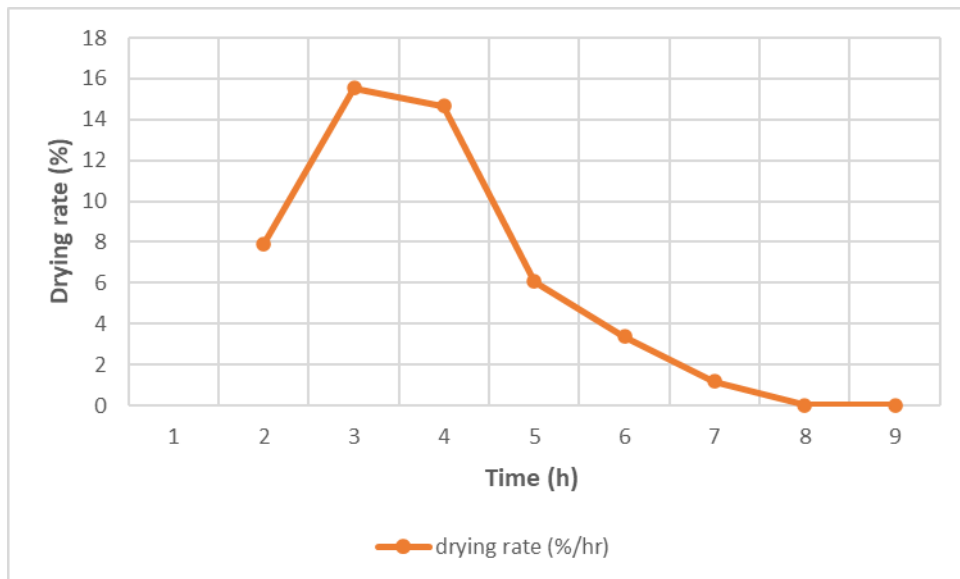
Adhatoda vasica



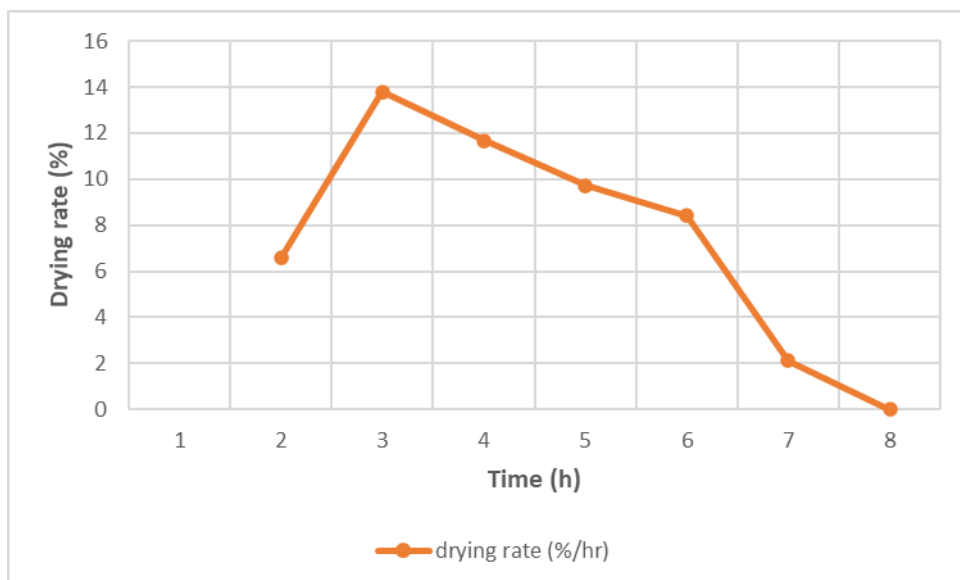
a) Drying rate vs drying time for sun-dried sample



b) Drying rate vs drying time for unblanched sample



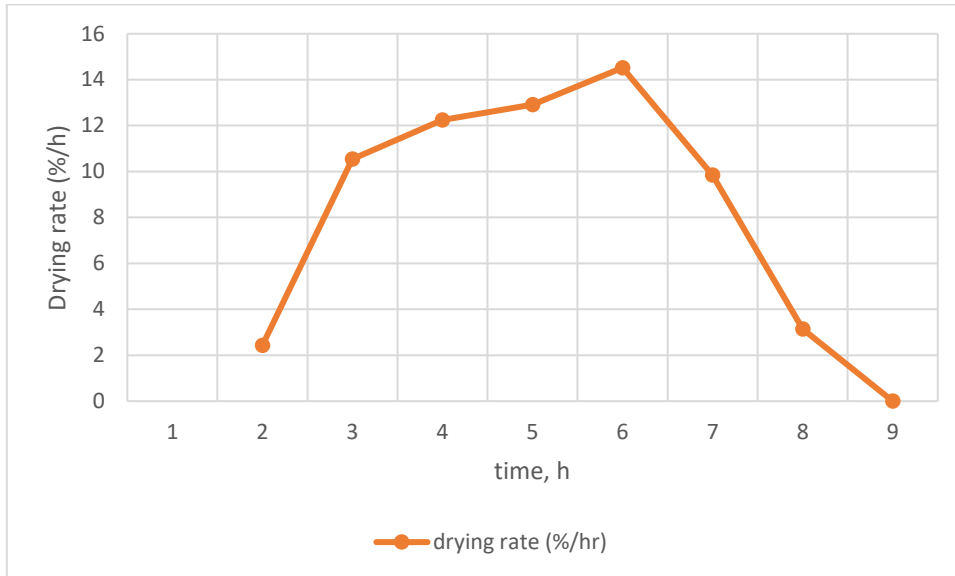
c) Drying rate vs drying time for 3-minute blanched sample



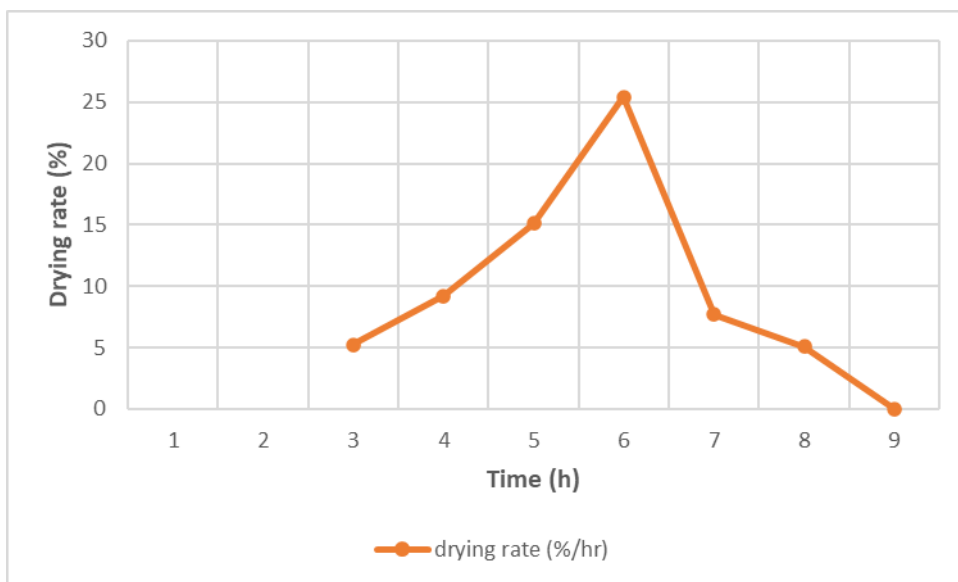
d) Drying rate vs drying time for 5-minute blanched sample

Fig. 4.26 (a), (b), (c), (d) Drying rate vs drying time for *Adhatoda vasica* for different trials

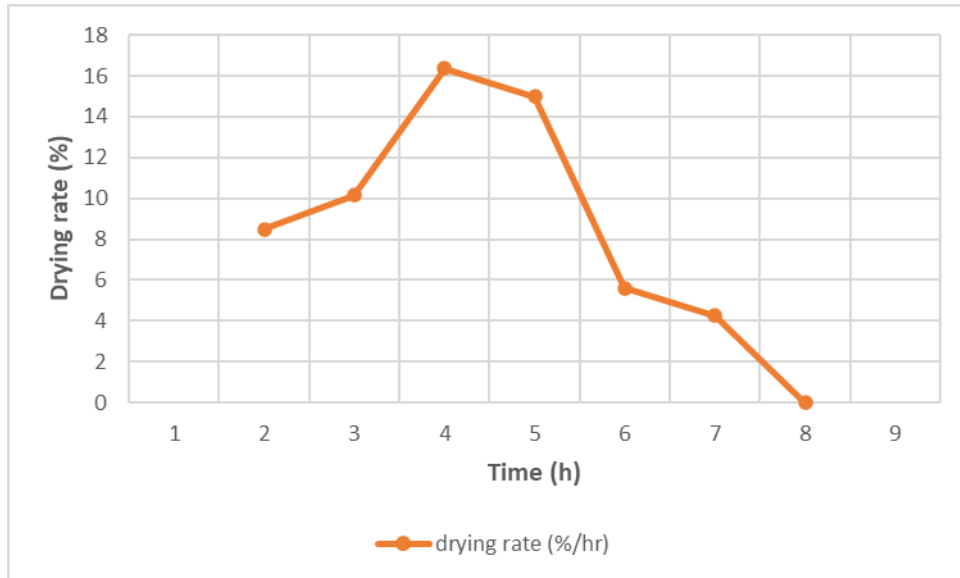
Moringa oleifera



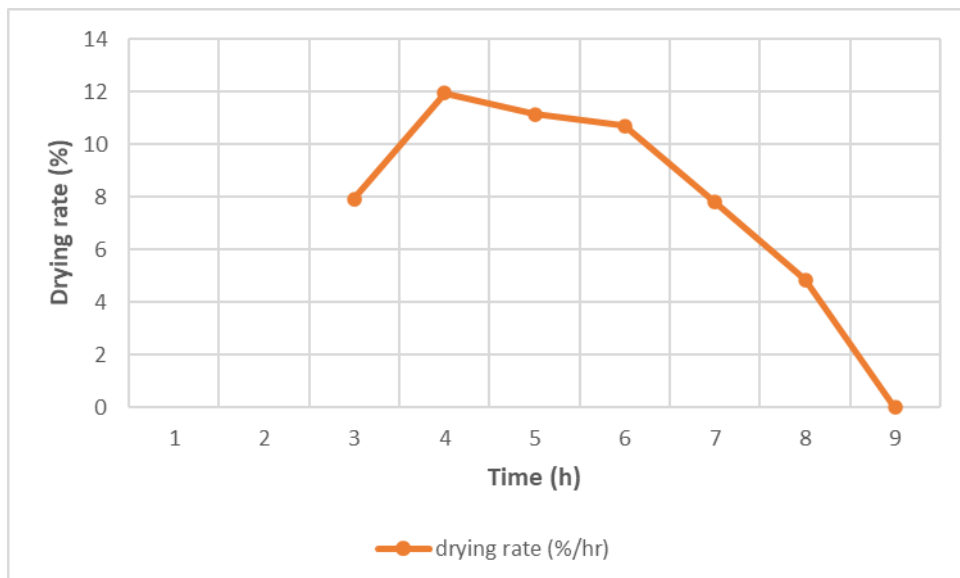
a) Drying rate vs drying time for sun dried sample



b) Drying rate vs drying time for unblanched sample



c) Drying rate vs drying time for 3-minute blanched sample



d) Drying rate vs drying time for 5-minute blanched sample

Fig. 4.27 (a), (b), (c), (d) Drying rate vs drying time for *Moringa oleifera* for different trials

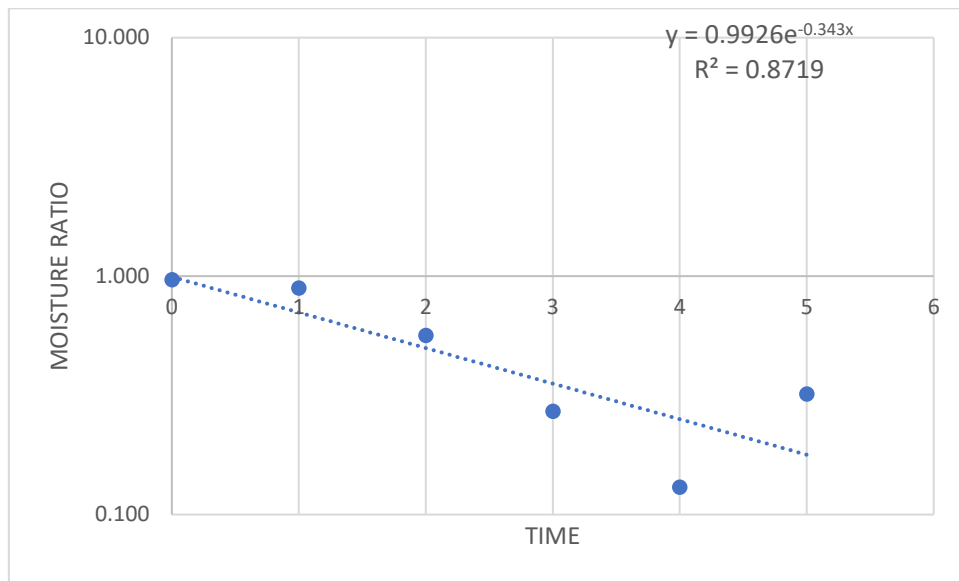
4.3.2.3 Moisture ratio vs drying time

The values of moisture ratio (MR) for different drying methods and pre-treatments are determined in Table 4.2 and 4.3 in the subsection 4.3.1 and their graph of moisture ratio vs drying time was plotted in a semi log scale for all the drying trays as presented in Fig. 4.28 for *Adhatoda vasica* and Fig. 4.29 for *Moringa oleifera*. The straight-line relationship between Log (MR) and drying time was obtained and the slope of which was designated as the drying constant (k). The drying equations are mentioned in the graph itself. All these drying equations were similar to those reported for thin layer convective drying by Goyal *et al.*, (2011) for mint leaves as well as by Ganapati Shinde (2009) for stevia leaves.

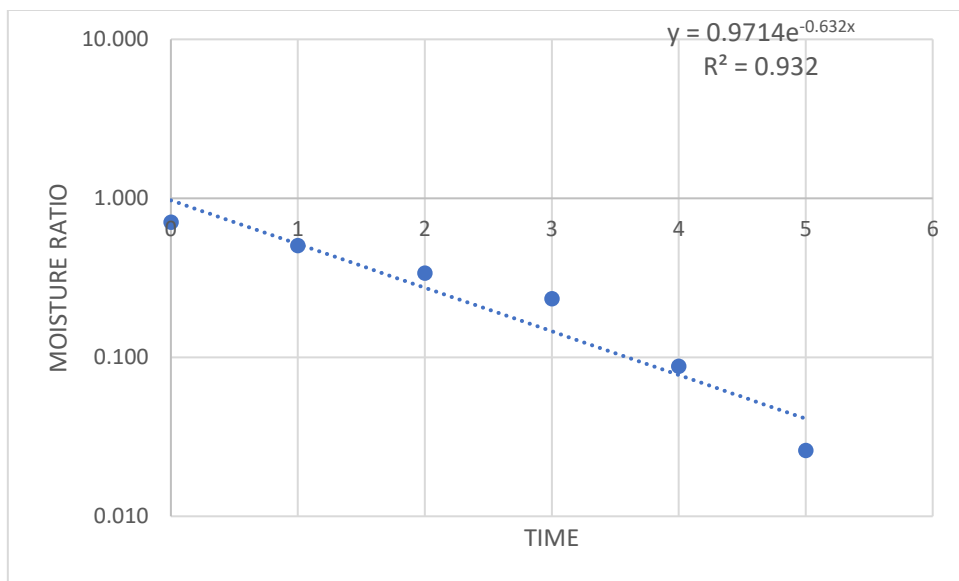
The Fig. 4.28 (a) revealed that the mean values of drying constant for the sun-dried sample of *Adhatoda vasica* leaves was -0.34 h^{-1} , whereas, for the unblanched sample leaves dried in solar tunnel dryer (Fig. 4.28 b), the drying constant was observed to be -0.63 h^{-1} . Similarly, for 3-minute blanched leaf samples, dried in solar tunnel dryer, the drying constant was observed as -0.64 h^{-1} , whereas for 5-minute blanched leaves which were dried in solar tunnel dryer the drying constant was measured to be -0.69 h^{-1} . It indicated that higher values of drying constants were obtained in case of solar tunnel dried leaf samples as compared to sun-dried samples corresponding to higher rates of drying and same may be concluded for 5-minute blanched and 3-minute blanched samples, respectively.

The Fig. 4.29 illustrates the graph for moisture ratio vs drying time for *Moringa oleifera*, in which (a) represents the mean values of drying constant for unblanched sun-dried sample, which was observed as -0.36 h^{-1} , whereas for unblanched solar tunnel dried sample, the drying constant was observed to be -0.65 h^{-1} , indicating higher rates of drying in the solar tunnel dryer. Similarly, the values of drying constant for 3-minute steam blanched leaf sample were measured as -0.64 h^{-1} and for 5-minute steam blanched leaf sample as -0.75 h^{-1} . Therefore, from these values it can be concluded that, the leaves which were steam blanched for 5-minutes and dried in the solar tunnel dryer had higher rate of drying as compared to other combinations of drying method and pre-treatment.

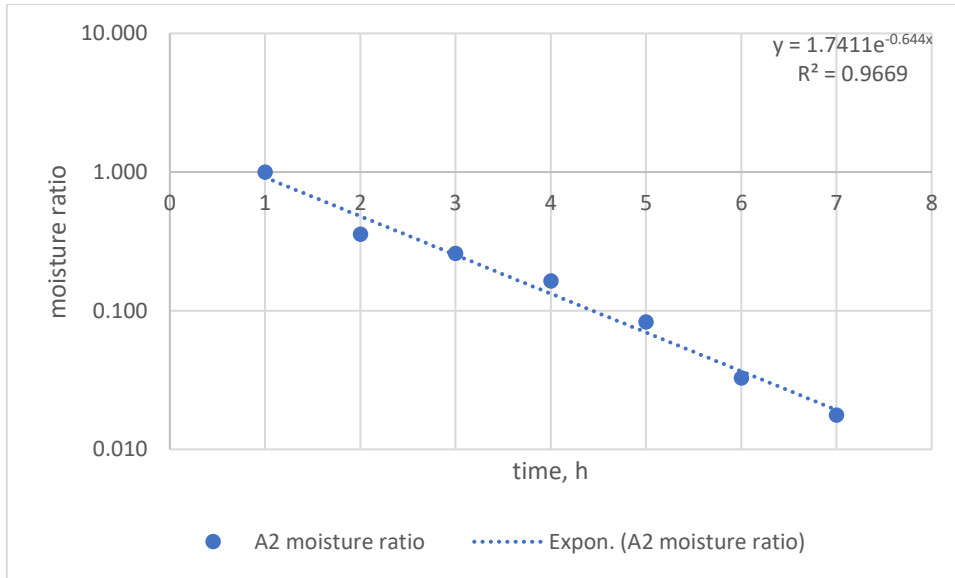
Adhatoda vasica



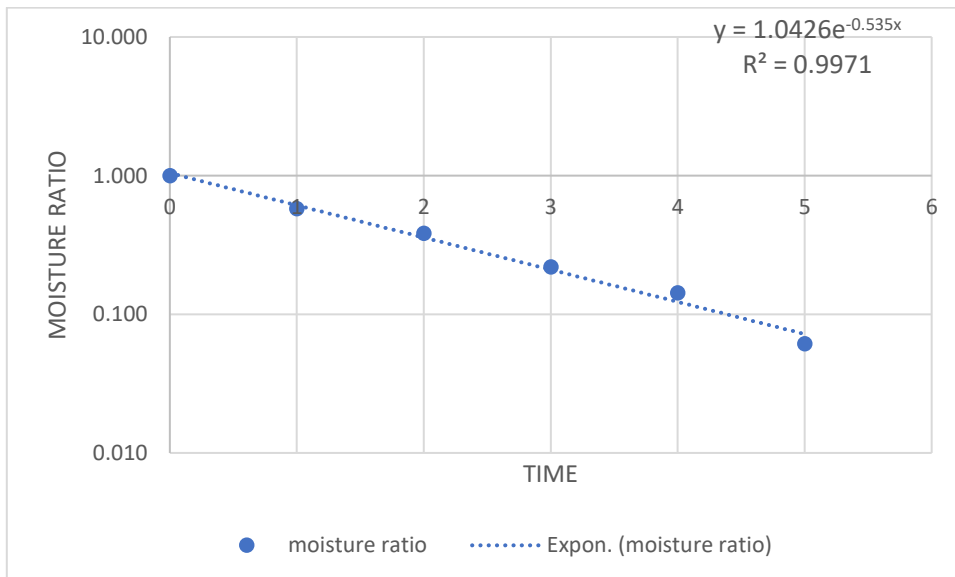
a) Moisture ratio vs drying time for sun dried sample



b) Moisture ratio vs drying time for unblanched sample



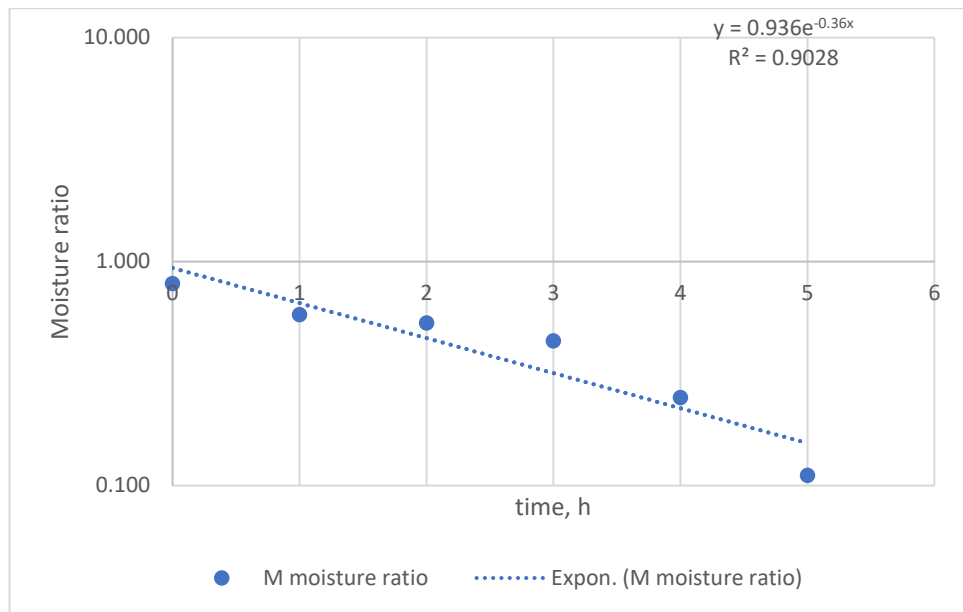
c) Moisture ratio vs drying time for 3-minute blanched sample



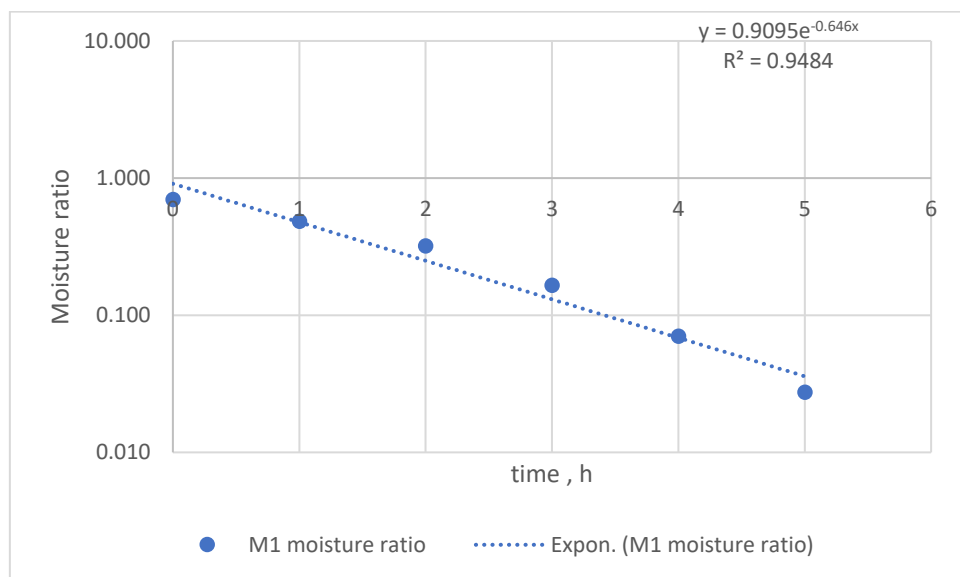
d) Moisture ratio vs drying time for 5-minute blanched sample

Fig. 4.28 (a), (b), (c), (d) Moisture ratio vs drying time for *Adhatoda vasica* for different trials

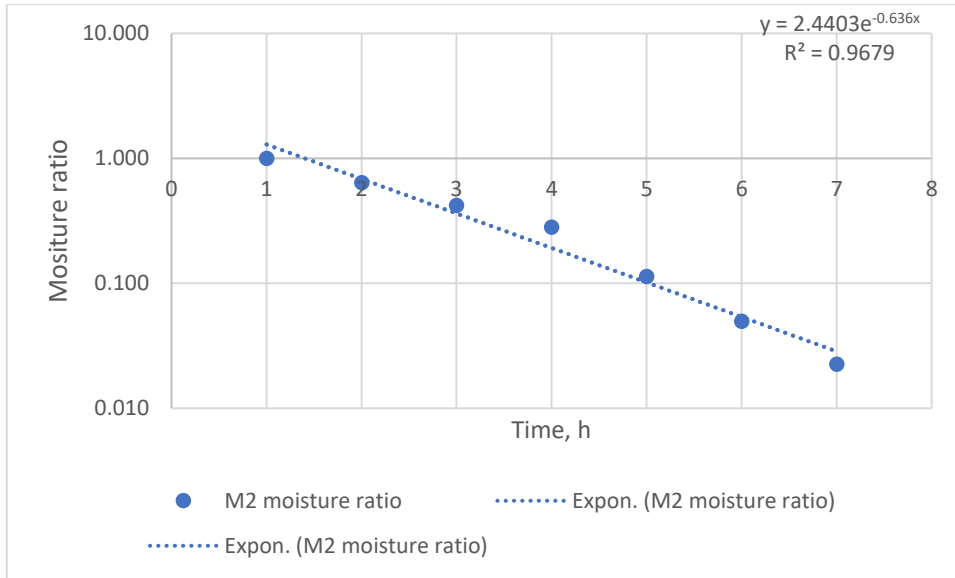
Moringa oleifera



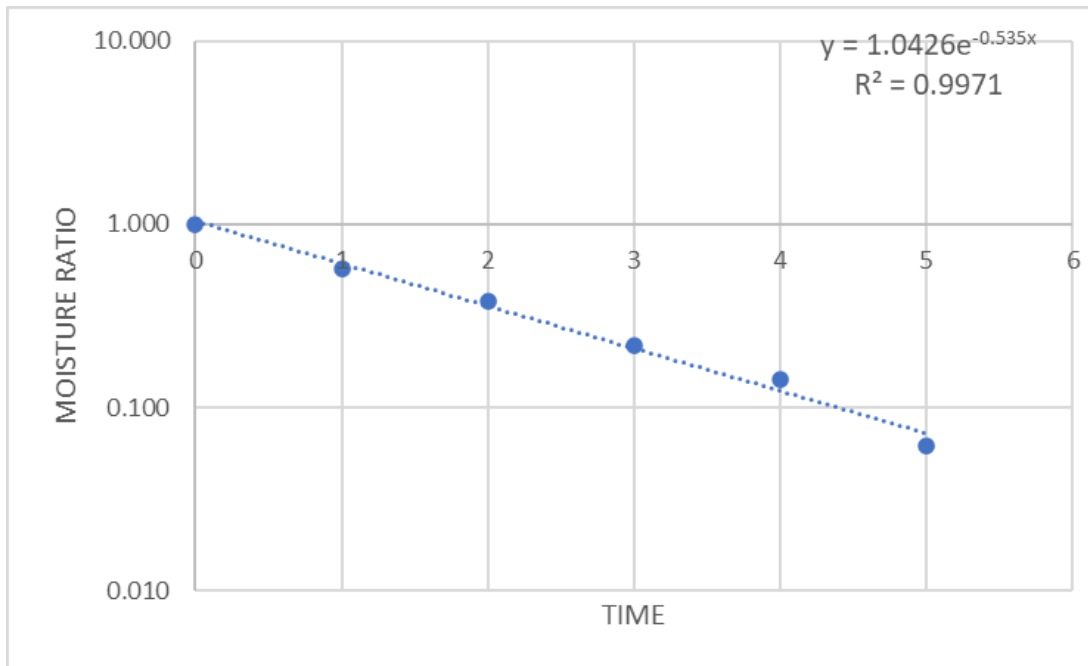
a) Moisture ratio vs drying time for sun dried sample



b) Moisture ratio vs drying time for unblanched sample



c) Moisture ratio vs drying time for 3-minute blanched sample



d) Moisture ratio vs drying time for 5-minute blanched sample

Fig. 4.29 (a), (b), (c), (d) Moisture ratio vs Drying time for *Moringa oleifera* for different trials

4.3.2.4 Solar tunnel dryer thermal and pick-up efficiency

The performance of solar tunnel dryer was evaluated in terms of thermal efficiency and the total energy required for drying of a single batch of the leaf sample as well as energy required per hour for drying of the medicinal plant leaves.

The total energy required for drying was also calculated according to the equation no. 3.4 as recommended by Dulawat (2012) and mentioned in chapter III under subsection 3.4.6. This total energy obtained was divided by the total drying time, which gave the energy required for drying per hour. The formula used for calculating energy required per hour is mentioned in equation 3.5, under subsection 3.4.7. The solar tunnel dryer's thermal efficiency and pick-up efficiency was calculated with the help of the equation no. 3.6 and 3.7, respectively, given by Dulawat (2012) and mentioned in chapter III under subsection 3.5.

Table 4.3 Solar tunnel dryer thermal and pick-up efficiency

| Sl. No. | Formula | Values | Calculation | Result |
|---------|--|---|--|--------|
| 1. | Thermal efficiency, $\eta_{th} = \frac{Q_t}{A \times I}$ | $Q_t = 4949.47\text{J/s}$ $A = 66.75 \text{ m}^2$ $I_g = 611 \text{ W/m}^2$ | η_{th} $= \frac{4949.47}{66.75 \times 611} \times 100$ | 12.14% |
| 2. | Pick-up efficiency, $\eta_p = \frac{w}{V} \times \rho \times t \times (h_{as} - h_i)$ | $w = 42.48 \text{ kg}$ $v = 245.45 \text{ m}^3/\text{s}$ $\rho = 1.22$ $t = 21600 \text{ s}$ $h_{as} = 0.0148 \text{ kg/m}^3$ $h_i = 0.009 \text{ kg/m}^3$ | η_p $= \frac{42.48}{245.45} \times 1.22 \times 21600 (0.0148 - 0.009)$ | 26.45% |

Therefore, the thermal efficiency of the solar tunnel dryer was found to be 12.14%. The pick-up efficiency was calculated with full load condition in the month of

February. The pick-up efficiency was calculated to be 26.45%. These calculated values were in accordance with the previous findings by Isaac and Sam (2017) for testing of natural convection solar tunnel dryer for mango, for which the thermal efficiency was 12.8% and pick-up efficiency was found to be 35.0%.

4.3.3 Physio-chemical Analysis of Raw and Dried Products

The physio-chemical and function properties of raw leaves and dried leaf powder of *Adhatoda vasica* and *Moringa oleifera*, viz., carbohydrate content, moisture content, fat content, fibre content, ascorbic acid content, protein content, ash content, bulk density, recovery rate, WAI and WSI were determined in the Food Testing Laboratory of College of Biotechnology, JAU, Junagadh as well as in the Processing and Food Engineering department of CAET, JAU, Junagadh as per the standard methods reported in Chapter III under subsection 3.5.8. The analysis was carried out in three trials and their mean values are reported in Table 4.3, 4.4 and 4.5.

4.3.3.1 Carbohydrate content

The carbohydrate content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. The highest carbohydrate content for *Adhatoda vasica* was found as 39.05% which was obtained in 5-minute blanched and solar tunnel dried leaves. Similarly, for *Moringa oleifera*, the highest carbohydrate content was 38.78%, also obtained in 5-minute blanched and solar tunnel dried leaves.

It was noticed (Table 4.5) that the carbohydrate content of both *Adhatoda vasica* and *Moringa oleifera* increased with increase in blanching time and the statistical analysis data (Table 4.7) revealed that the effect of the interaction S×D on carbohydrate content was found significant.

Thus, it could be concluded that the highest retention of carbohydrate content was found in the leaves which were dried in solar tunnel with 5-minutes blanching, among all other treatments.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in Adulsa (*Adhatoda vasica*) with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.2 Moisture content

The moisture content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the moisture content of freshly harvested leaves of *Adhatoda vasica* was 286.69% (db) and that of *Moringa oleifera* was 303.49% (db).

It was noticed (Table 4.5) that the lowest moisture content achieved for *Adhatoda vasica* leaves were for the samples, which were blanched for 5-minutes and dried in the solar tunnel dryer. The moisture content obtained was 5.77% (db). Similar results were observed for *Moringa oleifera* leaves, the lowest moisture content observed in this case was 4.93% (db). Also, from Fig. 4.22 and 4.23, it can be observed that, these samples had lower drying time as compared to all other samples. The statistical analysis data (Table 4.6) revealed that the effect of all the interaction, i.e., C×S, C×D, S×D and C× S×D on moisture content was found significant.

Thus, it could be concluded (Table 4.5) that the lowest moisture content with less drying time were obtained in the leaves dried in solar tunnel dryer, with a pre-treatment of 5-minute hot water steam blanching.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in Adulsa (*Adhatoda vasica*) with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.3 Ascorbic acid

The ascorbic acid content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the ascorbic acid content of freshly harvested leaves of *Adhatoda vasica* was 3.98% and that of *Moringa oleifera* was 0.23%. The highest ascorbic acid content of 3.76% in *Adhatoda vasica* was obtained in treatment of 5-minute steam blanching and solar tunnel dried leaf powder. Similarly, for *Moringa oleifera* leaves, the highest ascorbic acid content was obtained to be 3.06%, in 5-minute steam blanched and solar tunnel dried leaf powder. The statistical analysis data (Table

4.8) revealed that the effect of interactions, i.e., C×S and S×D on ascorbic acid content was found significant.

Thus, it could be concluded (Table 4.5) that the highest retention of ascorbic acid content was found in those dried leaves powder, which were dried in solar tunnel dryer with a 5-minute steam blanching pre-treatment, among all other treatment and drying methods.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in *Adulsa (Adhatoda vasica)* with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.4 Total ash

Ash usually represents the inorganic part of the plant and the amount and composition of ash remaining after combustion of plant material vary considerably according to the part of the plant, age, treatment, etc. The ash content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the ash content of freshly harvested leaves of *Adhatoda vasica* was 14.01% and that of *Moringa oleifera* was 8.37%.

It was noticed (Table 4.5) that the total ash for *Adhatoda vasica* leaves increased from 15.34% to 54.72%, 57.73% and 54.78% for unblanched, 3-minute blanched and 5-minute blanched samples which were dried in solar tunnel dryer, respectively. The total ash for *Moringa oleifera* leaves in the present study was found to be 78.08%, 63.53% and 48.98% in unblanched, 3-minute blanched and 5-minute blanched samples which were dried in solar tunnel dryer, respectively.

Thus, from the results of ash content, it can be understood that ash content was significantly reduced in 5-minute steam blanched sample, which leads to higher nutrient retention in the final product. The statistical analysis data (Table 4.9) revealed that the effect of interactions, i.e., C×S, C×D and C×S×D on total ash content was found significant.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in Adulsa (*Adhatoda vasica*) with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.5 Fat content

The fat acid content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the fat content of freshly harvested leaves of *Adhatoda vasica* was 2.31 % and that of *Moringa oleifera* was 1.75 %. The highest fat content was found to be 3.48 % in *Adhatoda vasica* was obtained in treatment of 5-minute steam blanching and solar tunnel dried leaf powder. Similarly, for *Moringa oleifera* leaves, the highest ascorbic acid content was obtained to be 6.88%, in 5-minute steam blanched and solar tunnel dried leaf powder.

It was noticed (Table 4.5) that the fat content of both *Adhatoda vasica* and *Moringa oleifera* increased with increase in blanching time and the statistical analysis data (Table 4.10) revealed that the effect of interactions, i.e., C×S and C×S×D on fat content was found significant.

Thus, it could be concluded that the highest retention of fat content was found in those dried leaves powder, which were dried in solar tunnel dryer with a 5-minute steam blanching pre-treatment, among all other treatment and drying methods.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in Adulsa (*Adhatoda vasica*) with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.6 Protein content

The protein acid content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the protein content of freshly harvested leaves of *Adhatoda vasica* was 7.73% and that of *Moringa oleifera* was 5.73%. The highest protein content of 10.71% in *Adhatoda vasica* was obtained in treatment of 5-minute steam blanching

and solar tunnel dried leaf powder. Similarly, for *Moringa oleifera* leaves, the highest ascorbic acid content was obtained to be 8.44%, in 5-minute steam blanched and solar tunnel dried leaf powder.

The statistical analysis data (Table 4.11) revealed that the coefficient of variance for the protein content was found to be 8.78%.

Thus, it could be concluded that the highest retention of fat content was found in those dried leaves powder, which were dried in solar tunnel dryer with a 5-minute steam blanching pre-treatment, among all other treatment and drying methods.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy metals in *Adulsa (Adhatoda vasica)* with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.7 Fibre content

The fibre acid content of freshly harvested leaves of *Adhatoda vasica* and *Moringa oleifera* are presented in Table 4.3 and 4.4, respectively. The values of the same for the leaves dried in open sun and solar tunnel dryer is presented in Table 4.5. It can be clearly seen that the fibre content of freshly harvested leaves of *Adhatoda vasica* was 17.8% and that of *Moringa oleifera* was 0.9%. The highest fibre content of 16.91% in *Adhatoda vasica* was obtained in treatment of 5-minute steam blanching and solar tunnel dried leaf powder. Similarly, for *Moringa oleifera* leaves, the highest ascorbic acid content was obtained to be 18.33%, in 5-minute steam blanched and solar tunnel dried leaf powder.

It was noticed (Table 4.5) that the fibre content of both *Adhatoda vasica* and *Moringa oleifera* increased with increase in blanching time and the statistical analysis data (Table 4.12) revealed that the effect of the interaction C×S on fibre content was found significant.

Thus, it could be concluded that the highest retention of fibre content was found in the leaves which were dried in solar tunnel with 5-minutes blanching, among all other treatments.

The results were found to be in accordance with the findings of Sagar *et al.* (2020), in the paper titled, “A study of some physio-chemical parameters and heavy

metals in *Adulsa (Adhatoda vasica)* with medicinal point of view” as well as with the findings of Nobosse *et al.* (2017) for the phytochemical analysis of *Moringa oleifera*.

4.3.3.8 Bulk density

The bulk density of sun-dried as well as solar tunnel dried *Adhatoda vasica* and *Moringa oleifera* obtained in different treatments is presented in Table 4.5. It is clearly shown that highest bulk density of 303.00 kg/m³ was obtained in 5-minute blanched treatment and solar tunnel dried leaves of *Adhatoda vasica*, whereas the lowest bulk density of 247.67 kg/m³ was obtained when the leaves were dried in the open sun. Similarly, for *Moringa oleifera* leaves powder, the highest bulk density was obtained as 451.67 kg/m³ in solar tunnel dryer whereas the lowest bulk density of 386.33 kg/m³ was obtained in open sun drying.

It was noticed (Table 4.5) that the bulk density of the *Adhatoda vasica* leaf powder increased with increase in blanching time and also when the leaves were dried in the solar tunnel dryer. Similar results were obtained for *Moringa oleifera* leaves. The statistical analysis (Table 4.13) revealed that, the effect of the interaction C×S and C×S×D on bulk density was found significant.

Thus, it could be concluded that, bulk density is increased when the leaves are dried in the solar tunnel dryer with a pre-treatment of 5-minute steam blanching. The results were in agreement with that reported by Singh and Prasad (2013) for the functional food powder of *Moringa oleifera* and Suliman *et al.* (2016) for the quality changes of moringa leaves.

4.3.3.9 Recovery

The percentage recovery of sun-dried as well as solar tunnel dried *Adhatoda vasica* and *Moringa oleifera* obtained in different treatments is presented in Table 4.5. It is clearly shown that the highest recovery of 22.53% for *Adhatoda vasica* leaves was obtained in 5-minute steam blanched and dried in the solar tunnel dried leaf powder samples, whereas the lowest recovery of 9.33% was obtained in unblanched sun dried leaf powder samples. Similar result was obtained for *Moringa oleifera* Leaf powder. The highest recovery obtained was 24.7% and the lowest recovery obtained was 9.75% for solar tunnel dried and sun-dried samples, respectively.

It was noticed (Table 4.5) that the recovery rate of the *Adhatoda vasica* leaf powder increased with increase in blanching time and also when the leaves were dried

in the solar tunnel dryer. Similar results were obtained for *Moringa oleifera* leaves. The statistical analysis (Table 4.14) revealed that, the effect of the interaction C×S, S×D and C×D on percentage recovery was found significant.

Thus, it could be concluded that, percentage recovery is increased when the leaves are dried in the solar tunnel dryer with a pre-treatment of 5-minute steam blanching. The results were in agreement with that reported by Singh and Prasad (2013) for the functional food powder of *Moringa oleifera* and Suliman *et al.* (2016) for the quality changes of moringa leaves.

4.3.3.10 Water solubility index

The Water Solubility Index (WSI) of *Adhatoda vasica* and *Moringa oleifera* leaf powder by different treatments is presented in Table 4.15. It is clearly shown that highest WSI of 57.75% and 57.31% was obtained in *Adhatoda vasica* and *Moringa oleifera* leaf powder, respectively for the 5-minute steam blanched and solar tunnel dried samples. Whereas, the lowest WSI of 19.22% and 22.53% was obtained in *Adhatoda vasica* and *Moringa oleifera* leaf powder, respectively for the unblanched and sun-dried samples.

It was noticed (Table 4.5) that the WSI of *Adhatoda vasica* and *Moringa oleifera* leaf powder increased with increase in blanching time and by drying in solar tunnel dryer. The statistical analysis of data (Table 4.15) revealed that the effect of the interaction C×S, S×D, C×D and C×S×D on WSI was found significant.

Malaviya (2011) studied the effect of hot air drying on osmosed papaya chips and found WSI of 55.5% for papaya chips. So, it could be concluded that the excellent dissolving characteristics with highest value of water solubility index (WSI) of 57.75% and 57.31% was obtained in *Adhatoda vasica* and *Moringa oleifera* leaf powder, respectively for the 5-minute steam blanched and solar tunnel dried samples, among all other samples.

4.3.3.11 Water absorption index

The Water Absorption Index (WAI) of *Adhatoda vasica* and *Moringa oleifera* leaf powder by different treatments is presented in Table 4.15. It is clearly shown that highest WAI of 344.88% and 259.68% was obtained in *Adhatoda vasica* and *Moringa oleifera* leaf powder, respectively for the 5-minute steam blanched and solar tunnel dried samples. Whereas, the lowest WAI of 150.98% and 149.01% was obtained in

Adhatoda vasica and *Moringa oleifera* leaf powder, respectively for the unblanched and sun-dried samples.

It was noticed (Table 4.5) that the WAI of *Adhatoda vasica* and *Moringa oleifera* leaf powder increased with increase in blanching time and by drying in solar tunnel dryer. The statistical analysis of data (Table 4.16) revealed that the effect of the interaction C×S, S×D, C×D and C×S×D on WAI was found significant.

Malaviya (2011) studied the effect of hot air drying on osmosed papaya chips and found WAI of 209.69% for papaya chips. So, it could be concluded that the excellent water absorbing characteristics with highest value of WAI of 344.88% and 259.68% was obtained in *Adhatoda vasica* and *Moringa oleifera* leaf powder, respectively for the 5-minute steam blanched and solar tunnel dried samples, among all other treatments.

Table 4.4 Biochemical analysis of freshly harvested *Adhatoda vasica*

| Sl. No. | Parameter | Raw leaves (%) |
|---------|------------------|----------------|
| 1 | Carbohydrate | 16.40 |
| 2 | Moisture content | 286.69% (db) |
| 3 | Ascorbic acid | 3.98 |
| 4 | Total ash | 14.01 |
| 5 | Fat | 2.31 |
| 6 | Fibre | 17.80 |
| 7 | Protein | 7.73 |

Table 4.5 Biochemical analysis of freshly harvested *Moringa Oleifera*

| Sl. No. | Parameter | Raw leaves (%) |
|---------|------------------|----------------|
| 1 | Carbohydrate | 10.13 |
| 2 | Moisture content | 303.486% (db) |
| 3 | Ascorbic acid | 0.231 |
| 4 | Total ash | 8.37 |
| 5 | Fat | 1.75 |
| 6 | Fibre | 0.9 |
| 7 | Protein | 5.73 |

Table 4.6 Effect of pre-treatment on physio-chemical parameters of dried *Adhatoda vasica* and *Moringa oleifera* leaves

| Sl no. | Pre-treatment | Average values of physio-chemical parameters | | | | | | | | | | |
|--|--------------------|--|-------------------------|-------------------|---------------|---------|-----------|-------------|-----------------------------------|-------------------|---------|---------|
| | | Carbohydrate (%) | Moisture content (% db) | Ascorbic acid (%) | Total ash (%) | Fat (%) | Fibre (%) | Protein (%) | Bulk Density (kg/m ³) | Recovery rate (%) | WAI (%) | WSI (%) |
| <i>Sun-dried leaf powder of Adhatoda vasica</i> | | | | | | | | | | | | |
| 1. | No blanching | 36.13 | 8.92 | 1.84 | 56.56 | 3.20 | 14.16 | 8.46 | 247.67 | 9.33 | 150.98 | 19.22 |
| 2. | 3-minute blanching | 37.33 | 8.56 | 2.08 | 54.48 | 3.39 | 14.94 | 8.62 | 236.00 | 9.89 | 158.54 | 20.45 |
| 3. | 5-minute blanching | 38.46 | 8.77 | 2.52 | 52.32 | 3.51 | 15.64 | 8.38 | 246.33 | 9.82 | 176.23 | 22.35 |
| <i>Solar tunnel dried leaf powder of Adhatoda vasica</i> | | | | | | | | | | | | |
| 1. | No blanching | 35.65 | 8.57 | 1.84 | 54.72 | 3.89 | 15.32 | 9.48 | 276.00 | 16.51 | 292.19 | 28.52 |
| 2. | 3-minute blanching | 37.68 | 7.96 | 2.96 | 57.73 | 4.37 | 15.71 | 9.52 | 297.00 | 17.43 | 297.26 | 48.63 |
| 3. | 5-minute blanching | 39.05 | 5.77 | 3.76 | 54.77 | 3.48 | 15.91 | 10.71 | 303.00 | 22.53 | 344.88 | 57.75 |
| <i>Sun-dried leaf powder of Moringa oleifera</i> | | | | | | | | | | | | |
| 1. | No blanching | 34.44 | 10.83 | 1.44 | 78.08 | 5.56 | 14.25 | 5.88 | 386.33 | 9.75 | 149.01 | 22.53 |
| 2. | 3-minute blanching | 36.75 | 9.91 | 1.44 | 63.53 | 5.76 | 15.62 | 6.18 | 388.00 | 9.85 | 149.63 | 25.43 |
| 3. | 5-minute blanching | 39.07 | 8.98 | 1.81 | 48.98 | 5.95 | 16.98 | 6.48 | 385.33 | 10.40 | 152.40 | 28.45 |
| <i>Solar tunnel dried leaf powder of Moringa oleifera</i> | | | | | | | | | | | | |
| 1. | No blanching | 35.06 | 7.50 | 2.04 | 66.36 | 5.81 | 14.88 | 7.37 | 413.67 | 22.84 | 155.51 | 30.71 |
| 2. | 3-minute blanching | 38.22 | 5.22 | 2.13 | 51.87 | 6.39 | 17.52 | 7.79 | 436.00 | 22.70 | 248.21 | 39.04 |
| 3. | 5-minute blanching | 38.78 | 4.93 | 3.06 | 43.52 | 6.88 | 18.33 | 8.44 | 451.67 | 24.71 | 259.68 | 57.31 |

4.3.4 Treatment Analysis of Medicinal Plant Leaves

The effectiveness of unblanched, 3-minute and 5-minutes blanched samples as well as the effect of solar tunnel drying as compared to sun drying on the leaves of *Adhatoda vasica* and *Moringa oleifera* were evaluated using three factorial completely randomised design. The dependent variables are:

1. Biochemical parameters: Moisture content, carbohydrate, ascorbic acid, total ash, fat, fibre and protein content.
2. Physical parameter: Bulk density.
3. Functional parameter: WSI, WAI, Recovery rate.

The independent variables are:

1. *Adhatoda vasica* leaves blanched for 3-minutes and 5-minutes and dried in solar tunnel dryer as well as in open sun.
2. *Moringa oleifera* leaves blanched for 3-minutes and 5-minutes and dried in solar tunnel dryer as well as in open sun.

Here, C1 = *Moringa oleifera*

C2 = *Adhatoda vasica*

D1 = Dried in solar tunnel dryer

D2 = Sun dried

S = Steam blanching

The result of the various analysis is represented in the following sub section.

4.3.4.1 Carbohydrate content

The carbohydrate content of *Adhatoda vasica* and *Moringa oleifera* leaves were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 4.18%.

Table 4.7 FCRD for the effect of different treatments on carbohydrate content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 34.42 | no blanching (S1) | 35.32 | STD (D1) | 37.41 |
| Ardusi (C2) | 35.11 | 3 minutes blanching (S2) | 30.13 | SD (D2) | 32.12 |
| | | 5 minutes blanching (S3) | 38.84 | | |
| S.Em± | 0.3421 | S.Em± | 0.419 | S.Em± | 0.3421 |
| CD at 5% | NS | CD at 5% | 1.223 | CD at 5% | 0.9986 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.5925 | S.Em± | 0.5925 | S.Em± | 0.4838 |
| CD at 5% | NS | CD at 5% | 1.7296 | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.838 | | CD at 5% | NS | |
| C.V.% | | | 4.1752 | | |

NS – Non-significant

4.3.4.2 Moisture content

The moisture content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 4.67%.

Table 4.8 FCRD for the effect of different treatments on moisture content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 7.89 | no blanching (S1) | 8.95 | STD (D1) | 6.82 |
| Ardusi (C2) | 8.26 | 3 minutes blanching (S2) | 7.91 | SD (D2) | 9.33 |
| | | 5 minutes blanching (S3) | 7.36 | | |
| S.Em± | 0.0889 | S.Em± | 0.1088 | S.Em± | 0.0889 |
| CD at 5% | 0.2594 | CD at 5% | 0.3177 | CD at 5% | 0.2594 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.1539 | S.Em± | 0.1539 | S.Em± | 0.1257 |
| CD at 5% | 0.4493 | CD at 5% | 0.4493 | CD at 5% | 0.3669 |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.2177 | | CD at 5% | 0.6354 | |
| C.V.% | | | 4.6688 | | |

NS – Non-significant

4.3.4.3 Ascorbic acid content

The ascorbic acid content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 9.77%.

Table 4.9 FCRD for the effect of different treatments on ascorbic acid content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 1.98 | no blanching (S1) | 1.76 | STD (D1) | 2.63 |
| Ardusi (C2) | 2.48 | 3 minutes blanching (S2) | 2.15 | SD (D2) | 1.84 |
| | | 5 minutes blanching (S3) | 2.79 | | |
| S.Em± | 0.0515 | S.Em± | 0.063 | S.Em± | 0.0515 |
| CD at 5% | 0.1502 | CD at 5% | 0.1839 | CD at 5% | 0.1502 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.0891 | S.Em± | 0.0891 | S.Em± | 0.0728 |
| CD at 5% | 0.2601 | CD at 5% | 0.2601 | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.126 | | CD at 5% | NS | |
| C.V.% | | | 9.7716 | | |

NS – Non-significant

4.3.4.4 Ash content

The ash acid content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 2.91%.

Table 4.10 FCRD for the effect of different treatments on ash content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 58.73 | no blanching (S1) | 66.18 | STD (D1) | 56.33 |
| Ardusi (C2) | 56.60 | 3 minutes blanching (S2) | 56.90 | SD (D2) | 58.99 |
| | | 5 minutes blanching (S3) | 49.90 | | |
| S.Em± | 0.3955 | S.Em± | 0.4844 | S.Em± | 0.3955 |
| CD at 5% | 1.1546 | CD at 5% | 1.414 | CD at 5% | 1.1546 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.6851 | S.Em± | 0.6851 | S.Em± | 0.5594 |
| CD at 5% | 1.9998 | CD at 5% | NS | CD at 5% | 1.6328 |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.9689 | | CD at 5% | 2.8281 | |
| C.V.% | | | 2.9104 | | |

NS – Non-significant

4.3.4.5 Fat content

The fat content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 8.07%.

Table 4.11 FCRD for the effect of different treatments on fat content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 6.06 | no blanching (S1) | 4.82 | STD (D1) | 5.25 |
| Ardusi (C2) | 3.78 | 3 minutes blanching (S2) | 4.98 | SD (D2) | 4.59 |
| | | 5 minutes blanching (S3) | 4.95 | | |
| S.Em± | 0.0936 | S.Em± | 0.1146 | S.Em± | 0.0936 |
| CD at 5% | 0.2732 | CD at 5% | NS | CD at 5% | 0.2732 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.1621 | S.Em± | 0.1621 | S.Em± | 0.1324 |
| CD at 5% | 0.4732 | CD at 5% | NS | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.2293 | | CD at 5% | 0.6692 | |
| C.V.% | | | 8.0741 | | |

NS – Non-significant

4.3.4.6 Protein content

The protein content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 8.78%.

Table 4.12 FCRD for the effect of different treatments on protein content

| Individual effect | | | | | |
|-------------------------|--------|--------------------------|--------|---------------------|--------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 7.02 | no blanching (S1) | 7.80 | STD (D1) | 8.89 |
| Ardusi (C2) | 9.20 | 3 minutes blanching (S2) | 8.03 | SD (D2) | 7.33 |
| | | 5 minutes blanching (S3) | 8.50 | | |
| S.Em± | 0.1679 | S.Em± | 0.2057 | S.Em± | 0.1679 |
| CD at 5% | 0.4901 | CD at 5% | NS | CD at 5% | 0.4901 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.2908 | S.Em± | 0.2908 | S.Em± | 0.2375 |
| CD at 5% | NS | CD at 5% | NS | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.4113 | CD at 5% | NS | NS | |
| C.V.% | | | 8.784 | | |

NS – Non-significant

4.3.4.7 Fibre content

The fibre content of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 3.90%.

Table 4.13 FCRD for the effect of different treatments on fibre content

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 16.26 | no blanching (S1) | 14.65 | STD (D1) | 16.28 |
| Ardusi (C2) | 15.28 | 3 minutes blanching (S2) | 15.95 | SD (D2) | 15.26 |
| | | 5 minutes blanching (S3) | 16.71 | | |
| S.Em± | 0.1453 | S.Em± | 0.1779 | S.Em± | 0.1453 |
| CD at 5% | 0.424 | CD at 5% | 0.5193 | CD at 5% | 0.424 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.2516 | S.Em± | 0.2516 | S.Em± | 0.2054 |
| CD at 5% | 0.7343 | CD at 5% | NS | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.3558 | | CD at 5% | NS | |
| C.V.% | | | 3.9073 | | |

NS – Non-significant

4.3.4.8 Bulk density

The bulk density of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 1.60%.

Table 4.14 FCRD for the effect of different treatments on bulk density

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 410.17 | no blanching (S1) | 319.83 | STD (D1) | 362.89 |
| Ardusi (C2) | 267.67 | 3 minutes blanching (S2) | 341.58 | SD (D2) | 314.94 |
| | | 5 minutes blanching (S3) | 355.33 | | |
| S.Em± | 1.279 | S.Em± | 1.5664 | S.Em± | 1.279 |
| CD at 5% | 3.7333 | CD at 5% | 4.5723 | CD at 5% | 3.7333 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 2.2153 | S.Em± | 2.2153 | S.Em± | 1.8088 |
| CD at 5% | 6.4662 | CD at 5% | NS | CD at 5% | NS |
| Interaction (C x S x D) | | | | | |
| S.Em± | 3.1329 | | CD at 5% | 9.1446 | |
| C.V.% | | | 1.6011 | | |

NS – Non-significant

4.3.4.9 Recovery rate

The recovery rate of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 6.04%.

Table 4.15 FCRD for the effect of different treatments on recovery rate

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 16.71 | no blanching (S1) | 14.94 | STD (D1) | 21.12 |
| Ardusi (C2) | 15.33 | 3 minutes blanching (S2) | 15.48 | SD (D2) | 10.92 |
| | | 5 minutes blanching (S3) | 17.64 | | |
| S.Em± | 0.228 | S.Em± | 0.2792 | S.Em± | 0.228 |
| CD at 5% | 0.6655 | CD at 5% | 0.8151 | CD at 5% | 0.6655 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.3949 | S.Em± | 0.3949 | S.Em± | 0.3224 |
| CD at 5% | 1.1527 | CD at 5% | 1.1527 | CD at 5% | 0.9412 |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.5585 | | CD at 5% | NS | |
| C.V.% | | | 6.0382 | | |

NS – Non-significant

4.3.4.10 Water solubility index

The water solubility index of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 4.75%.

Table 4.16 FCRD for the effect of different treatments on water solubility index

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 35.15 | no blanching (S1) | 26.69 | STD (D1) | 24.36 |
| Ardusi (C2) | 34.27 | 3 minutes blanching (S2) | 34.59 | SD (D2) | 45.07 |
| | | 5 minutes blanching (S3) | 42.85 | | |
| S.Em± | 0.389 | S.Em± | 0.4764 | S.Em± | 0.389 |
| CD at 5% | NS | CD at 5% | 1.3906 | CD at 5% | 1.1354 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.6737 | S.Em± | 0.6737 | S.Em± | 0.5501 |
| CD at 5% | 1.9665 | CD at 5% | 1.9665 | CD at 5% | 1.6057 |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.9528 | | CD at 5% | 2.7811 | |
| C.V.% | | | 4.7542 | | |

NS – Non-significant

4.3.4.11 Water absorption index

The water absorption index of *Adhatoda vasica* and *Moringa oleifera* were analysed when it was dried in open sun as well as in the solar tunnel dryer, with a pre-treatment of steam blanching varied for unblanched, 3 minute and 5 minutes blanching. The coefficient of variance was found to be 0.68%.

Table 4.17 FCRD for the effect of different treatments on water absorption index

| Individual effect | | | | | |
|--------------------------------|--------------|----------------------------|---------------|----------------------------|--------------|
| Crop leaves (C) | | Steam blanching (S) | | Drying methods (D) | |
| Level | Value | Level | Value | Level | Value |
| Moringa (C1) | 187.21 | no blanching (S1) | 188.38 | STD (D1) | 157.61 |
| Ardusi (C2) | 238.10 | 3 minutes blanching (S2) | 214.80 | SD (D2) | 267.70 |
| | | 5 minutes blanching (S3) | 234.79 | | |
| S.Em± | 0.3435 | S.Em± | 0.4207 | S.Em± | 0.3435 |
| CD at 5% | 1.0026 | CD at 5% | 1.2279 | CD at 5% | 1.0026 |
| Interaction effect | | | | | |
| Interaction (C x S) | | Interaction (S x D) | | Interaction (C x D) | |
| S.Em± | 0.5949 | S.Em± | 0.5949 | S.Em± | 0.4857 |
| CD at 5% | 1.7365 | CD at 5% | 1.7365 | CD at 5% | 1.4179 |
| Interaction (C x S x D) | | | | | |
| S.Em± | 0.8413 | | CD at 5% | 2.4558 | |
| C.V.% | | | 0.6853 | | |

NS – Non-significant

4.3.4.12 Mean Table for the Analysis of Medicinal Plant Leaves

The significant interactions between the variables and their mean for the physio-chemical parameters are illustrated in the Tables below.

Table 4.18 Significant interactions of moisture content

| SI No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|-------|----------|
| 1 | C | C1 | 23.685 | 0.090 | 0.26 |
| | | C2 | 17.001 | | |
| 2 | S | S1 | 8.953 | 0.110 | 0.32 |
| | | S2 | 7.911 | | |
| | | S3 | 7.364 | | |
| 3 | D | D1 | 6.825 | 0.090 | 0.26 |
| | | D2 | 9.328 | | |
| 4 | CxS | C1S1 | 9.166 | 0.150 | 0.45 |
| | | C1S2 | 7.563 | | |
| | | C1S3 | 6.955 | | |
| | | C2S1 | 8.741 | | |
| | | C2S2 | 8.260 | | |
| | | C2S3 | 7.773 | | |
| 5 | CxD | C1D1 | 5.884 | 0.130 | 0.37 |
| | | C1D2 | 9.906 | | |
| | | C2D1 | 7.766 | | |
| | | C2D2 | 8.750 | | |
| 6 | SxD | S1D1 | 8.036 | 0.15 | 0.45 |
| | | S1D2 | 9.871 | | |
| | | S2D1 | 6.592 | | |
| | | S2D2 | 9.231 | | |
| | | S3D1 | 5.847 | | |
| | | S3D2 | 8.882 | | |
| 7 | CxSxD | C1S1D1 | 7.504 | 0.22 | 0.6354 |
| | | C1S1D2 | 10.828 | | |
| | | C1S2D1 | 5.220 | | |
| | | C1S2D2 | 9.906 | | |
| | | C1S3D1 | 4.927 | | |
| | | C1S3D2 | 8.984 | | |
| | | C2S1D1 | 8.567 | | |
| | | C2S1D2 | 8.915 | | |
| | | C2S2D1 | 7.963 | | |
| | | C2S2D2 | 8.557 | | |
| | | C2S3D1 | 6.767 | | |
| | | C2S3D2 | 8.779 | | |

Table 4.19 Significant interactions of carbohydrate content

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|--------|----------|
| 1 | S | S1 | 35.321 | 0.419 | 1.223 |
| | | S2 | 30.127 | | |
| | | S3 | 38.842 | | |
| 2 | D | D1 | 37.409 | 0.342 | 0.9986 |
| | | D2 | 32.118 | | |
| 3 | SxD | S1D1 | 35.357 | 0.5925 | 1.7296 |
| | | S1D2 | 35.285 | | |
| | | S2D1 | 37.952 | | |
| | | S2D2 | 22.303 | | |
| | | S3D1 | 38.918 | | |
| | | S3D2 | 38.765 | | |

Table 4.20 Significant interactions of ascorbic acid content

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|-------|--------|----------|
| 1 | C | C1 | 5.954 | 0.052 | 0.1502 |
| | | C2 | 4.311 | | |
| 2 | S | S1 | 1.764 | 0.063 | 0.1839 |
| | | S2 | 2.151 | | |
| | | S3 | 2.786 | | |
| 3 | D | D1 | 2.631 | 0.052 | 0.1502 |
| | | D2 | 1.837 | | |
| 4 | CxS | C1S1 | 1.738 | 0.089 | 0.261 |
| | | C1S2 | 1.782 | | |
| | | C1S3 | 2.434 | | |
| | | C2S1 | 1.790 | | |
| | | C2S2 | 2.521 | | |
| | | C2S3 | 3.138 | | |
| 5 | SxD | S1D1 | 1.938 | 0.0891 | 0.2601 |
| | | S1D2 | 1.590 | | |
| | | S2D1 | 2.542 | | |
| | | S2D2 | 1.761 | | |
| | | S3D1 | 3.412 | | |
| | | S3D2 | 2.161 | | |

Table 4.21 Significant interactions of ash content

| SI No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|---------|-------|----------|
| 1 | C | C1 | 176.175 | 0.396 | 1.1546 |
| | | C2 | 116.245 | | |
| 2 | S | S1 | 66.180 | 0.484 | 1.414 |
| | | S2 | 56.904 | | |
| | | S3 | 49.900 | | |
| 3 | D | D1 | 56.331 | 0.396 | 1.1546 |
| | | D2 | 58.992 | | |
| 4 | CxS | C1S1 | 72.222 | 0.684 | 1.999 |
| | | C1S2 | 57.702 | | |
| | | C1S3 | 46.252 | | |
| | | C2S1 | 60.138 | | |
| | | C2S2 | 56.107 | | |
| | | C2S3 | 53.548 | | |
| 5 | CxD | C1D1 | 53.920 | 0.56 | 1.6328 |
| | | C1D2 | 63.530 | | |
| | | C2D1 | 58.742 | | |
| | | C2D2 | 54.453 | | |
| 6 | CxSxD | C1S1D1 | 66.363 | 0.968 | 2.8281 |
| | | C1S1D2 | 78.080 | | |
| | | C1S2D1 | 51.873 | | |
| | | C1S2D2 | 63.530 | | |
| | | C1S3D1 | 43.523 | | |
| | | C1S3D2 | 48.980 | | |
| | | C2S1D1 | 63.717 | | |
| | | C2S1D2 | 56.560 | | |
| | | C2S2D1 | 57.733 | | |
| | | C2S2D2 | 54.480 | | |
| | | C2S3D1 | 54.777 | | |
| | | C2S3D2 | 52.320 | | |

Table 4.22 Significant interactions of fat content

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|--------|----------|
| 1 | C | C1 | 18.173 | 0.094 | 0.2732 |
| | | C2 | 7.843 | | |
| 2 | D | D1 | 5.250 | 0.094 | 0.2732 |
| | | D2 | 4.587 | | |
| 3 | CxS | C1S1 | 5.683 | 0.162 | 0.4732 |
| | | C1S2 | 6.076 | | |
| | | C1S3 | 6.413 | | |
| | | C2S1 | 3.962 | | |
| | | C2S2 | 3.881 | | |
| | | C2S3 | 3.495 | | |
| 4 | CxSxD | C1S1D1 | 5.807 | 0.2293 | 0.6692 |
| | | C1S1D2 | 5.560 | | |
| | | C1S2D1 | 6.397 | | |
| | | C1S2D2 | 5.755 | | |
| | | C1S3D1 | 6.877 | | |
| | | C1S3D2 | 5.950 | | |
| | | C2S1D1 | 4.573 | | |
| | | C2S1D2 | 3.350 | | |
| | | C2S2D1 | 4.367 | | |
| | | C2S2D2 | 3.395 | | |
| | | C2S3D1 | 3.480 | | |
| | | C2S3D2 | 3.510 | | |

Table 4.23 Significant interactions of protein content

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|-------|----------|
| 1 | C | C1 | 21.070 | 0.168 | 0.26 |
| | | C2 | 18.044 | | |
| 2 | D | D1 | 8.887 | 0.168 | 0.4901 |
| | | D2 | 7.334 | | |

Table 4.24 Significant interactions of fibre content

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|-------|----------|
| 1 | C | C1 | 48.788 | 0.145 | 0.424 |
| | | C2 | 30.067 | | |
| 2 | S | S1 | 14.653 | 0.178 | 0.5193 |
| | | S2 | 15.947 | | |
| | | S3 | 16.714 | | |
| 3 | D | D1 | 16.279 | 0.145 | 0.424 |
| | | D2 | 15.264 | | |
| 4 | CxS | C1S1 | 14.565 | 0.252 | 0.7343 |
| | | C1S2 | 16.569 | | |

| | | | | | |
|--|--|------|--------|--|--|
| | | C1S3 | 17.653 | | |
| | | C2S1 | 14.742 | | |
| | | C2S2 | 15.325 | | |
| | | C2S3 | 15.775 | | |

Table 4.25 Significant interactions of bulk density

| SI No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|----------|-------|----------|
| 1 | C | C1 | 1230.500 | 1.279 | 3.7333 |
| | | C2 | 516.333 | | |
| 2 | S | S1 | 319.833 | 1.566 | 4.5723 |
| | | S2 | 341.583 | | |
| | | S3 | 355.333 | | |
| 3 | D | D1 | 362.889 | 1.279 | 3.7333 |
| | | D2 | 314.944 | | |
| 4 | CxS | C1S1 | 395.167 | 2.215 | 6.4662 |
| | | C1S2 | 411.333 | | |
| | | C1S3 | 424.000 | | |
| | | C2S1 | 244.500 | | |
| | | C2S2 | 271.833 | | |
| | | C2S3 | 286.667 | | |
| 5 | CxDxS | C1S1D1 | 413.667 | 9.145 | 9.1446 |
| | | C1S1D2 | 376.667 | | |
| | | C1S2D1 | 436.000 | | |
| | | C1S2D2 | 386.667 | | |
| | | C1S3D1 | 451.667 | | |
| | | C1S3D2 | 396.333 | | |
| | | C2S1D1 | 276.000 | | |
| | | C2S1D2 | 213.000 | | |
| | | C2S2D1 | 297.000 | | |
| | | C2S2D2 | 246.667 | | |
| | | C2S3D1 | 303.000 | | |
| | | C2S3D2 | 270.333 | | |

Table 4.26 Significant interactions of recovery rate

| SI No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|-------|----------|
| 1 | C | C1 | 50.124 | 0.228 | 0.6655 |
| | | C2 | 28.295 | | |
| 2 | S | S1 | 14.943 | 0.279 | 0.8151 |
| | | S2 | 15.479 | | |
| | | S3 | 17.638 | | |
| 3 | D | D1 | 21.119 | 0.228 | 0.6655 |
| | | D2 | 10.921 | | |
| 4 | CxS | C1S1 | 16.286 | 0.395 | 1.1527 |
| | | C1S2 | 16.263 | | |
| | | C1S3 | 17.575 | | |
| | | C2S1 | 13.600 | | |
| | | C2S2 | 14.695 | | |
| | | C2S3 | 17.700 | | |
| 5 | SxD | S1D1 | 19.674 | 0.395 | 1.153 |
| | | S1D2 | 10.212 | | |
| | | S2D1 | 20.063 | | |
| | | S2D2 | 10.895 | | |
| | | S3D1 | 23.620 | | |
| | | S3D2 | 11.655 | | |
| 6 | CxD | C1D1 | 23.416 | 0.322 | 0.941 |
| | | C1D2 | 10.000 | | |
| | | C2D1 | 18.822 | | |
| | | C2D2 | 11.841 | | |

Table 4.27 Significant interactions of water absorption index

| SI No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|---------|--------|----------|
| 1 | C | C1 | 561.644 | 0.344 | 1.0026 |
| | | C2 | 452.274 | | |
| 2 | S | S1 | 188.376 | 0.421 | 1.2279 |
| | | S2 | 214.803 | | |
| | | S3 | 234.788 | | |
| 3 | D | D1 | 157.610 | 0.344 | 1.0026 |
| | | D2 | 267.702 | | |
| 4 | CxS | C1S1 | 153.712 | 0.595 | 1.7365 |
| | | C1S2 | 200.370 | | |
| | | C1S3 | 207.562 | | |
| | | C2S1 | 223.039 | | |
| | | C2S2 | 229.235 | | |
| | | C2S3 | 262.015 | | |
| 5 | CxD | C1D1 | 151.845 | 0.486 | 1.4179 |
| | | C1D2 | 222.584 | | |
| | | C2D1 | 163.374 | | |
| | | C2D2 | 312.819 | | |
| 6 | SxD | S1D1 | 151.449 | 0.5949 | 1.7365 |
| | | S1D2 | 225.302 | | |
| | | S2D1 | 155.540 | | |
| | | S2D2 | 274.065 | | |
| | | S3D1 | 165.839 | | |
| | | S3D2 | 303.737 | | |
| 7 | CxSxD | C1S1D1 | 150.462 | 0.8413 | 2.4558 |
| | | C1S1D2 | 156.962 | | |
| | | C1S2D1 | 151.083 | | |
| | | C1S2D2 | 249.657 | | |
| | | C1S3D1 | 153.990 | | |
| | | C1S3D2 | 261.134 | | |
| | | C2S1D1 | 152.437 | | |

| | | | | | |
|--|--|--------|---------|--|--|
| | | C2S1D2 | 293.642 | | |
| | | C2S2D1 | 159.997 | | |
| | | C2S2D2 | 298.473 | | |
| | | C2S3D1 | 177.689 | | |
| | | C2S3D2 | 346.341 | | |

Table 4.28 Significant interactions of water solubility index

| Sl No. | Parameter | Treatment | Mean | S.Em± | CD at 5% |
|--------|-----------|-----------|--------|--------|----------|
| 1 | S | S1 | 26.694 | 0.4764 | 1.3906 |
| | | S2 | 34.589 | | |
| | | S3 | 42.853 | | |
| 2 | D | D1 | 24.356 | 0.389 | 1.1354 |
| | | D2 | 45.068 | | |
| 3 | CxS | C1S1 | 28.070 | 0.6737 | 1.9665 |
| | | C1S2 | 33.189 | | |
| | | C1S3 | 44.204 | | |
| | | C2S1 | 25.318 | | |
| | | C2S2 | 35.989 | | |
| | | C2S3 | 41.501 | | |
| 4 | CxD | C1D1 | 26.588 | 0.5501 | 1.6057 |
| | | C1D2 | 43.720 | | |
| | | C2D1 | 22.123 | | |
| | | C2D2 | 46.415 | | |
| 5 | SxD | S1D1 | 22.325 | 0.6737 | 1.9665 |
| | | S1D2 | 31.063 | | |
| | | S2D1 | 23.892 | | |
| | | S2D2 | 45.286 | | |
| | | S3D1 | 26.850 | | |
| | | S3D2 | 58.855 | | |
| 6 | CxSxD | C1S1D1 | 23.980 | 0.9528 | 2.7811 |
| | | C1S1D2 | 32.159 | | |
| | | C1S2D1 | 25.884 | | |
| | | C1S2D2 | 40.494 | | |

| | | | | | |
|--|--|--------|--------|--|--|
| | | C1S3D1 | 29.900 | | |
| | | C1S3D2 | 58.508 | | |
| | | C2S1D1 | 20.670 | | |
| | | C2S1D2 | 29.966 | | |
| | | C2S2D1 | 21.900 | | |
| | | C2S2D2 | 50.077 | | |
| | | C2S3D1 | 23.800 | | |
| | | C2S3D2 | 59.202 | | |

4.4 DEVELOPMENT OF MATHEMATICAL MODELS

The mathematical models for the different combination of solar tunnel dryer environment control conditions have been developed by incorporating energy balance equations at different components (sub-section 3.6.2) and necessary assumptions (sub-section 3.6.1) of the system. The computer programs were developed in FORTRAN-77 language using finite difference technique for solutions of equations as reported in sub-section 3.6.3. The programming codes are presented in Appendix III.

Fig. 4.30 shows the simulation results for air temperature inside the solar tunnel dryer under natural ventilation condition. It can be observed that the predicted curve obtained for the air temperature inside solar tunnel dryer is similar to the experimental curve but during the peak temperature, the predicted curve is higher than the experimental curve.

Fig. 4.31 shows the simulation results for relative humidity inside the solar tunnel dryer under natural ventilation condition. It can be observed that the predicted curve obtained for the humidity inside solar tunnel dryer is similar to the experimental curve but the minima of the predicted curve is lower than the experimental curve.

From Fig. 4.32 it can be seen that the predicted results for moisture content of the product is similar to the experimental results, and the lowest moisture content in dry basis (%) is obtained after 7 hours of drying in the predicted curve.

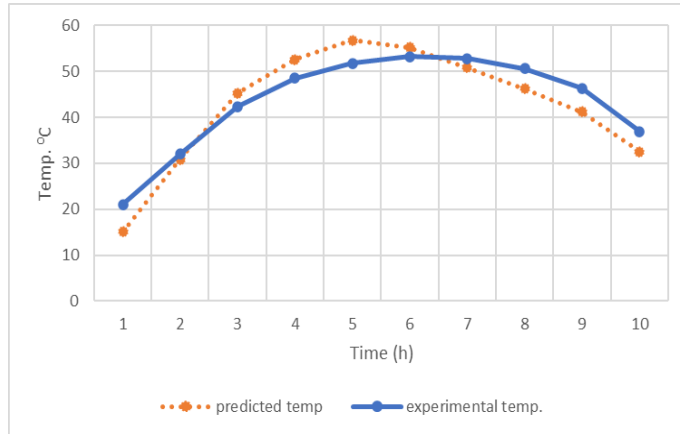


Fig. 4.30 Simulations results of air temperature inside the solar tunnel dryer

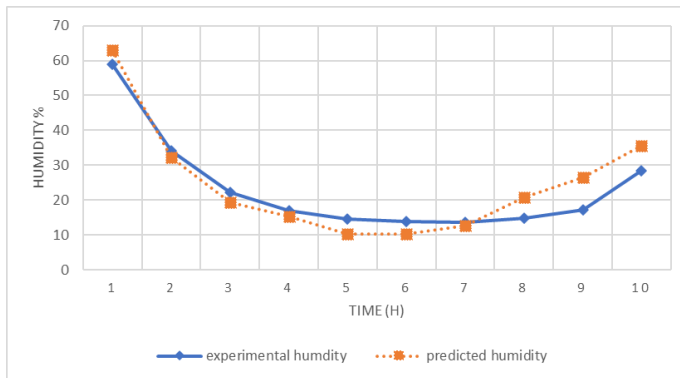


Fig. 4.31 Simulations results of relative humidity inside the solar tunnel dryer

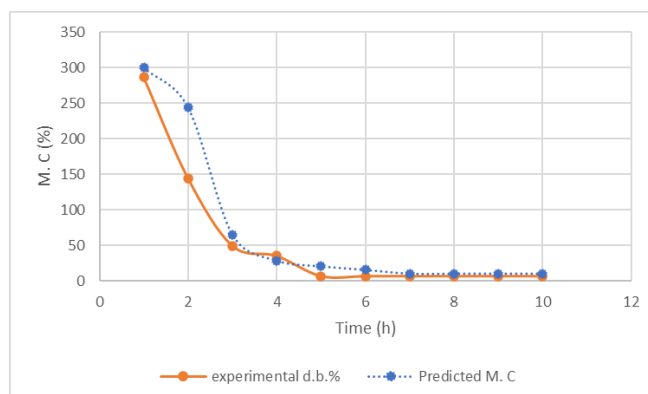


Fig. 4.32 Simulations results of moisture content of the products inside the sola tunnel dryer

4.5 ECONOMIC ANALYSIS OF SOLAR TUNNEL DRYER

To determine the success and commercialization of the solar tunnel dryer techno-economic analysis was carried out and payback period of the solar tunnel dryer was also determined. The following parameters were assumed to carry out the techno-economics of the solar tunnel dryer for drying of medicinal plants.

Table 4.29 Total cost of solar tunnel dryer

| Sl. No. | Details of components | Total cost |
|---------|---|---|
| 1. | <p>Structure</p> <ul style="list-style-type: none"> • Six arcs made of GI pipe (40 mm x 40 mm x 1.2 mm) Square GI pipes (50 mm x 50 mm x 2 mm) spaced at 2 m interval. • All the sides of STD structures were supported with square GI pipes of (35 mm x 35 mm x 2 mm). • On the north side of the STD structure, a north wall of 3.5 feet made of GI sheet (22 gauge) was painted with black colour and insulated to minimize heat losses. <p>Drying stand</p> <ul style="list-style-type: none"> • No. of tray stand : 4 • Drying tray per stand : 16 • Size of stand : 1.5 m x 3.0 m • Material used : 25 mm x 25 mm x 1 mm square GI pipes <p>15% Fabrication charge</p> | <p>₹1,22,380/-</p> <p>₹18,357/-</p> <p>Total amount=</p> <p>₹1,40,737/-</p> |
| 2. | <p>Drying tray</p> <ul style="list-style-type: none"> • Size : 700 mm x 700 mm x 50 mm • Total no. : 64 • Total no. of tray per stand : 64 • Tray Material wire mesh : SS 304 (10 Mesh size) • Tray side supports : SS 202 | <p>₹89,000/-</p> <p>(including labour charge)</p> |

| | | |
|----|--|---|
| 3. | Electrical fittings for analytical instruments such as : <ul style="list-style-type: none"> • Two exhaust fan (0.557 hp, 1400 rpm) were provided • 2 wind turbo ventilator were mounted on the top of solar tunnel dryer • Sensors Total cost | ₹3000/- ₹3000/- ₹9000/- ₹15000/- |
| 4. | Total Cost of solar tunnel dryer | ₹2,44,737/- |

The above Table 4.29 represents the details and cost of each and every component of the solar tunnel dryer and therefore, the total cost of solar tunnel dryer comes be ₹2,44,737/-.

In Table 4.30 the useful life of the solar tunnel dryer is assumed to be 20 years. The capacity of the dryer for *Adhatoda vasica* and *Moringa oleifera* is 32 kg/batch or 48 kg/day considering drying time as 6.0 hrs/batch and 44.8 kg/batch or 67.2 kg/day (for 9 hours), respectively.

Table 4.30 Fixed cost for the solar tunnel dryer

| Sl. No. | Description | Values |
|---------|--|----------------------------|
| 1. | Cost of solar tunnel dryer | ₹ 2,44,737/- |
| 2. | Useful life of solar tunnel dryer (years) | 20 years |
| 3. | Annual use | 240 days/ annum |
| 4. | Capacity of dryer per day a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | 48 kg/ day 67.2 kg/ day |
| 6. | Interest | 10% per annum |
| 7. | Housing | 1% per annum |
| 8. | Repair and maintenance | 3% per annum |

Table 4.31 shows the calculation for the operating cost of the solar tunnel dryer. The annual fixed cost is calculated to be ₹29368 per annum, the annual maintenance

cost was calculated as 3% of CI which was ₹881 per annum. The annual operating cost was calculated as ₹72000 per annum as the labour charge per day was ₹300. The annual salvage value was calculated as ₹2312.60 per annum. The cost of raw material was ₹7.80 and ₹5.60 for *Adhatoda vasica* and *Moringa oleifera*, respectively. The annual production cost was calculated as ₹99937 per annum. The cost of *Adhatoda vasica* was calculated to be ₹75.30/kg and the revenue was ₹95/kg, therefore the profit was ₹19.70/kg. Similarly, for *Moringa oleifera*, the cost of the product was calculated as ₹44/kg and the revenue was ₹75/kg, thus the profit was calculated as ₹31/kg.

Table 4.31 Head wise operating cost of the solar tunnel dryer

| Sl. No. | Particular and Formula | Amount (₹/annum) | Amount ₹/kg. |
|---------|--|------------------|----------------|
| 1. | Annual Fixed Cost (AFC) (Equation 3.31) | 29368.00 | |
| 2. | Annual maintenance cost (AMC) 3% of CI | 881.00 | |
| 3. | Annual Operating cost (AOC) Labour charges @ Rs. 300/day | 72000.00 | |
| 4. | Annual salvage value (ASV) | 2312.60 | |
| 5. | Cost of raw material i. <i>Adhatoda vasica</i> ii. <i>Moringa oleifera</i> | | 7.80 5.60 |
| 6. | Annual Production Cost (APC) Equation 3.30 | 99937.00 | |
| 7. | Cost of the products i. <i>Adhatoda vasica</i> ii. <i>Moringa oleifera</i> | | 75.00 44.00 |
| 8. | Revenue i. <i>Adhatoda vasica</i> ii. <i>Moringa oleifera</i> | | 95.00 74.00 |
| 9. | Profit i. <i>Adhatoda vasica</i> ii. <i>Moringa oleifera</i> | | 20.00 30.00 |

The Table 4.32 depicts the comparison of cost of 100kg *Adhatoda vasica* and *Moringa oleifera* leaves powder production in solar tunnel dryer and in open sun drying. From this table, it can be concluded that solar tunnel dryer is more cost-effective than

open sun drying as the profit per kg of *Adhatoda vasica* leaf powder was ₹20.00/kg as compared to ₹6.21/kg which was dried in open sun. Similarly, for *Moringa oleifera* leaves powder, the profit was ₹30.00/kg for the products dried in solar tunnel dryer as compared to ₹16.30/kg, for the products dried in the open sun.

Table 4.32 Comparison of cost of 100 kg *Adhatoda vasica* and *Moringa oleifera* leaves powder production in solar tunnel dryer and in open sun drying.

| Sl. No. | Particulars | Solar Tunnel Drying | Open Sun drying |
|---------|--|---|--|
| 1. | Capacity a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | 32 kg/batch or 48kg/day 44.8 kg/batch or 67.2 kg/day | 100 kg/day |
| 2. | Labour, man-h | 8 | 16 |
| 3. | Drying time | 6 hours/batch | 12 hours/batch |
| 4. | Dried weight of c) <i>Adhatoda vasica</i> d) <i>Moringa oleifera</i> | 10.56 kg/day 18.0 kg/day | 18.7 kg/day 21.6 kg/day |
| 5. | Drying cost, ₹/day of dried leaves | ₹416.00 /day | ₹600.00/day |
| 6. | Raw material cost/day a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | ₹374.40/day ₹376.32/day | ₹780.00/day ₹560.00/day |
| 7. | Total Production cost (5+6) a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | ₹790.00/day ₹792.32/day | ₹1380.00/day ₹1160.00/day |
| 8. | Percentage recovery of dried leaves (%) (a) <i>Adhatoda vasica</i> (b) <i>Moringa oleifera</i> | 22% 27% | 15% loss is consiered 18.70% 21.60% |
| 9. | Total production cost of dried powder a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | ₹75.00/kg ₹44.00/kg | ₹73.79/kg ₹53.70/kg |

| | | | |
|-----|---|------------------------|------------------------|
| 10. | Market value of dried leaves a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | ₹95.00/kg ₹74.00/kg | ₹80.00/kg ₹70.00/kg |
| 11 | Profit (9-10) a) <i>Adhatoda vasica</i> b) <i>Moringa oleifera</i> | ₹20.00/kg ₹30.00/kg | ₹6.21/kg ₹16.30/kg |

(Elements of Agril. Engg. by Dr. J. Sahay 2008)

Table 4.33 computes the total present worth of cash outflow as ₹8,83,772/-, the present worth of cash inflow as ₹55,54,689/- and the net present worth after 10 years as ₹46,70,917/-. The computation for the payback period of the solar tunnel dryer is shown in Table 4.34.

Table 4.33 Cash flow (₹) for the drying of medicinal plants in solar tunnel dryer

| Year | Cash outflow | PW of cash outflow | Cash inflow | PW of cash inflow | NPW |
|------|--------------|--------------------|-------------|-------------------|----------------|
| | (₹) | (₹) | (₹) | (₹) | |
| 0 | 244737 | 244737 | 0 | 0 | -244737 |
| 1 | 104000 | 94545 | 904000 | 821818 | 727273 |
| 2 | 104000 | 85950 | 904000 | 747107 | 661157 |
| 3 | 104000 | 78137 | 904000 | 679189 | 601052 |
| 4 | 104000 | 71033 | 904000 | 617444 | 546411 |
| 5 | 104000 | 64576 | 904000 | 561313 | 496737 |
| 6 | 104000 | 58705 | 904000 | 510284 | 451579 |
| 7 | 104000 | 53368 | 904000 | 463895 | 410526 |
| 8 | 104000 | 48517 | 904000 | 421723 | 373206 |
| 9 | 104000 | 44106 | 904000 | 383384 | 339278 |
| 10 | 104000 | 40097 | 904000 | 348531 | 308435 |
| | TOTAL | 883772 | | 5554689 | 4670917 |

Table 4.34 Computation of payback period of solar tunnel dryer

| Year | PW of total Cash outflow in 10 years | Cash Inflow | PW of cash Inflow | Cumulative Inflow |
|------|--------------------------------------|-------------|-------------------|-------------------|
| | (₹) | (₹) | (₹) | (₹) |
| 0 | 883772 | | | |
| 1 | | 904000 | 821818 | 821818 |
| 2 | | 904000 | 747107 | 1568926 |
| 3 | | 904000 | 679189 | 2248114 |
| 4 | | 904000 | 617444 | 2865558 |
| 5 | | 904000 | 561313 | 3426871 |
| 6 | | 904000 | 510284 | 3937156 |
| 7 | | 904000 | 463895 | 4401051 |
| 8 | | 904000 | 421723 | 4822773 |
| 9 | | 904000 | 383384 | 5206158 |
| 10 | | 904000 | 348531 | 5554689 |

The various economic indicators are shown in Table 4.35.

Table 4.35 Economic indicators for drying of medicinal plants

| Sl. No. | Economic Indicators | Value |
|---------|-----------------------|----------------|
| 1. | Net present worth (₹) | 4670917/- |
| 2. | B/C ratio | 6.29 |
| 3. | Payback period | 1 year 20 days |

The cost benefit ratio was 6.29 with a payback period of 1 year 20 days. It can be inferred that the developed dryer is technically as well as economically feasible.

SUMMARY
AND
CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSIONS

Drying refers to the reduction of moisture content of the product to a level to limit microbial growth by preserving flavour and nutritive growth is an important method. The drying process is accelerated and is more effective with a solar tunnel dryer. The solar tunnel dryer is the most affordable dryer with a large drying capacity. It occupies minimum area and is simple to use. As the solar tunnel dried products are more hygienic and have a longer shelf life, they are able to get a better value in the market as compared to open sun-dried products. The products in solar tunnel dryer are shielded from insects and other pests, preventing contamination or product loss. This results in higher yield of the dried product as well as high income.

In hot climates, direct sun radiation is frequently applied to food commodities for drying. Birds, insects, wind, and rain all cause significant losses during natural sun drying, causing degradation in the quality of the final product. Natural sun drying is characterised by excessive drying, contamination by dust, and insect infestation. Solar tunnel dryers can be used to dry food products in an efficient manner while also reducing drying time, improving quality, and conserving a sizable amount of energy.

One of the most promising pre-treatments for leafy medicinal plants before drying is blanching. Prior to drying, steam blanching has many advantages, including improved nutrient retention and improved colour, texture, flavour, odour, and taste. Blanching before drying speeds up the drying process and cuts down on drying time. One of the promising possibilities for drying numerous medicinal plants on a wide scale is the solar tunnel dryer. By using solar tunnel drying on leafy medicinal plants, the problems of conventional sun drying could be removed. The solar tunnel dryer's benefits include relatively quick drying times, greater product quality, a requirement for less space, hygienic products, less contamination, and low operating costs.

In addition, compared to conventional sun drying, solar tunnel drying of medical products reduces post-harvest losses. The mechanical dryers that are now on the market are expensive, large capacity, and powered by fossil fuels, electricity, etc. Therefore, a simple, affordable solar tunnel drier is necessary for drying newly harvested medicinal plants, such as *Adhatoda vasica* (Ardusi) and *Moringa oleifera*

leaves. Therefore, the present research was undertaken to study the performance of solar tunnel dryer for drying of medicinal plants, keeping the following objectives in mind.

1. To study the diurnal variation of micro-climate of the dryer.
2. To evaluate the techno-economic performance of solar tunnel dryer.
3. To analyse the biochemical, physical and functional properties of dried products.
4. To carry out the thermal analysis of solar tunnel dryer and develop mathematical model.

Six arcs of GI pipe (40 mm x 40 mm x 1.2 mm) that were inserted, riveted, and welded into square GI pipes (50 mm x 50 mm x 2 mm), i.e., foundation reinforced pipes, were used to construct a solar tunnel dryer that measured 3 m (length), 5 m (width), and 3 m (height) and used natural convection. Square GI pipes of various sizes were used to support the sides of STD constructions (35 mm x 35 mm x 2 mm). To reduce heat losses, a 3.5 foot long north wall made of 22 gauge GI sheet was painted black on the north side of the STD building. Polystyrene sheet 40 mm thick was used to insulate the north wall's back side along its full length. To maximise the benefits of solar radiation, the entire STD structure was covered with a UV stabilised thermic clear plastic cladding film of 200 micron. In order to more effectively absorb incident sun radiation, the floor was painted black.

The medicinal plants like *Adhatoda vasica* and *Moringa oleifera* leaves were dried both in sun as well as in solar tunnel dryer. Steam blanching as a pre-treatment was provided for 3-minute and 5-minutes. The initial and final moisture content of each of the sample is given below.

For *Adhatoda vasica* leaves, the initial moisture content was same for all the samples, that is, 286.69% (db), but the final moisture content varied according to the treatment provided to the sample. Accordingly, the conclusions are drawn below:

- 1) For the sun-dried samples, the final moisture content was 10.38% (db) on an average.
- 2) In the first trial the final moisture content (%) for *Adhatoda vasica* which was dried in solar tunnel dryer and subjected to no blanching and steam blanching for 3-minutes and 5-minutes were 9.00%, 8.27% and 6.80% (db), respectively.

- 3) In the second trial, the final moisture content (%) for the sun dried sample of *Adhatoda vasica* was 7.13% (db) and for the sample dried in solar tunnel dryer and subjected to no blanching and steam blanching for 3-minutes and 5-minutes were 8.42%, 7.80% and 6.74% (db), respectively.
- 4) In the third trial, the final moisture content (%) for the sun dried sample of *Adhatoda vasica* was 1038% (db) and for the sample dried in solar tunnel dryer and subjected to no blanching and steam blanching 3-minutes and 5-minutes were 8.27%, 7.82% and 6.75% (db), respectively.

Correspondingly, for *Moringa oleifera* the initial moisture content on dry basis (%) was 303.23% for all the samples, but the final moisture content varied according to the pre-treatments provided to the samples kept for drying. The final moisture content for each of the samples is given below:

- 1) For the sun-dried sample the final moisture content was measured to be 10.59%, 11.92% and 8.60% (db) for 1st, 2nd and 3rd trial respectively.
- 2) In the first trial, the final moisture content (%) for *Moringa oleifera* which was dried in solar tunnel dryer and subjected to no blanching and steam blanching for 3-minutes and 5-minutes were 5.64%, 5.64% and 5.06% (db), respectively.
- 3) In the second trial, the final moisture content (%) for *Moringa oleifera* which was dried in solar tunnel dryer and subjected to no blanching and steam blanching for 3-minutes and 5-minutes were 7.65%, 4.97% and 4.75% (db), respectively.
- 4) In the third trial, the final moisture content (%) for *Moringa oleifera* which was dried in solar tunnel dryer and subjected to no blanching and steam blanching for 3-minute and 5-minutes were 7.65%, 4.97% and 5.05% (db), respectively.

The following conclusions could be drawn from the present research.

- 1) The average value for daily maximum ambient radiation intensity at 12:00 h was 887.21 W/m², while the average daily maximum radiation intensity inside the solar tunnel dryer was found at 13:00 h was 586.82 W/m². Similarly, the average value for daily minimum ambient radiation intensity at 18:00 h was 13.92 W/m², and the same for inside the solar tunnel dryer was found at 18:00 h was 0.626 W/m².

- 2) The average value for maximum ambient temperature recorded was 30.19°C, and the same for the dryer was 55.09°C. The corresponding relative humidity was 32.54% and 10.92% respectively. Similarly, the average minimum ambient temperature was 19.58°C, and for the dryer was 21.12°C. The corresponding relative humidity was 75.84% and 63.12%, respectively.
- 3) The drying time for *Adhatoda vasica* and *Moringa oleifera* was found to decrease with the increase in time of steam blanching. The average time taken for the sample without blanching to dry was 8 hours and the average time taken for the sample with 5-minute blanching was 5 hours.
- 4) The drying of *Adhatoda vasica* and *Moringa oleifera* in open sun took 12 hours as compared to 6 hours in the solar tunnel dryer.
- 5) The biochemical analysis was carried out to determine the carbohydrate content, ascorbic acid, ash, fat, fibre and protein content of the dried samples. It was found that the samples which were blanched retained the most nutrients as well as had lower moisture content.
- 6) The minimum value of carbohydrate content, ascorbic acid, ash, fat, fibre and protein content for unblanched sun-dried leaves of *Adhatoda vasica* were found to be 36.13%, 1.84%, 56.56%, 3.20%, 14.16% and 8.46%, respectively.
- 7) The maximum value of carbohydrate content, ascorbic acid, ash, fat, fibre and protein content for 5-minute blanched solar tunnel dried leaves of *Adhatoda vasica* were found to be 39.05%, 3.76%, 54.77%, 3.48%, 15.91% and 10.71%, respectively.
- 8) The minimum value of carbohydrate content, ascorbic acid, ash, fat, fibre and protein content in sun-dried leaves of *Moringa oleifera* were 34.44%, 1.44%, 78.08%, 5.56%, 14.25% and 5.88%, respectively.
- 9) The maximum value of carbohydrate content, ascorbic acid, ash, fat, fibre and protein content in solar tunnel dried leaves of *Moringa oleifera* for 5-minute blanched samples were 38.78%, 3.06%, 43.52%, 6.88%, 18.33% and 8.44%, respectively.
- 10) The average value of bulk density for unblanched open sun-dried sample was found to be 247.67 kg/m³ and 386.33 kg/m³ for *Adhatoda vasica* and *Moringa oleifera* leaves, respectively. The average value of recovery rate for *Adhatoda vasica* and *Moringa oleifera* was found to be 9.33% and 9.75%, respectively.

- 11) The average value of WAI for unblanched and sun-dried sample of *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 150.98% and 149.01%, respectively. The average value of WSI for *Adhatoda vasica* and *Moringa oleifera* was found to be 19.22% and 22.53%, respectively.
- 12) The mean value of bulk density was found to be 303.00 kg/m³ and 451.67 kg/m³ for solar tunnel dried samples of *Adhatoda vasica* and *Moringa oleifera* leaves, respectively. The mean value of recovery rate for *Adhatoda vasica* and *Moringa oleifera* was found to be 22.53% and 24.71%, respectively.
- 13) The average value of WAI for solar tunnel dried *Adhatoda vasica* and *Moringa oleifera* leaves was found to be 344.88% and 259.68%, respectively. The average value of WSI for *Adhatoda vasica* and *Moringa oleifera* was found to be 57.75% and 57.31%, respectively.
- 14) The thermal efficiency of the solar tunnel dryer was found to be 12.14%.
- 15) The pick-up efficiency of the solar tunnel dryer was obtained as 26.45%.
- 16) The mathematical models developed for the prediction of inside micro-climate of the solar tunnel dryer, using energy balance equations, which was ran in FORTRAN has shown good fitting.
- 17) The total dryer cost was ₹2,44,737.
- 18) It can be concluded that solar tunnel dryer is more cost-effective than open sun drying as the profit per kg of *Adhatoda vasica* leaf powder was ₹20.00/kg as compared to ₹6.21/kg which was dried in open sun. Similarly, for *Moringa oleifera* leaves powder, the profit was ₹30.00/kg for the products dried in solar tunnel dryer as compared to ₹16.30/kg, for the products dried in the open sun.
- 19) The payback period of the solar tunnel dryer was found to be 1 year and 20 days.

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APPENDICES

APPENDIX - I

MICRO- CLIMATE VARIATION

| WEEK 1- 14TH JANUARY 2022 to 21ST JANUARY 2022 | | | | | | | | | | | | |
|--|--------|--------|--------|--------|--------|--------|---------|----------|----------|-----------|------------|-------------|
| TIME | T1 | T2 | T3 | T4 | T5 | TP | HUM. IN | HUM. OUT | TEMP. IN | TEMP. OUT | PYRANO. IN | PYRANO. OUT |
| 9:00 AM | 21.783 | 24.852 | 24.866 | 27.160 | 25.720 | 35.920 | 58.998 | 68.278 | 21.071 | 18.998 | 115.845 | 701.816 |
| 10:00 AM | 35.373 | 38.536 | 38.559 | 39.982 | 34.568 | 51.195 | 34.177 | 61.523 | 31.998 | 22.252 | 328.801 | 806.685 |
| 11:00 AM | 43.668 | 46.743 | 46.750 | 47.424 | 43.356 | 60.594 | 22.171 | 54.199 | 42.340 | 24.744 | 450.352 | 858.004 |
| 12:00 PM | 49.248 | 53.157 | 53.160 | 52.628 | 45.984 | 62.999 | 17.048 | 48.272 | 48.578 | 26.943 | 568.181 | 859.693 |
| 1:00 PM | 51.251 | 53.661 | 53.659 | 55.913 | 49.802 | 61.114 | 14.603 | 43.523 | 51.789 | 28.118 | 586.823 | 834.105 |
| 2:00 PM | 51.684 | 57.414 | 57.425 | 57.446 | 52.100 | 59.128 | 13.765 | 41.138 | 53.237 | 29.250 | 427.737 | 773.120 |
| 3:00 PM | 50.291 | 56.146 | 56.153 | 57.441 | 52.588 | 56.250 | 13.644 | 40.060 | 52.814 | 29.423 | 307.620 | 606.827 |
| 4:00 PM | 47.791 | 52.601 | 52.598 | 53.228 | 48.896 | 51.348 | 14.728 | 40.739 | 50.643 | 29.084 | 276.709 | 435.006 |
| 5:00 PM | 42.722 | 46.240 | 46.240 | 47.244 | 41.810 | 43.989 | 17.275 | 41.900 | 46.324 | 28.464 | 84.027 | 234.848 |
| 6:00 PM | 35.991 | 36.701 | 36.705 | 35.834 | 32.347 | 32.339 | 28.340 | 52.110 | 36.967 | 25.796 | 0.626 | 2.517 |

| WEEK 2- 22ND JANUARY 2022 to 29TH JANUARY 2022 | | | | | | | | | | | | |
|--|--------|--------|--------|--------|--------|--------|---------|----------|----------|-----------|------------|-------------|
| TIME | T1 | T2 | T3 | T4 | T5 | TP | HUM. IN | HUM. OUT | TEMP. IN | TEMP. OUT | PYRANO. IN | PYRANO. OUT |
| 9:00 AM | 20.722 | 23.095 | 22.448 | 24.665 | 25.440 | 34.144 | 52.174 | 55.767 | 18.631 | 16.999 | 137.822 | 600.267 |
| 10:00 AM | 33.653 | 36.038 | 34.915 | 35.200 | 34.407 | 47.017 | 29.633 | 44.234 | 29.902 | 21.066 | 291.756 | 759.768 |
| 11:00 AM | 43.537 | 46.498 | 43.730 | 43.348 | 42.509 | 58.969 | 16.002 | 31.735 | 39.851 | 24.010 | 445.002 | 859.543 |
| 12:00 PM | 47.979 | 51.149 | 48.864 | 45.861 | 44.668 | 59.249 | 11.922 | 30.094 | 45.589 | 26.336 | 549.583 | 887.210 |
| 1:00 PM | 50.527 | 51.935 | 49.478 | 48.090 | 47.700 | 58.188 | 10.817 | 28.800 | 48.768 | 27.919 | 595.841 | 841.291 |
| 2:00 PM | 51.546 | 55.993 | 53.156 | 49.874 | 49.485 | 57.114 | 10.272 | 27.718 | 50.672 | 27.814 | 467.149 | 793.917 |
| 3:00 PM | 51.130 | 55.477 | 52.347 | 49.825 | 50.102 | 55.873 | 10.079 | 27.537 | 50.761 | 27.934 | 390.672 | 800.137 |
| 4:00 PM | 48.105 | 52.211 | 49.159 | 46.395 | 46.432 | 51.866 | 10.234 | 26.630 | 49.523 | 27.737 | 279.101 | 673.001 |
| 5:00 PM | 42.882 | 46.399 | 43.477 | 41.289 | 39.635 | 44.916 | 11.549 | 27.876 | 45.905 | 27.235 | 130.473 | 410.550 |
| 6:00 PM | 35.824 | 37.295 | 34.755 | 31.272 | 30.417 | 33.423 | 16.614 | 29.780 | 37.867 | 26.364 | 10.634 | 13.916 |

| WEEK 3- 29TH JAN to 5TH FEBRAURY 2022 | | | | | | | | | | | | |
|---------------------------------------|--------|--------|--------|--------|--------|--------|------------|----------|----------|-----------|------------|-------------|
| TIME | T1 | T2 | T3 | T4 | T5 | TP | HUM. IN | HUM. OUT | TEMP. IN | TEMP. OUT | PYRANO. IN | PYRANO. OUT |
| 9:00 AM | 22.562 | 24.796 | 24.798 | 26.838 | 28.003 | 35.063 | 63.127 | 75.841 | 21.117 | 19.578 | 145.683 | 406.522 |
| 10:00 AM | 36.310 | 38.540 | 38.537 | 39.949 | 38.860 | 50.632 | 37.200 | 63.186 | 32.156 | 23.004 | 301.170 | 527.536 |
| 11:00 AM | 46.352 | 49.830 | 49.829 | 48.853 | 47.092 | 61.169 | 22.236 | 53.252 | 42.009 | 25.096 | 415.251 | 649.574 |
| 12:00 PM | 51.274 | 55.021 | 55.018 | 54.633 | 52.933 | 63.758 | 15.118 | 44.037 | 48.990 | 26.982 | 538.024 | 664.846 |
| 1:00 PM | 54.085 | 56.758 | 56.763 | 56.361 | 55.861 | 63.629 | 12.406 | 39.829 | 53.226 | 28.361 | 520.339 | 680.337 |
| 2:00 PM | 54.973 | 60.495 | 60.496 | 57.947 | 57.828 | 61.369 | 10.920 | 32.837 | 55.093 | 29.456 | 453.766 | 650.207 |
| 3:00 PM | 53.917 | 59.516 | 59.519 | 57.911 | 58.111 | 59.285 | 10.738 | 32.649 | 55.049 | 30.055 | 364.565 | 564.896 |
| 4:00 PM | 51.343 | 56.064 | 56.066 | 49.858 | 49.739 | 55.107 | 11.608 | 32.570 | 53.021 | 30.193 | 300.168 | 479.382 |
| 5:00 PM | 46.426 | 50.198 | 50.207 | 45.136 | 43.081 | 48.075 | 13.254 | 35.034 | 49.610 | 29.490 | 131.312 | 336.111 |
| 6:00 PM | 39.339 | 41.045 | 41.052 | 35.977 | 34.302 | 36.985 | 19.404 | 42.666 | 41.436 | 27.299 | 16.714 | 43.083 |

APPENDIX II
DRYING OF ADHATODA VASICA – TRIAL 1

| A- sun drying without blanching | | | | | | |
|--|----------------------|------------|----------------------|----------------------------|-------|---------|
| time | Tray + Sample weight | Sample wt. | wt. of water loss(g) | weight of water in product | M.C | A d.b.% |
| 1 | 3010 | 515 | | 381.821 | 0.741 | 286.698 |
| 2 | 2981 | 486 | 29 | 352.821 | 0.726 | 264.922 |
| 3 | 2905 | 410 | 76 | 276.821 | 0.675 | 207.856 |
| 4 | 2850 | 355 | 55 | 221.821 | 0.625 | 166.559 |
| 5 | 2742 | 247 | 108 | 113.821 | 0.461 | 85.465 |
| 6 | 2690 | 195 | 52 | 61.821 | 0.317 | 46.419 |
| 7 | 2648 | 153 | 42 | 19.821 | 0.130 | 14.883 |
| 8 | 2642 | 147 | 6 | 13.821 | 0.094 | 10.378 |
| 9 | 2642 | 147 | 0 | 13.821 | 0.094 | 10.378 |

| <i>Adhatoda vasica</i> drying in STD without blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A1 d.b.% |
| 9am | 2900 | 425 | | 314 | 0.741 | 286.698 |
| 10am | 2814 | 339 | 86 | 228 | 0.673 | 205.405 |
| 11am | 2751 | 276 | 63 | 165 | 0.598 | 148.649 |
| 12am | 2700 | 225 | 51 | 114 | 0.507 | 102.703 |
| 1pm | 2668 | 193 | 32 | 82 | 0.425 | 73.874 |
| 2pm | 2623 | 148 | 45 | 37 | 0.250 | 33.333 |
| 3pm | 2604 | 129 | 19 | 18 | 0.140 | 16.216 |
| 4pm | 2596 | 121 | 8 | 10 | 0.083 | 9.009 |
| 5pm | 2596 | 121 | 0 | 10 | 0.083 | 9.009 |

| <i>Adhatoda vasica</i> drying in STD with 3 minute blanching | | | | | | |
|---|----------------------|------------|----------------------|----------------------------|-------|----------|
| time | Tray + Sample weight | Sample wt. | wt. of water loss(g) | weight of water in product | M.C | A2 d.b.% |
| 9am | 2360 | 275 | | 203.885 | 0.741 | 286.698 |
| 10am | 2261 | 176 | 99 | 104.885 | 0.596 | 147.486 |
| 11am | 2229 | 144 | 32 | 72.885 | 0.506 | 102.489 |
| 12am | 2203 | 118 | 26 | 46.885 | 0.397 | 65.928 |
| 1pm | 2184 | 99 | 19 | 27.885 | 0.282 | 39.211 |
| 2pm | 2170 | 85 | 14 | 13.885 | 0.163 | 19.525 |
| 3pm | 2163 | 78 | 7 | 6.885 | 0.088 | 9.682 |
| 4pm | 2162 | 77 | 1 | 5.885 | 0.076 | 8.275 |
| 5pm | 2162 | 77 | 0 | 5.885 | 0.076 | 8.275 |

| <i>Adhatoda vasica</i> drying in STD with 5-minute blanching | | | | | | |
|---|----------------------|------------|----------------------|----------------------------|-------|----------|
| time | Tray + Sample weight | Sample wt. | wt. of water loss(g) | weight of water in product | M.C | A3 d.b.% |
| 9am | 2805 | 315 | | 233.541 | 0.741 | 286.698 |
| 10am | 2674 | 184 | 131 | 102.541 | 0.557 | 125.881 |
| 11am | 2643 | 153 | 31 | 71.541 | 0.468 | 87.825 |
| 12am | 2619 | 129 | 24 | 47.541 | 0.369 | 58.362 |
| 1pm | 2601 | 111 | 18 | 29.541 | 0.266 | 36.265 |
| 2pm | 2588 | 98 | 13 | 16.541 | 0.169 | 20.306 |
| 3pm | 2579 | 89 | 9 | 7.541 | 0.085 | 9.257 |
| 4pm | 2577 | 87 | 2 | 5.541 | 0.064 | 6.802 |
| 5pm | 2577 | 87 | 0 | 5.541 | 0.064 | 6.802 |

TRAIL 2

| A- sun drying without blanching | | | | | | |
|---------------------------------|--------------------------|----------------|----------------------|--------------------------------|-------|---------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A d.b.% |
| 9am | 3010 | 515 | | 381.821 | 0.741 | 286.698 |
| 10am | 29782978 | 483 | 32 | 349.821 | 0.724 | 262.670 |
| 11am | 2905 | 410 | 73 | 276.821 | 0.675 | 207.856 |
| 12am | 2849 | 354 | 56 | 220.821 | 0.624 | 165.808 |
| 1pm | 2751 | 256 | 98 | 122.821 | 0.480 | 92.222 |
| 2pm | 2696 | 201 | 55 | 67.821 | 0.337 | 50.925 |
| 3pm | 2648 | 153 | 48 | 19.821 | 0.130 | 14.883 |
| 4pm | 2645 | 150 | 3 | 16.821 | 0.112 | 12.630 |
| 5pm | 2645 | 150 | 0 | 16.821 | 0.112 | 12.630 |

| <i>Adhatoda vasica</i> drying in STD without blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|--------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A1 d.b.% |
| 9am | 2900 | 425 | | 314 | 0.7414 | 286.6976 |
| 10am | 2817 | 342 | 83 | 231 | 0.675 | 208.108 |
| 11am | 2751 | 276 | 66 | 165 | 0.598 | 148.649 |
| 12am | 2703 | 228 | 48 | 117 | 0.513 | 105.405 |
| 1pm | 2668 | 193 | 35 | 82 | 0.425 | 73.874 |
| 2pm | 2629 | 154 | 39 | 43 | 0.279 | 38.739 |
| 3pm | 2607 | 132 | 22 | 21 | 0.159 | 18.919 |
| 4pm | 2595 | 120 | 12 | 9 | 0.075 | 8.108 |
| 5pm | 2595 | 120 | 0 | 9 | 0.075 | 8.108 |

| <i>Adhatoda vasica</i> drying in STD with 3-minute blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A2 d.b.% |
| 9am | 2360 | 275 | | 203.885 | 0.741 | 286.698 |
| 10am | 2232 | 147 | 128 | 75.885 | 0.516 | 106.707 |
| 11am | 2213 | 128 | 19 | 56.885 | 0.444 | 79.990 |
| 12am | 2194 | 109 | 19 | 37.885 | 0.348 | 53.273 |
| 1pm | 2178 | 93 | 16 | 21.885 | 0.235 | 30.774 |
| 2pm | 2168 | 83 | 10 | 11.885 | 0.143 | 16.712 |
| 3pm | 2165 | 80 | 3 | 8.885 | 0.111 | 12.494 |
| 4pm | 2161.5 | 76.5 | 3.5 | 5.385 | 0.070 | 7.572 |
| 5pm | 2161.5 | 76.5 | 0 | 5.385 | 0.070 | 7.572 |

| <i>Adhatoda vasica</i> drying in STD with 5-minute blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A3 d.b.% |
| 9am | 2805 | 315 | | 233.541 | 0.741 | 286.698 |
| 10am | 2659 | 169 | 146 | 87.541 | 0.518 | 107.466 |
| 11am | 2638 | 148 | 21 | 66.541 | 0.450 | 81.686 |
| 12am | 2609 | 119 | 29 | 37.541 | 0.315 | 46.086 |
| 1pm | 2591 | 101 | 18 | 19.541 | 0.193 | 23.989 |
| 2pm | 2581 | 91 | 10 | 9.541 | 0.105 | 11.713 |
| 3pm | 2577 | 87 | 4 | 5.541 | 0.064 | 6.802 |
| 4pm | 2577 | 87 | 0 | 5.541 | 0.064 | 6.802 |
| 5pm | 2577 | 87 | 0 | 5.541 | 0.064 | 6.802 |

TRAIL 3

| <i>Adhatoda vasica</i> drying without blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|---------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A d.b.% |
| 9am | 3010 | 515 | | 381.821 | 0.741 | 286.698 |
| 10am | 2978 | 483 | 32 | 349.821 | 0.724 | 262.670 |
| 11am | 2948 | 453 | 30 | 319.821 | 0.706 | 240.144 |
| 12am | 2897 | 402 | 51 | 268.821 | 0.669 | 201.849 |
| 1pm | 2796 | 301 | 101 | 167.821 | 0.558 | 126.012 |
| 2pm | 2688 | 193 | 108 | 59.821 | 0.310 | 44.918 |
| 3pm | 2655 | 160 | 33 | 26.821 | 0.168 | 20.139 |
| 4pm | 2642 | 147 | 13 | 13.821 | 0.094 | 10.378 |
| 5pm | 2642 | 147 | 0 | 13.821 | 0.094 | 10.378 |

| <i>Adhatoda vasica</i> drying in STD without blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A1 d.b.% |
| 9am | 2900 | 425 | | 314 | 0.741 | 286.698 |
| 10am | 2807 | 332 | 93 | 221 | 0.666 | 199.099 |
| 11am | 2749 | 274 | 58 | 163 | 0.595 | 146.847 |
| 12am | 2696 | 221 | 53 | 110 | 0.498 | 99.099 |
| 1pm | 2662 | 187 | 34 | 76 | 0.406 | 68.468 |
| 2pm | 2615 | 140 | 47 | 29 | 0.207 | 26.126 |
| 3pm | 2604 | 129 | 11 | 18 | 0.140 | 16.216 |
| 4pm | 2596 | 121 | 8 | 10 | 0.083 | 9.009 |
| 5pm | 2596 | 121 | 0 | 10 | 0.083 | 9.009 |

| <i>Adhatoda vasica</i> drying in STD with 3-minute blanching | | | | | | |
|---|-------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray +sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A2 d.b.% |
| 9am | 2360 | 275 | | 203.885 | 0.741 | 286.698 |
| 10am | 2258 | 173 | 102 | 101.885 | 0.589 | 143.268 |
| 11am | 2234 | 149 | 24 | 77.885 | 0.523 | 109.520 |
| 12am | 2208 | 123 | 26 | 51.885 | 0.422 | 72.959 |
| 1pm | 2190 | 105 | 18 | 33.885 | 0.323 | 47.648 |
| 2pm | 2172 | 87 | 18 | 15.885 | 0.183 | 22.337 |
| 3pm | 2161.6 | 76.6 | 10.4 | 5.485 | 0.072 | 7.713 |
| 4pm | 2161.6 | 76.6 | 0 | 5.485 | 0.072 | 7.713 |
| 5pm | 2161.6 | 76.6 | 0 | 5.485 | 0.072 | 7.713 |

| <i>Adhatoda vasica</i> drying in STD with 5-minute blanching | | | | | | |
|---|-------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray +sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | A3 d.b.% |
| 9am | 2805 | 315 | | 233.541 | 0.741 | 286.698 |
| 10am | 2673 | 183 | 132 | 101.541 | 0.555 | 124.653 |
| 11am | 2634 | 144 | 39 | 62.541 | 0.434 | 76.776 |
| 12am | 2606 | 116 | 28 | 34.541 | 0.298 | 42.403 |
| 1pm | 2586 | 96 | 20 | 14.541 | 0.151 | 17.851 |
| 2pm | 2576.7 | 86.7 | 9.3 | 5.241 | 0.060 | 6.434 |
| 3pm | 2576.7 | 86.7 | 0 | 5.241 | 0.060 | 6.434 |
| 4pm | 2576.7 | 86.7 | 0 | 5.241 | 0.060 | 6.434 |
| 5pm | 2576.7 | 86.7 | 0 | 5.241 | 0.060 | 6.434 |

DRYING OF MORINGA OLEIFERA – TRIAL 1

| <i>Moringa oleifera</i> sun drying without blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|---------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M d.b.% |
| 1 | 3090 | 610 | | 459 | 0.752 | 303.486 |
| 2 | 3035 | 555 | 55 | 404 | 0.728 | 267.550 |
| 3 | 2880 | 400 | 155 | 249 | 0.623 | 164.901 |
| 4 | 2782 | 302 | 98 | 151 | 0.500 | 100.000 |
| 5 | 2720 | 240 | 62 | 89 | 0.371 | 58.940 |
| 6 | 2675 | 195 | 45 | 44 | 0.226 | 29.139 |
| 7 | 2653 | 173 | 22 | 22 | 0.127 | 14.570 |
| 8 | 2647 | 167 | 6 | 16 | 0.096 | 10.596 |
| 9 | 2647 | 167 | 0 | 16 | 0.096 | 10.596 |

| <i>Moringa oleifera</i> drying in STD without blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M1 d.b.% |
| 9am | 2925 | 445 | | 334.462 | 0.752 | 303.486 |
| 10am | 2827 | 347 | 98 | 236.462 | 0.681 | 213.919 |
| 11am | 2751 | 271 | 76 | 160.462 | 0.592 | 145.165 |
| 12am | 2688 | 208 | 63 | 97.462 | 0.469 | 88.171 |
| 1pm | 2654 | 174 | 34 | 63.462 | 0.365 | 57.412 |
| 2pm | 2623 | 143 | 31 | 32.462 | 0.227 | 29.367 |
| 3pm | 2605 | 125 | 18 | 14.462 | 0.116 | 13.083 |
| 4pm | 2598.5 | 118.5 | 6.5 | 7.962 | 0.067 | 7.203 |
| 5pm | 2598.5 | 118.5 | 0 | 7.962 | 0.067 | 7.203 |

| <i>Moringa oleifera</i> drying in STD with 3-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M2 d.b.% |
| 9am | 2880 | 400 | | 300.64 | 0.752 | 303.486 |
| 10am | 2778 | 298 | 102 | 198.64 | 0.667 | 199.919 |
| 11am | 2708 | 228 | 70 | 128.64 | 0.564 | 129.469 |
| 12am | 2662 | 182 | 46 | 82.64 | 0.454 | 83.172 |
| 1pm | 2631 | 151 | 31 | 51.64 | 0.342 | 51.973 |
| 2pm | 2603 | 123 | 28 | 23.64 | 0.192 | 23.792 |
| 3pm | 2595 | 115 | 8 | 15.64 | 0.136 | 15.741 |
| 4pm | 2698 | 218 | 4 | 11.64 | 0.053 | 5.641 |
| 5pm | 2698 | 218 | 0 | 11.64 | 0.053 | 5.641 |

| <i>Moringa oleifera</i> drying in STD with 5-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M3 d.b.% |
| 9am | 2745 | 265 | | 199.3224 | 0.752 | 303.486 |
| 10am | 2662 | 182 | 83 | 116.3224 | 0.639 | 177.111 |
| 11am | 2624 | 144 | 38 | 78.3224 | 0.544 | 119.253 |
| 12am | 2592 | 112 | 32 | 46.3224 | 0.414 | 70.530 |
| 1pm | 2577 | 97 | 15 | 31.3224 | 0.323 | 47.691 |
| 2pm | 2561 | 81 | 16 | 15.3224 | 0.189 | 23.330 |
| 3pm | 2550 | 70 | 11 | 4.3224 | 0.062 | 6.581 |
| 4pm | 2549 | 69 | 1 | 3.3224 | 0.048 | 5.059 |
| 5pm | 2549 | 69 | 0 | 3.3224 | 0.048 | 5.059 |

TRIAL 2

| <i>Moringa oleifera</i> sun drying without blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|---------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M d.b.% |
| 9am | 3090 | 610 | | 459 | 0.752 | 303.486 |
| 10am | 3001 | 521 | 89 | 370 | 0.710 | 245.033 |
| 11am | 2905 | 425 | 96 | 274 | 0.645 | 181.457 |
| 12am | 2884 | 404 | 21 | 253 | 0.626 | 167.550 |
| 1pm | 2844 | 364 | 40 | 213 | 0.585 | 141.060 |
| 2pm | 2758 | 278 | 86 | 127 | 0.457 | 84.106 |
| 3pm | 2698 | 218 | 60 | 67 | 0.307 | 44.371 |
| 4pm | 2649 | 169 | 49 | 18 | 0.107 | 11.921 |
| 5pm | 2649 | 169 | 0 | 18 | 0.107 | 11.921 |

| <i>Moringa oleifera</i> drying in STD without blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M1 d.b.% |
| 9am | 2925 | 445 | | 334.462 | 0.752 | 303.486 |
| 10am | 2827 | 347 | 98 | 236.462 | 0.681 | 213.919 |
| 11am | 2758 | 278 | 69 | 167.462 | 0.602 | 151.497 |
| 12am | 2704 | 224 | 54 | 113.462 | 0.507 | 102.645 |
| 1pm | 2653 | 173 | 51 | 62.462 | 0.361 | 56.507 |
| 2pm | 2622 | 142 | 31 | 31.462 | 0.222 | 28.463 |
| 3pm | 2608 | 128 | 14 | 17.462 | 0.136 | 15.797 |
| 4pm | 2599 | 119 | 9 | 8.462 | 0.071 | 7.655 |
| 5pm | 2599 | 119 | 0 | 8.462 | 0.071 | 7.655 |

| <i>Moringa oleifera</i> drying in STD with 3-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M2 d.b.% |
| 9am | 2880 | 400 | | 300.64 | 0.752 | 303.486 |
| 10am | 2777 | 297 | 103 | 197.64 | 0.665 | 198.913 |
| 11am | 2702 | 222 | 75 | 122.64 | 0.552 | 123.430 |
| 12am | 2659 | 179 | 43 | 79.64 | 0.445 | 80.153 |
| 1pm | 2629 | 149 | 30 | 49.64 | 0.333 | 49.960 |
| 2pm | 2601 | 121 | 28 | 21.64 | 0.179 | 21.779 |
| 3pm | 2587 | 107 | 14 | 7.64 | 0.071 | 7.689 |
| 4pm | 2584.3 | 104.3 | 2.7 | 4.94 | 0.047 | 4.972 |
| 5pm | 2584.3 | 104.3 | 0 | 4.94 | 0.047 | 4.972 |

| <i>Moringa oleifera</i> drying in STD with 5-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|-------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C | M3 d.b.% |
| 9am | 2745 | 265 | | 199.3224 | 0.752 | 303.486 |
| 10am | 2637 | 157 | 108 | 91.3224 | 0.582 | 139.046 |
| 11am | 2593 | 113 | 44 | 47.3224 | 0.419 | 72.053 |
| 12am | 2568 | 88 | 25 | 22.3224 | 0.254 | 33.988 |
| 1pm | 2556 | 76 | 12 | 10.3224 | 0.136 | 15.717 |
| 2pm | 2553 | 73 | 3 | 7.3224 | 0.100 | 11.149 |
| 3pm | 2548.8 | 68.8 | 4.2 | 3.1224 | 0.045 | 4.754 |
| 4pm | 2548.8 | 68.8 | 0 | 3.1224 | 0.045 | 4.754 |
| 5pm | 2548.8 | 68.8 | 0 | 3.1224 | 0.045 | 4.754 |

TRAIL 3

| <i>Moringa oleifera</i> sun drying without blanching | | | | |
|--|----------------------|--------------------------------|------------|---------|
| Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C (w.b.) | M d.b.% |
| 610 | | 459 | 0.752 | 303.486 |
| 565 | 45 | 414 | 0.733 | 274.172 |
| 517 | 48 | 366 | 0.708 | 242.384 |
| 418 | 99 | 267 | 0.639 | 176.821 |
| 320 | 98 | 169 | 0.528 | 111.921 |
| 234 | 86 | 83 | 0.355 | 54.967 |
| 180 | 54 | 29 | 0.161 | 19.205 |
| 164 | 16 | 13 | 0.079 | 8.609 |
| 164 | 0 | 13 | 0.079 | 8.609 |

| <i>Moringa oleifera</i> drying in STD without blanching | | | | | | |
|---|--------------------------|----------------|----------------------|--------------------------------|------------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C (w.b.) | M1 d.b.% |
| 9am | 2925 | 445 | | 334.462 | 0.752 | 303.486 |
| 10am | 2827 | 347 | 98 | 236.462 | 0.681 | 213.919 |
| 11am | 2721 | 241 | 106 | 130.462 | 0.541 | 118.025 |
| 12am | 2672 | 192 | 49 | 81.462 | 0.424 | 73.696 |
| 1pm | 2631 | 151 | 41 | 40.462 | 0.268 | 36.605 |
| 2pm | 2617 | 137 | 14 | 26.462 | 0.193 | 23.939 |
| 3pm | 2604 | 124 | 13 | 13.462 | 0.109 | 12.179 |
| 4pm | 2599 | 119 | 5 | 8.462 | 0.071 | 7.655 |
| 5pm | 2599 | 119 | 0 | 8.462 | 0.071 | 7.655 |

| <i>Moringa oleifera</i> drying in STD with 3-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|------------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C (w.b.) | M2 d.b.% |
| 9am | 2880 | 400 | | 300.64 | 0.752 | 303.486 |
| 10am | 2774 | 294 | 106 | 194.64 | 0.662 | 195.894 |
| 11am | 2709 | 229 | 65 | 129.64 | 0.566 | 130.475 |
| 12am | 2658 | 178 | 51 | 78.64 | 0.442 | 79.147 |
| 1pm | 2618 | 138 | 40 | 38.64 | 0.280 | 38.889 |
| 2pm | 2599 | 119 | 19 | 19.64 | 0.165 | 19.767 |
| 3pm | 2591 | 111 | 8 | 11.64 | 0.105 | 11.715 |
| 4pm | 2584.3 | 104.3 | 6.7 | 4.94 | 0.047 | 4.972 |
| 5pm | 2584.3 | 104.3 | 0 | 4.94 | 0.047 | 4.972 |

| <i>Moringa oleifera</i> drying in STD with 5-minute blanching | | | | | | |
|--|--------------------------|----------------|----------------------|--------------------------------|------------|----------|
| time | Tray + Sample weight (g) | Sample wt. (g) | wt. of water loss(g) | weight of water in product (g) | M.C (w.b.) | M3 d.b.% |
| 9am | 2745 | 265 | | 199.3224 | 0.752 | 303.486 |
| 10am | 2663 | 183 | 82 | 117.3224 | 0.641 | 178.634 |
| 11am | 2620 | 140 | 43 | 74.3224 | 0.531 | 113.162 |
| 12am | 2583 | 103 | 37 | 37.3224 | 0.362 | 56.827 |
| 1pm | 2565 | 85 | 18 | 19.3224 | 0.227 | 29.420 |
| 2pm | 2553 | 73 | 12 | 7.3224 | 0.100 | 11.149 |
| 3pm | 2549 | 69 | 4 | 3.3224 | 0.048 | 5.059 |
| 4pm | 2549 | 69 | 0 | 3.3224 | 0.048 | 5.059 |
| 5pm | 2549 | 69 | 0 | 3.3224 | 0.048 | 5.059 |

APPENDIX-III

```

C          *****NO VENTILATION
GREENHOUSE*****

REAL LI,KS,NWRITE,LGH,KA,MU,NUE,NUP,NUGM,NUS

DIMENSION TS(1),TSOLD(1),TAIN(24),SOLIN(24),WIN(24),
WINDIN(24),RHIN(24)

OPEN(2,FILE='FPAD_12.RES')

DATA ROA,ROS,ROP/1.2,1600.,650./

DATA CA,CS,CP,CCO/1.05,2.0,3.8,0.84/

DATA ALCO,ALP,ALS,TAUCO/0.05,0.55,0.75,0.8/

DATA THICKG,THICKP/0.003,0.25E-3/

DATA ECO,EP,EG,EPB/0.95,0.98,0.9,0.3/

DATA SIGMA,RLL,WP/5.67E-8,0.05,0.661/

DATA MU,PR,KA,CV,PATM/1.81E-5,0.7,0.10,1.860,101.325E3/

DATA ALPHA,GAMA,NUE,BETA,G/2.69E-5,66.0,1.88E-5,0.785,9.80/

DATA
TAIN/17.67,21.69,30.81,40.22,47.43,52.70,54.73,54.83,52.51,
*48.81,41.93,32.78,28.60,27.47,26.87,25.49,23.77,22.62,21.55,
*20.47,20.61,20.79,18.91,18.78/

DATA
RHIN/0.75,0.59,0.53,0.39,0.23,0.23,0.24,0.23,0.23,0.24,0.26,
*0.35,0.41,0.27,0.26,0.30,0.54,0.66,0.71,0.59,0.39,
*0.66,0.52,0.63/

DATA
SOLIN/264.4,409.6,499.4,541.46,636.4,643.9,616.8,552.4,423.2,1.9,
*0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
*0.0,0.0,0.0,0.0/

C          DATA
WIN/0.00751,0.00759,0.0077,0.00784,0.00752,0.00743,0.0077,

C
*0.00725,0.0072,0.00735,0.00789,0.00792,0.00797,0.00734,0.00711,

```

```

C
*0.00718,0.0074,0.00846,0.00860,0.00761,0.00945,0.00856,0.00845,
C   *0.0088/
      DATA WINDIN/0.99,1.08,1.33,2.0,1.84,2.34,2.74,3.49,4.78,
*5.21,4.56,3.35,1.99,2.39,2.69,2.94,3.27,3.23,2.77,2.14,
*1.30,1.64,1.22,1.08/
C   DATA TDEWIN/10.22,10.24,10.53,10.68,10.04,
C
*10.0,10.49,9.73,9.31,9.77,10.59,11.13,10.73,9.78,9.64,9.08,10.16,
C   *12.11,12.33,10.43,13.50,12.03,11.91,12.42/

      LGH=10.0

      BGH=5.0

      H1GH=2.10

      H2GH=2.55

      HGH=H1GH+H2GH

      WRITE(2,10) LGH, BGH, HGH

      WRITE(6,10) LGH, BGH, HGH

10  FORMAT(1X, 'LENGTH=', F6.2, 2X, 'WIDTH=', F6.2, 2X, 'HEIGHT=', F6.2)

      WRITE(2,*) ' TA ', ' TGH ', ' TP '

*, ' TGM ', ' TPAD ', ' ET ', ' RH '

      WRITE(6,*) ' TA ', ' TGH ', ' TP '

*, ' TGM ', ' TPAD ', ' ET ', ' RH '

      Z=SQRT(((BGH**2.)/4.)+H2GH**2.)

      ACO=BGH*H1GH+2.*(LGH*H1GH+Z*LGH)

      CORA=2.*(Z*LGH)

      VCO=ACO*THICKG

      AGH=LGH*BGH

      VGH=AGH*(H1GH+0.5*H2GH)

      VP=AP*THICKP

      AS=AGH

```

```

VS=AS*DH

DP=H1GH+ (H2GH/2.)

R1=1./ (ROGL*VCO*CCO)

R3=1./ (WP*AP*CP)

R4=1./ (ROGM*VGM*CGM)

R5=1./ (ROS*CS*VS)

R6=1./ (ROA*VGH)

C *****INITIALIZATION*****

KK=1

TAMB=19.35

TCOOLD=19.36

TGHOLD=19.37

TPOLD= 19.35

TSOLD(1)=20.0

WGHOLD=0.00745

NWRITE=0.0

51 DSOL= (SOLIN (KK+1) -SOLIN (KK) )

SOLXX=3.6* (SOLIN (KK) +NWRITE*DSOL*DT)

SOLP=0.65*SOLXX

SOLBS=0.65*SOLXX

SOLSS=0.115*SOLXX

DWIND= (WINDIN (KK+1) -WINDIN (KK) )

WINDXX= (WINDIN (KK) +NWRITE*DWIND*DT)

DTA= (TAIN (KK+1) -TAIN (KK) )

TAXX=TAIN (KK) +NWRITE*DTA*DT

DRH= (RHIN (KK+1) -RHIN (KK) )

RHXX=RHIN (KK) +NWRITE*DRH*DT

DEW=TDEWIN (KK+1) -TDEWIN (KK)

TDEWXX=TDEWIN (KK) +DEW*NWRITE*DT

```

```

TSKY=0.055*(TAXX)**1.5

HCOA=3.6*(5.3+3.8*WINDXX)

HCOGH= 3.6*(1.75*ABS(TGHOLD-TCOOLD)**0.333)

TAVP=(TPOLD+TGHOLD)/2.

BP=1/TAVP

GRP=G*BP*ABS(TPOLD-TGHOLD)*(RLL**3.)/MU

NUP=0.25*(GRP**0.3)

C   V=QF/(BGH*HGH*3600.0)

C   RE=ROA*V*HGH/MU

C   NUP=0.664*(RE**0.5)*(PR**0.3)

   HPGH=3.6*(NUP*KA/RLL)

C   WRITE(*,*) HPGH

   TAVS=(TSOLD(1)+TGHOLD)/2.

   BS=1/TAVS

   GRS=G*BS*ABS(TSOLD(1)-TGHOLD)*(DP**3.)/MU

   NUS=0.25*(GRS**0.3)

   HSGH=3.6*(NUS*KA/DP)

   A1=TPOLD+273.16

   A2=TCOOLD+273.16

   A3=TSOLD(1)+273.16

   A4=TGHOLD+273.16

   A5=TAXX+273.16

   AX1=SIGMA*((A1**2.)+(A2**2.))

   BX1=A1+A2

   CX1=(1.0/EP)+(1.0/ECO)-1.0

   HRPCO=3.6*(AX1*BX1/CX1)

   AX2=SIGMA*((A2**2.)+(A3**2.))

   BX2=A2+A3

   CX2=(1.0/EG)+(1.0/ECO)-1.0

```

```

HRCOS=3.6*(AX2*BX2/CX2)

AX3=SIGMA*((A2**2.)+(TSKY**2.))

BX3=TCOOLD+TSKY

CX3=(1./ECO)-1

HRCOA=3.6*(AX3*BX3/CX3)

AX4=SIGMA*((A3**2.)+(A1**2.))

BX4=A3+A1

CX4=(1.0/EG)+(1.0/EPB)-1.0

HRPS=3.6*(AX4*BX4/CX4)

AX6=SIGMA*((A1**2.)+(A6**2.))

BX6=A1+A6

HFGCO=2500.78-2.3601*TCOOLD

HFGP=2500.78-2.3601*TPOLD

HFGS=2500.78-2.3601*TSOLD(1)

TRCOOLD=(9./5.)*TCOOLD+491.69

TRPOLD=(9./5.)*TPOLD+491.69

TRGHOLD=(9./5.)*TGHOLD+491.69

TRAXX=(9./5.)*TAXX+491.69

TRSOLD=(9./5.)*TSOLD(1)+491.69

PSCO=6894.0*EXP(54.63-(12301.69/TRCOOLD)-5.17*LOG(TRCOOLD))

PSP=6894.0*EXP(54.63-(12301.69/TRPOLD)-5.17*LOG(TRPOLD))

PSGH=6894.0*EXP(54.63-(12301.69/TRGHOLD)-5.17*LOG(TRGHOLD))

PSS=6894.0*EXP(54.63-(12301.69/TRSOLD)-5.17*LOG(TRSOLD))

PSA=6894.0*EXP(54.63-(12301.69/TRAXX)-5.17*LOG(TRAXX))

WSCO=0.622*PSCO/(PATM-PSCO)

WSP=0.622*PSP/(PATM-PSP)

WSS=0.622*PSS/(PATM-PSS)

WAXX=0.622*RHXX*PSA/(PATM-PSA)

CGH=(CA+CV*WGHOLD)

```

```

IF (SOLXX.LE.0.0) THEN

RT=0.9*(HPGH/CGH)

ELSE

RT=(HPGH/CGH)

ENDIF

C -----COVER TEMPERATURE-----

DTCO=R1*DT*(ALCO*ACO*SOLXX+ACO*HCOGH*(TGHOLD-TCOOLD)-ACO*
*HCOA*(TCOOLD-TAXX)-ACO*HRCOA*(TCOOLD-TSKY)
*+AP*HRPCO*(TPOLD-TCOOLD)+AS*HRCOS*(TSOLD(1)-TCOOLD))

TCO=TCOOLD+DTCO

C -----GREENHOUSE TEMPERATURE-----

DTGH=DT*R2*(HCOGH*(TCOOLD-TGHOLD)*ACO+HSGH*(TSOLD(1)-
TGHOLD)*AS
*+HPGH*(TPOLD-TGHOLD)*AP+RT*AP*07750*
*(WSP-WGHOLD)*HFGP)-0.0356

TGH=TGHOLD+DTGH

C -----PRODUCT-----

DTP=DT*R3*(ALP*0.7*AP*SOLXX)-HPGH*(TPOLD-TGHOLD)*
*AP-HRPCO*AP*(TPOLD-TCOOLD))

TP=TPOLD+DTP

C -----FLOOR-----

DTS=R5*DT*(ALS*(0.7*AS*SOLSS)-HSGH*
*(TSOLD(1)-TGHOLD)*AS-HRCOS*AS*(TSOLD(1)-TCOOLD))

TS(1)=TSOLD(1)+DTS

C =====

DTAGH=TGH-TAXX

DTPGH=TP-TGH

C =====

TCOOLD=TCO

TGHOLD=TGH

```

```
TPOLD=TP
WGHOLD=WGH
DO 61 I=1,3,1
TSOLD(I)=TS(I)
61 CONTINUE
T=T+DT
NWRITE=NWRITE+1.
IF(NWRITE.EQ.3600.0) THEN
KK=KK+1.
WRITE(2,5) TAXX, TGH, TP, TPAD, ETP, RH
WRITE(6,5) TAXX, TGH, TP, TGM, TPAD, ETP, RH
5 FORMAT(2X,6(F7.2),2X,F6.2)
C WRITE(2,5) DTAGH, DTPGH, DTGMGH
C WRITE(6,5) DTAGH, DTPGH, DTGMGH
C 5 FORMAT(2X,3(F7.2))
TIME=T+1
C WRITE(2,15) TIME
C WRITE(6,15) TIME
C 15 FORMAT(6X,'TIME=',F5.2)
NWRITE=0.0
ENDIF
IF(T.LE.24.) GO TO 51
STOP
END
```