INTEGRATION OF BIOGAS PLANT AND SOLAR WATER HEATER FOR DEVELOPMENT OF IMPROVED MUSHROOM DRYING SYSTEM

मशरुम शुष्कन की उन्नत प्रणाली के विकास हेतु बायोगैस संयंत्र एवं सौर जल उष्मक का एकीकरण

BY

NARALE PRADIP DIGAMBAR

THESIS

Doctor of Philosophy

IN

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DEPARTMENT OF RENEWABLE ENERGY ENGINEERING
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MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
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This is to certify that this thesis entitled **"Integration of biogas plant and solar water heater for development of improved mushroom drying system"** submitted for the degree of **Doctor of Philosophy** in **Agricultural Engineering** in the subject of **Renewable Energy Engineering** embodies bonafide research work carried- out by **Mr. Narale Pradip Digambar** under my guidance and supervision and that no part of this thesis has been submitted to any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 10.05.2017.

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Place: Udaipur (Pradip Narale)

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LIST OF SYMBOLS AND ABBREVIATIONS

AD	After digestion
ADM1	Anaerobic Digestion Model No. 1
AICRP	All India Co-ordinated Research Project
AOAC	Association of Analytical Communities
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
ANC	Artificial nutrient compound
BCR	Benefit-cost ratio
BD	Before digestion
BET	Brunauer-Emmett-Teller model of multilayer adsorption
C	Carbon
CD	Cattle dung
CH_4	Methane
CITT	Classical integral transform technique
C/N	Carbon–nitrogen ratio
CO_2	Carbon dioxide
COP	Coefficients of performance
CS	Corn stover
CTAE	College of Technology and Engineering
db	Dry basis
DBF	Dry biogas factor
dm	Dry matter of the sample
DM	Dairy manure
DPSC	Dual phase solar collector
DRA	Diffuse reflectance accessory
EDTA	Ethylene diamine tetra acetic acid
EHD	Electro hydro dynamic dryer
EMC	Equilibrium moisture content
EURs	Energy utilization ratios
EW	Electrolyzed water
FAO	Food and agricultural organization of the united nations
FD	Freeze drying
g	gram
GAB	Guggenheim, Anderson, and de Boer model
h	hour
HP	Heat pump
HRT	Hydraulic retention times
IMC	Initial moisture content
IRR	Internal rate of return
K	Potash
kg	Kilogram
kcal	Kilocalories
kHz	Kilohertz
KMS	Potassium metabisulphite
kpa	Kilopascal
L	Litre

PBP	Payback period
m^3	Cubic meter
MC	Moisture Content
MF	Mesocarp Fibers
min	Minutes
ml	Milliliter
MIRD	Mid infrared radiation
mm	Millimeter
MVD	Microwave vacuum drying
N	Total kjeldahl nitrogen
N_2O	Nitrous oxide
NPW	Net present worth
OLR	Organic loading rate
P	Phosphate
PBP	Pay back period
PCM	Phase change material
PK	Palm Kernel
RR	Rehydration ratio
R^2	Correlation coefficient
RHF	Readily hydrolysable fraction
RMSE	Root mean square error
SAHP	Solar assisted heat pump system
SE	Solar energy
SHF	Slowly hydrolysable fraction
SMER	Specific moisture extraction rate
SMS	Sodium metabisulfite
SpBMS	Spent button mushroom substrate
SpMS	Spent mushroom substrate
SpOMS	Spent oyster mushroom substrate
spp	Species
STP	Standard temperature and pressure
TPA	Texture profile analysis
TS	Total solids
TVSM	Total volatile solids input mass
TVSMR	Total volatile solids mass removed
TVSMRE	Total volatile solids mass removal efficiency
UV	Ultraviolet
VFA	Volatile fatty acid
VIS	Visible spectroscopy
viz	Latin ‘videlicet’ used as synonym for ‘namely’, ‘that is to say’.
VS	Volatile solids
W	watt
WAC	Water absorption capacity
WML	(Initial mass of sample – Mass of sample after time θ)
%	Per cent

LIST OF NOMENCLATURE

D_{eff}	Effective moisture diffusivities
D_0	Diffusivity constant
E_a	Activation energy
M_d	Bone dry weight of product, kg
M_w	Mass of the water to be removed during drying, kg
M_f	Final moisture content of product (% wb)
M_i	Initial moisture content of the product (% wb)
M	Mass of the wet product, kg
Q_a	Quantity of air needed to absorb m_w kg of water
Q_e	Total quantity of energy required for drying, kJ
C	Specific heat of wet product, kJ/kg °C.
T_d	Drying air temperature, °C
T_a	Ambient air temperature, °C
λ	Latent heat of vaporization of water, kJ/kg
M_a	Mass of air required for drying, kg/hr
H_e	Humidity ratio of exit air, kg of water/ kg of dry air
H_d	Humidity ratio of drying air, kg of water/kg of dry air
C_a	Specific heat of air, kJ/kg°C
ρ_a	density of air at ambient temperature, kg/m^3
ρ_e	density of exit air kg/m^3
T_e	Temperature of moist air at chimney outlet, °C
T_a	ambient temperature, °C.
D_i	Produced Draft
D_a	Actual Draft
t	Drying time, hr
V_a	Volumetric air flow rate required for drying, m^3/hr
M_a	Mass flow rate of drying air, kg/hr
V_h	Humid volume, m^3/kg
V	Volume of the product to be dried, m^3
ρ	Density of the product to be dried, kg/m^3
A_d	Drying area, m^2
T_{dl}	Thickness of drying layer, m
M_θ	Mass of the sample at time θ, g
R	Drying rate at time θ
a_w	Water activity
BV_0	Daily biogas production at STP (m^3 or L)

BV	Daily biogas production at temperature T (m^3 or L);
T	Observed biogas temperature (substrate temperature).
$BVo_{Specific\ dm}$	Specific biogas production, L/kg dm
$BVo_{Specific\ VS}$	Specific biogas production, L/kg VS
M_i	Initial mass of the sample, (g)
M_d	Mass of the oven dried sample, (g).
M_{ash}	Mass of dry ash, (g)
C_t	Cost in each year
B_t	Benefit in each year
i	Discount rate

CHAPTER I
INTRODUCTION

India is a country with a varied agro-climate, abundance of agricultural wastes, relatively low cost labour and a rich fungal biodiversity. These factors combined make India a potential major producer of temperate, tropical and subtropical mushroom species. Mushroom is a nutritious product and contains many vitamins and minerals. India is majorly producing button and oyster mushroom. Mushroom cultivation has been done on artificial soil media, the media generally made of either wheat straw or rice straw in addition with required fertilizers for mushroom production. Apart from mushroom production, huge quantity of spent mushroom substrate is produced after harvesting of mushroom which is unutilized. In the following subsections importance of mushroom drying, need of mushroom drying, it's drying techniques, utilization of spent mushroom substrate and biomethanation of spent mushroom substrate is discussed.

1.1 General:

With the ever increasing population and shrinking land, secondary agriculture is going to occupy a prominent place to fill the void of quality food requirements. The demand for quality food and novel products is increasing with the changes in life style and income. The present era is promising for functional foods free from synthetic chemicals. Also, widespread malnutrition necessitated the search for alternative source of protein because the production of pulses has not kept pace with our requirement. In present context, mushroom cultivation offers number of remunerative options in food industry. Diversification in any farming system imparts sustainability. Mushrooms not only impart diversification but also help in addressing the problems of quality food, health and environmental sustainability.

The button mushroom (*Agaricus bisporus*) is the most widely cultivated and consumed mushroom throughout the world and it contributes about 40% of the total world production of mushroom. The white button mushroom still contributing about 90 % of total country's production as against its global share of about 40 % (Rai and

Arumuganthan, 2003). As a high-class food, button mushrooms not only provide delicious taste but also possess abundant nutritive value (Cremades *et al*., 2012). However, the cultivated button mushroom is a highly perishable vegetable, having a very short shelf-life especially in summer (Oliveira *et al.,* 2012; Sommer *et al.,* 2010). Since these mushrooms have very short shelf life, these cannot be stored or transported for more than 24 hours at the ambient conditions prevailing in most parts of year and the country.

The oyster mushroom (*Pleurotus ostreatus)* is the second largest cultivated and consumed mushroom in India (Naik *et al*., 2006). Oyster mushroom is widely consumed after button mushroom in hotels. It gives delicious taste after cooking and has high nutritive values. The cultivated oyster mushroom is highly perishable and needs immediate processing to prohibit from microbial attack.

1.2 Importance of Mushrooms:

Mushroom is a rich source of good quality proteins having most of the essential amino acids, vitamins and minerals and is popular for its delicacy and exotic flavour (Rai *et al*., 2003). Indian diet, essentially vegetarian, supplemented with highly digestible superior quality mushroom protein will help eradicate malnutrition in our country. Realizing the importance of mushrooms to fight malnutrition, poverty and to manage agro-waste, FAO has recommended mushrooms for developing countries to bridge the protein gap (Nehru and Kumar, 1995). Having a high protein value, mushrooms are foodstuffs that are used as garniture in vegetable and meat dishes and in soup making. Ground mushrooms as flour are used in the medical industry.

Mushrooms have traditionally been used for medicinal and tonic properties for treating hepatitis and other diseases of liver and for promoting longevity and cosmetic products such as skin whitening agent. Compounds extracted from white button mushroom have been reported to have anti-fungal and anti-bacterial properties (Chang and Buswell, 1996). The high proteins, sterols, macro-elements and low calorie content (i.e. low fat, starch and sugar) make mushroom ideal for prevention of cardiovascular diseases (Poongkodi and Sakthisekaran, 1995). Thus, they are an ideal food ever for

patients, old people, pregnant ladies and children. Therapeutic properties of mushroom include enhancement of macrophase function and host resistance to many bacterial, viral, fungal and parasitic infections, activation of non-specific immune stimulation and reduction of blood cholesterol and glucose levels (Cheung, 1998). Thus, mushroom occupy a special role in the formulation of diets, low in calories, cholesterol-free that can find application for treating obesity, diabetes and coronary heart disease conditions (Rajarathnam and Bano, 1992).

1.3 Need of Mushroom Drying:

Today, mushroom cultivation is one of the biggest money spinning enterprises in the world and mushroom is an important horticultural cash crop. Its production has tremendous scope as an income generating activity. Mushroom being an indoor crop does not require arable land, except for some non-agricultural land to build infrastructure for preparation of substrate, raising of crop, preparation of spawn and post harvest handling, hence it is of great importance for landless and marginal farmers (Mehta *et al*., 2012). But post-harvest problems of mushroom arise due to its high moisture content (i.e. about 90 per cent) and respiration at a very fast rate (Rajarathnam *et al*., 1983). The respiration heat of button mushrooms is ten times higher at 20°C than at 0°C being 1450 kcal at 20°C and 154 kcal at 0°C for 100 kg button mushroom in 24 hours (Vedder, 1978). This accelerates deteriorative changes, with the result product becomes high perishable with the shelf life of 1-2 days only under ambient temperature and humidity (Saxena and Rai, 1989; Lal Kaushal and Sharma, 1995). Unlike other fruits and vegetables, mushrooms lack thick protective surface coating of cuticle and suberin. Being rich in many amino acids, phenols, water content and the enzymes such as polyphenol – oxidase, peroxidase, catalase and proteases leads to rapid loss of water and enzymatic browning resulting in fast deterioration at ambient temperature (Rajarathnam and Bano, 1992). The enzyme which initiates browning is tyrosinase, a copper containing oxides which catalyses the oxidation of phenols. This is followed by a series of chemical reactions which convert the oxidation products to the brown polymer melanin (Noble and Burton, 1993). Loss of texture, development of off flavour and discolouration results in poor marketable quality and restricts trade of fresh mushrooms. Besides they grow in flushes and every 8-10 days,

they are harvested in batches. In between the flushes, the production comes down quite low. About 10-14 kg fresh mushrooms per 100 kg fresh compost can be obtained in two months in winter season at 15-18^{o}C temperature and 85 per cent humidity. The demand, therefore, never coincides with supply. In the peak period of harvesting due to the gluts in the market, owing to highly perishable nature, ensuring income security to farmers and bring nutritional security, its preservation in the form of more stable products is of great importance.

In order to keep mushrooms safe and unspoiled for a long time, it is vital to remove the bacteria causing fermentation or decomposition from their environment and from their structure. So, this bacterium should be killed and their contact with mushrooms cut. In order to provide this, the moisture should be removed from the mushroom. Short term preservation methods like low temperature storage, steeping preservation, irradiation and chemical treatment help to prolong shelf life up to three weeks, but long term preservation methods such as canning, pickling and drying can make the product available throughout the year at reasonable cost (Mehta *et al*., 2012). Drying is relatively inexpensive (Chen and Chen, 1974) and reduces bulk; thus, facilitates its transportation, handling and storage.When the mushroom is dried, it keeps almost all of its taste and other features. In addition, dried mushrooms occupy very little space. In case of the mushroom all the four most deleterious changes namely, browning, veil-opening, weight loss and microbial spoilage ask for the utmost post-harvest care.

Drying process of mushrooms is generally based on circulating the heated dry air over the mushroom in order to remove the moisture from it. Browning, veil-opening, weight-loss and microbial spoilage are the most common post harvest changes in the mushrooms which often result into enormous economic losses. Proper, sound and appropriate post harvest practices of storage and processing are needed to sustain the budding mushroom farming and industry in the country. Mushroom may be baked, fried, boiled, creamed, roasted, pickled and stuffed. In India, it is mostly consumed fresh and a small amount is used for processing. However, mushrooms can be grown at ambient temperature like in hilly areas but cannot be transported quickly to consumption places

such as big cities in plains. Therefore there is need to process mushroom for its long time storage. They can be processed as canned, dried and frozen mushrooms.

1.4 Drying Methods of Mushroom:

Drying is the oldest preservation technique of agricultural products. Drying is a widely employed preservation method to prevent the different types of spoilage including enzymatic or non enzymatic browning and microbial growth by reducing the moisture content to a level for safe storage. The methods of drying, as well as physiological changes that occur in foods during drying, affect the quality of the dried products (Naik *et al*., 2006). More specifically, the duration and temperature of the drying process are the important factors affecting the properties such as color, texture, density, porosity and rehydration characteristics of the dried materials (Krokida *et al.*, 1998).

Drying is considered an effective preservation method to prolong the shelf life of button mushroom. Currently, a variety of drying methods, which include hot air drying, vacuum drying, freeze-drying and microwave vacuum drying are applied in processing fruits and vegetables such as mushroom (Giri and Prasad. 2007). Every drying technique has its own advantages and disadvantages.

Conventional air drying is one of the most frequently used methods for mushroom drying, which involves thermal and/or chemical pre treatment and drying at temperature maintained between 50 and 70°C. Because of long drying time and overheating of surface during hot-air drying, the problems of darkening in color, loss in flavor and decrease in rehydration ability occur.

Freeze drying is the removal of water from a substance by sublimation from the frozen state to the vapour state. Freeze-drying takes place in three stages: water present in the product is removed by formation of ice crystals; the ice crystals are then removed from the outer surface of the material by sublimation; after removal of all the ice, the little quantity of water left is then removed by evaporation. Original shape and size can be retained and the shrinkage, which is a problem with other drying methods, is almost

negligible in freeze drying. Freeze-drying produces a high quality product, but being an expensive process, its application for mushroom drying is limited.

Recently, microwave-vacuum drying has been proposed as an alternative to dry heat-sensitive products as it can combine the advantages of drying at reduced temperature to those of microwave drying. Apart from this advantage, microwave-vacuum drying shows other disadvantages such as the use of expensive equipment, high energy consumption and high cost. Therefore its application for mushroom drying is limited.

Sun-drying is the cheapest and oldest method among various drying methods. It is still widely used for preservation of agricultural products in the tropics and subtropics. It is a very simple operation, where no fuel or mechanical energy is required. However, it is completely dependent on weather and it is not possible round-the-clock and round the year. Even though the quality of the product is affected by the environmental factors, due to free availability of heat source, it is considered to be the cheapest method of drying.

The dried product offers, apart from increased shelf life and pleasant flavor, the advantages of decreased mass and volume, which have the potential for savings in the cost of packaging, handling, storage and transport of the product. It was noted that when dealing with materials very sensitive to temperature, such as mushrooms, the choice of the right drying method can be the key factor for developing dried products of superior quality (Arumuganathan *et al.,* 2010).

1.5 Utilization of Spent Mushroom Substrate:

Spent mushroom substrate is a byproduct of mushroom cultivation technique. It is the organic substrate material left over after harvesting of mushroom. It is different from typically available dry leafy biomass. Spent mushroom substrate cannot be utilized directly without sterilization for animal feeding like dry leafy biomass. It was estimated that for one kg production of mushroom around 5 kg of spent mushroom substrate produced. This huge quantity of spent mushroom substrate was not utilized most of the time and may be either buried openly in the environment or composted to prepare enriched organic manure. Open burning of spent mushroom substrate can cause emission

of harmful greenhouse gases in the environment which may results in to global warming and climate change effects. Composting of organic manure take a long time to convert organic material in to enriched fertilizer and may create unhygienic surrounding condition. During the process of composting carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) is released in to the environment. These untapped greenhouse gases stays in the atmosphere for longer duration and contributes heavily in global warming of the earth. Therefore biomethanation study of spent mushroom substrate provides an important role to utilized methane produced through anaerobic digestion and enriched organic solid-liquid fertilizer for agriculture production (Deublein and Steinhauser, 2008).

1.6 Biomethanation of Spent Mushroom Substrate:

Biomethanation is production of biogas through anaerobic digestion of spent mushroom substrate. Anaerobic digestion is a series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen and produces biogas. The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates, fats, sugar and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide. The produced biogas consists of composition of methane, carbon dioxide, hydrogen sulphide, and traces of other gases. Methane is main combustible gas in biogas and can be used as energy source for drying of mushrooms. Spent mushroom substrate can be digested anaerobically and converted in to biogas (Bisaria, 1983). The produced biogas can be used as source of energy for drying of mushroom.

1.7 Justification:

Solar energy is effectively available only in day time with average sunshine duration of eight hours. Mushroom is highly perishable fungal product with moisture

content of around 90 %. Availability of sunshine hours for drying of button and oyster mushroom is not sufficient and therefore there is need to have some additional source of energy to dry mushroom product continuously to avoid spoilage and damage to the quality of dried product. Through review and literature it was found many researchers observed that button and oyster mushroom can be effectively dried at 50 °C temperature approximately within 10 to 12 hours in various controlled dryers. Therefore it is essential to provide some additional source of energy like biogas produced from the spent mushroom substrate for the continuous drying of button and oyster mushrooms to avoid the spoilage in product and improve quality of dried product. Spent mushroom substrate is the unwanted organic material left over after harvesting of mushroom. The disposal of spent mushroom substrate is still a problem for most mushroom growers. Piles of spent mushroom waste create unhygienic condition to the people living surrounding in urban areas and may cause of several diseases due to contamination in air and water body. Therefore the utilization of spent mushroom substrate for biogas production through anaerobic digestion technology not only provides additional source of energy for drying of mushroom but its utilization can also save emission of harmful greenhouse gases in the atmosphere and solve waste disposal problem.

Keeping all above mentioned points in view and also identifying the needs and gaps in research as evident from the literature reviewed, an urgent need has been felt to develop improved mushroom dryer through energy integration of solar water heater & biogas plant and biomethanation study of spent mushroom substrate. Therefore the proposed work is undertaken with following mention objectives.

1.8 Objectives:

1. Design and development of improved mushroom dryer through energy integration of solar water heater and biogas plant.
2. Biomethanation study on spent mushroom substrate and development of biogas plant based on it.
3. Performance evaluation of improved mushroom drying system.
4. Study of physiochemical and nutritional characteristics of dried mushroom.
5. Economic evaluation of improved mushroom drying system

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the review of literature used for the present study and the supporting references for methods used in research. The reviews are divided under following heads:

2.1 Drying of mushroom

2.2 Post-harvest operations of mushroom before drying

- 2.2.1 Washing
- 2.2.2 Slicing
- 2.2.3 Pretreatment of Mushroom
- 2.3.4 Process Temperature

2.3 Quality evaluation of dried mushroom products

- 2.3.1 Rehydration
- 2.3.2 Colour
- 2.3.3 Sensory Evaluation

2.4 Potential uses of spent mushroom substrate

2.5 Biomethanation of spent mushroom substrate

2.1 Drying of Mushroom:

Fruits, vegetables and their products are generally dried to enhance storage stability, minimise packaging requirements and reduce transport weight. Drying techniques are probably the oldest method of fruit and vegetable preservation applied by mankind. Brief reviews of various drying techniques are presented;

Mohamed and Hoo (1994) studied effect of sodium hypochlorite, sodium metabisulphite and glycerol in reducing the browning of dried mushrooms. Addition of glycerol also improved the texture of rehydrated dried mushrooms while $CaCl_2$ and alum produced a firm textured product, calcium being more effective than alum. Pretreatment with 0.3% cysteine-HCl helped preserve 82% of the ascorbic acid content in dried mushrooms compared to fresh mushrooms. The best drying temperature for colour and

texture was 40°C whereas 60°C temperature was found best for ascorbic acid retention. Glycerol reduced shrinkage during drying and improved the ability of the dried mushrooms to rehydrate almost to an extent characteristic of fresh mushrooms. Sensory evaluation showed that dried grey oyster mushrooms were well accepted; pretreatments caused a significant improvement in texture and colour ($P < 0.05$). The panel lists gave insignificantly different scores for flavour and overall acceptability for all the rehydrated dried mushrooms even when compared to the fresh mushrooms.

Pal and Chakraverty (1997) studied dehydration characteristics of the Oyster Pleurotus variety of mushroom. Both untreated and treated (steam blanching followed by sulphiting and citric acid pretreatment before drying) mushrooms were dried in the thin layer drying experimental equipment at each of the drying air temperatures of 45, 50 and 60°C with air velocities of 0.9 and 1.6 m/s. Studies on the equilibrium moisture content (EMC) of both untreated and treated dehydrated mushrooms were performed at different relative humidities ranging from 11.2 to 86.3% at 30°C. In thin layer drying, mushrooms are dried under a constant-rate period for a short time at the beginning, and subsequently, they are dried under a falling-rate period for the rest of the time. Drying equations and EMC models for both untreated and treated mushrooms were developed. The quality characteristics of dehydrated mushrooms were analysed. Taking drying time and quality of the dehydrated product into account, a combination of a drying air temperature of 50°C and an air velocity of 0.9 m/s appears to be suitable for drying of both untreated and treated mushrooms for a good dehydrated product.

Arumuganathan *et al.* (2003) dehydrated button mushroom (*Agaricus bisporus*) slices by sun drying, fluidized bed drying, cabinet air drying, osmo-air drying and freeze drying technique. The dried products were assessed for rehydration characteristics including their suitability for preparation of mushroom curry. Rehydration characteristics included rehydration ratio, coefficient of rehydration, pH, total soluble sugars and moisture content and organoleptic qualities. Though the mushrooms dehydrated by all the methods reconstituted well, those dehydrated by freeze drying and cabinet air drying showed better rehydration characteristics. Rehydrated mushrooms were used for

preparation of mushroom curry which was found acceptable in the organoleptic evaluation.

Giri and Prasad (2007) evaluated dehydration characteristics of button mushroom (*Agaricus bisporus*) in a commercially available microwave oven (0–600 W) modified to a drying system by incorporating a vacuum chamber in the cavity. The effect of drying parameters, namely microwave power, system pressure and product thickness on the drying kinetics and rehydration characteristics were investigated. The drying system was operated in the microwave power range of 115–285 W, pressure range of 6.5–23.5 kPa having mushroom slices of 6–14 mm thickness. Convective air drying at different air temperatures (50, 60 and 70 ºC) was performed to compare the drying rate and rehydration properties of microwave-vacuum drying with conventional method. Microwave-vacuum drying resulted in 70–90% decrease in the drying time and the dried products had better rehydration characteristics as compared to convective air drying. The rate constants of the exponential and Page's model for thin layer drying were established by regression analysis of the experimental data which were found to be affected mainly by the microwave power level followed by sample thickness while system pressure had a little effect on the drying rate. Rehydration ratio was significantly affected by the system pressure. Empirical models were also developed for estimating the drying rate constant and rehydration ratio as a function of the microwave-vacuum drying process parameters.

Singh *et al.* (2007) studied tray drying of button mushroom. Pretreated slices were dried in a tray dryer at 40, 45, 50 and 55°C temperature and constant air velocity of 2.8 m/s. The qualities of dehydrated slices were evaluated on the basis of veil opening and amino acid content and recommended that samples dried at 50 °C showed better quality.

Addo *et al*. (2009) studied thin-layer drying of cap and stem of mushroom at temperatures of 40, 50 and 60°C. Drying took place in the falling rate period, and the drying behaviour was adequately described by the Page's equation. The activation energy values of cap and stem were determined to be 26.96 and 26.85 kJ/mol, respectively. The computed values of frequency factor k_o for cap and stem were 4174 and 6247 h–1, respectively. The higher k_o value for stem implied lower resistance to diffusion of moisture and therefore resulted in less drying time for stem at similar moisture content.

Jo *et al.* (2009) investigated the changes in characteristics of the *Phellinus gilvus* mushroom as influenced by drying methods after harvest. The lowest weight loss rate of *P. gilvus* mushroom was 75.8% with drying in the shade and 80% by dryer (60°C). The size loss rate of pileus was 19.3% of that in a hot air dryer (60°C). The hardness of dried material context using a hot air dryer (60°C) was the lowest (20 kg/cm^2), and that by a dry oven (60°C) was the highest (457 kg/m^2). For ΔE value, 4.9 of context and 2.6 of tubes using drying in the shade (20°C) were found to be the lowest. The survival rate of sarcoma 180 treated with *P. gilvus* dried in the sun was the lowest (51.8%), and this was considered the most effective method for antitumor activity against sarcoma 180.

Apati *et al.* (2010) investigated dehydration and rehydration processes of *Pleurotus ostreatus* fruiting bodies. Mushroom samples were dehydrated at 40, 50 and 60 ºC, using drying air with relative humidity of 75 %. The rehydration was investigated at different temperatures of immersion water (25, 55 and 85 ºC) and different immersion times (30, 75 and 120 minutes). The best rehydration occurred for the samples dried at 40 ºC. The rehydration could be done in water at room temperature, during 30 minutes. Water sorption isotherms of samples were determined at 30, 40 and 50 ºC. Both GAB and BET models satisfactorily represented the experimental data of moisture sorption of dried mushrooms.

Artnaseaw *et al.* (2010) investigated drying characteristics of the Shiitake mushroom and Jinda chili under varying conditions of the drying temperatures (50, 55, 60 and 65 ◦C) and the vacuum pressures (0.1, 0.2, 0.3 and 0.4 bar) in a new design of a vacuum heat pump dryer. Nine different thin layer mathematical drying models were compared according to their correlation coefficient, reduced chi-square and root mean square error to estimate vacuum heat pump drying curves. The result indicates that the Midilli model can present better predictions than the others. The constants and coefficients of this model could be explained by the effect of the drying temperature and the drying pressure. The drying temperature and pressure significantly affects color degradation (probability $P < 0.05$). Drying temperature has little effects on rehydration capacity (probability $P > 0.05$). Rehydration capacity notably decreases with an increase in the vacuum pressure.

Silva *et al.* (2010) studied modeling of the mass transfer phenomenon in the drying process of agricultural products, using Fick's second law of diffusion adapted to infinite flat plate geometry, are described. An analytical solution methodology, the classical integral transform technique (CITT), was employed. Predicted results were compared with experimental data on the drying of sliced mushrooms in different operating conditions. A phenomenological analysis was made using graphics and tables. The data obtained by CITT and experimentally show negligible differences. The mass diffusion coefficient during hot air drying of mushrooms was estimated. Experimental drying kinetics were applied to the product at different air temperatures and air flow rates aiming to find a solution for the mass transfer equation, using an inverse problem with the Levenberg–Marquardt optimization technique in successive trials. Experimental data were also modified by a normal distribution of random errors. Statistical analyses show good agreement between experimental and predicted curves.

Zecchi *et al.* (2010) obtained a technological and economic alternative for mushroom and parsley dehydration combining convective and vacuum drying. Depending of product, this combination of technologies allows minimization of total drying time and avoids negative effects on quality of thermo-sensitive products during drying. Experimental drying curves were determined in a cross-flow convective dryer and in a cabinet vacuum dryer at 35, 45 and 55 ºC. The most appropriate theoretical models were obtained and applied for combined processes in order to minimize the overall drying time and avoid final product damage. For parsley at the highest temperature (45 ºC), reductions of 63% and 16% in drying time were observed with the combined drying process compared to the sole convective and sole vacuum drying, respectively. This reduction in process time was obtained when dryer change was done at the intermediate moisture condition that determines the highest drying rate during the whole combined process of convective and vacuum drying. For mushrooms, 9+convective drying throughout the process, at the highest temperature (55 ºC) compatible with product visual quality, minimized drying time.

Motevali *et al.* (2011) evaluated energy consumption for drying of mushroom slices using various drying methods including hot air, microwave, vacuum, infrared,

microwave-vacuum and hot air-infrared. Results of data analysis showed that the lowest and highest energy consumption levels in drying mushroom slices were associated with microwave and vacuum dryers, respectively. The use of vacuum in conjunction with microwave drying increased energy consumption relative to microwave drying alone. Energy consumption in the hot air dryer showed a downward trend with increasing temperature and an upward trend with increasing air velocity. In drying mushroom using infrared radiation, it was observed that increased air velocity increases drying time and consequently the amount of consumed energy. Using a combination of hot air and infrared drying decreased energy consumption relative to infrared drying alone and increased it relative to hot air drying. In the combined microwave-vacuum dryer, drying time and consequently energy consumption decreased in comparison to the vacuum dryer. Hot air-infrared drying of mushroom slices proved to have the lowest energy consumption.

Tulek (2011) investigated drying kinetics of oyster mushroom, *Pleurotus ostreatus*. Mushrooms were dried using a cabinet-type convective dryer. Air temperatures of 50, 60 and 70 °C were used for the drying experiments. The experimental drying data were fitted to different theoretical models to predict the drying kinetics. Nonlinear regression analysis was performed to relate the parameters of the model with the drying conditions. The performance of these models was evaluated by comparing the correlation coefficient (R^2), root mean square error (RMSE) and the chi-square between the observed and the predicted moisture ratios. Among all the models, the model of Midilli *et al*. was found to have the best fit in this study. Effective moisture diffusivities (D_{eff}), diffusivity constant (D_0) and activation energy (E_a) were calculated. D_{eff} varied from 9. 619x10^{-10} to 1.556x10^{-9} m^2s^{-1} over the temperature range studied and E_a was 22.228 kJ mol^{-1}.

Mohajer *et al*. (2013) investigated the performance of the DPSC by mathematical modeling of the system using e-NTU method. In their study, hot air had been released to ambient, while in this study, it was applied as heating fluid in a forced convection indirect solar dryer for drying parsley, dill and coriander vegetables. Furthermore, hot water obtained from the system can be used for two purposes. The experiments showed that the system was capable to be used as a domestic drying system as well as providing

domestic consumptive hot water as shown in Fig. 2.1. The system reduces the costs and the required space of installation (about 50%) in comparison with two separate systems for water and air heating. Furthermore, it is possible to speed up the drying process by using a heater as an auxiliary source of heating.

Sevik *et al*. (2013) proposed simple and cost effective solar assisted heat pump system (SAHP) with flat plate collectors and a water source heat pump. Mushroom drying was examined experimentally in the drying system. Solar energy (SE) system and heat pump (HP) system can be used separately or together. A computer program has been developed for the system. Drying air temperature, relative humidity, weight of product values, etc. were monitored and controlled with different scenarios by using PLC. Mushrooms were dried at 45 °C and 55 °C drying air temperature and 310 kg/h mass flow rate. Mushrooms were dried from initial moisture content 13.24 g water/g dry matter (dry basis) to final moisture content 0.07 g water/ g dry matter (dry basis). Mushrooms were dried by using HP system, SE system and SAHP system respectively at 250–220 min, at 270–165 min and at 230–190 min. The coefficients of performance of system (COP) are calculated in a range from 2.1 to 3.1 with respect to the results of experiments. The energy utilization ratios (EURs) were found to vary between 0.42 and 0.66. Specific moisture extraction rate (SMER) values were found to vary between 0.26 and 0.92 kg/kW h.

Dinani *et al*. (2014) studied drying behavior of thin layer mushroom slices in a laboratory scale dryer at voltages of 17, 19, and 21 kV and electrode gaps of 5, 6, and 7 cm. The drying curves were fitted to ten different mathematical models (Newton, Page, Modified Page, Henderson and Pabis, Logarithmic, Two-term exponential, Midilli and Kucuk, Wang and Singh, Weibull and Parabolic models) and a proposed new empirical model to select a suitable drying equation for drying mushroom slices in a hot air combined with EHD dryer. Coefficients of the models were determined by non-linear regression analysis and the models were compared based on their coefficient of determination (R^2), sum of square errors (SSE) and root mean square error (RMSE) between experimental and predicted moisture ratios. According to the results, the proposed model that contains only three parameters provided the best fit with the

experimental data. It was closely followed by the Midilli and Kucuk model that contains four parameters.

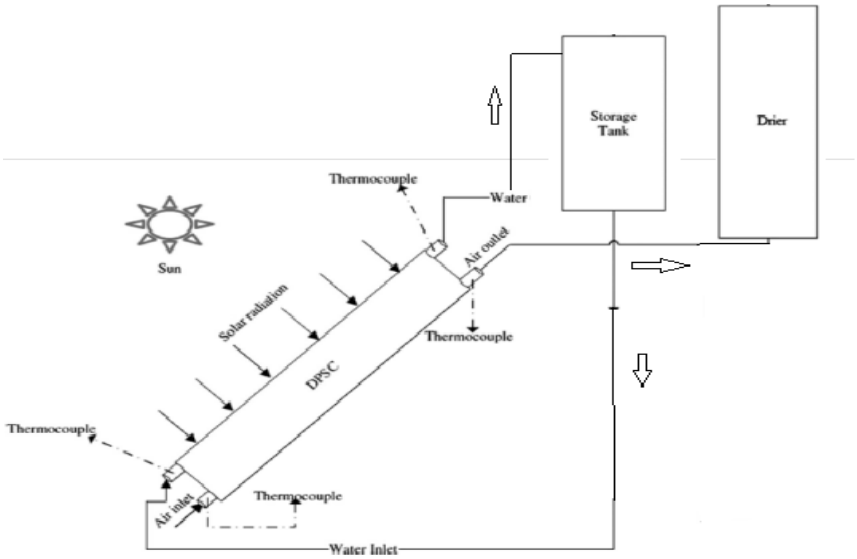


Fig 2.1. Schematic diagram of DPSC

Hui *et al*. (2014) experimentally determined the characteristics and drying process of mushroom (*Lentinus edodes*) by 6 different hot-air drying methods namely isothermal drying, uniform raise drying, non-uniform raise drying, uniform intermittent drying, non-uniform intermittent drying and combined drying. The chemical composition (dry matter, ash, crude protein, crude fat, total sugars, dietary fiber, and energy), color parameters (L, a*, b*, c*, and h0) and rehydration capacities were determined. Among all the experiments, non-uniform intermittent drying reached a better comprehensive results due to the higher chemical composition, better color quality associated with high bright (26.381±5.842), high color tone (73.670±2.975), low chroma (13.349±3.456) as well as the highest rehydration (453.76% weigh of dried body). Nine kinds of classical mathematical model were used to obtained moisture data and the Midili-kucuk model can be described by the drying process with the coefficient (R^2 ranged from 0.99790 to

0.99967), chi-square (χ^2 ranged from 0.00003 to 0.00019) and root mean square error (RMSE ranged from 0.000486 to 0.0012367).

Mustayen *et al*. (2014) carried out study on the design, performance, and application of various types of solar dryers. These dryers examined are the direct, indirect, mixed-mode, active, and passive solar dryers. The study focuses on solar dryer models that are suitable for producing high-quality dried products. The best solutions to solve the issues associated with traditional drying (i.e., open sun drying) were discussed, along with the ways by which to create simple, inexpensive, and low-cost solar dryers can be created.

Reyes *et al.* (2014) dehydrated mushroom in a hybrid solar dryer using electric resistances and paraffin wax as phase change material. Mushrooms were cut in 8 mm or 12 mm slices. At the outlet of the drying chamber the air was recycled (70% or 80%) and the air temperature was adjusted to 60°C. The dehydrated mushrooms showed a notorious darkening and shrinkage. Rehydration assays at 30 °C showed that in less than 30 min rehydrated mushrooms reached a moisture content of 1.91 (dry basis). Rehydrated mushrooms had a higher hardness compared with fresh mushrooms. Thermal efficiency fluctuated between 22% and 62%, while the efficiency of the accumulator panel varied between 10% and 21%. The accumulator allowed reducing the electric energy input.

Shalaby *et al.* (2014) reviewed solar dryers designed with PCM as energy storage medium. This paper reviews the previous work on solar drying systems which implemented the phase change material as an energy storage medium. It is concluded that the solar dryer with a PCM reduces the heat losses and improves the efficiency of the system. Furthermore, this review paper summarizes the previous methods that have been used for improving the thermal conductivity of the used phase change material particularly paraffin wax since it is commonly used as a storage medium in solar drying systems. It is inferred that carbon fibers, expanded graphite, graphite foam and high thermal conductive particles may improve the thermal efficiency of solar energy devices employing paraffin waxes as thermal energy storage media.

Taghian *et al*. (2014) designed electrohydrodynamic (EHD) drying system and examined for drying button mushroom (*Agaricus bisporus*) slices. The effects of three levels of voltage (17, 19 and 21 kV) and electrode gap (5, 6 and 7 cm) on solid and bulk density, porosity, shear strength, water absorption capacity (WAC) and total color difference (ΔE) of dried mushroom slices in comparison to oven dried mushroom slices were investigated. ANOVA showed that the hot air combined with EHD drying method had significant effects on bulk density and shear strength ($p \leq 0.01$) reduction as well as on porosity ($p \leq 0.001$) and WAC increase ($p \leq 0.01$), but this system had no significant effects ($p \geq 0.05$) on the solid density and ΔE parameters in comparison to the oven drying system. In addition, results indicated that increasing the voltage or decreasing the electrode gap resulted in some advantages such as bulk density and shear strength reduction or porosity and WAC increase that introduced this combined drying method as an improved method for drying mushroom slices.

Wang *et al*. (2015) studied drying of shitake mushroom by combining freeze drying and mid infrared radiation. The effect of application of MIRD before freeze drying (MIRD–FD) and after freeze drying (FD–MIRD) on drying time, color, rehydration ratio, apparent density, microstructure and aroma compounds was measured, explained and compared with the effect of FD on these parameters. The results showed that the combination of FD (for 4 h) followed by MIRD saves 48% time compared to FD while keeping the product quality at an acceptable level. The MIRD–FD combination was found to be inferior compared to the FD–MIRD as the former tended to produce products with a collapsed surface layer and poor rehydration capability. The combination of MIRD with FD had a significant effect on aroma retention and caused an increase of sulfur compounds such as dimethyl, tri sulfide and 1, 2, 4-trithiolane.

Kumar *et al*. (2016) reviewed progress in solar dryer for drying various agricultural commodities. A review of various types of solar dryers namely, direct solar dryers, indirect solar dryers, hybrid solar dryers and their various drying applications were represented in the paper.

Pei *et al*. (2016) dehydrated button mushroom slices using freeze drying (FD) or combined with microwave vacuum drying (MVD), and the changes in volatile

composition were investigated and compared by using headspace GCeMS and electronic nose (E-nose). The results showed that the content of C8 compounds decreased during FD/MVD process, while more alkanes and heterocyclic compounds were generated in the latter drying periods. The content of original thermal volatile compounds in MVD products were significantly lower compared to FD, and the same trent was observed on alkanes and heterocyclic compounds. Moreover, the volatile compounds of MVD products were more similar with fresh ones according to cluster analysis, and the critical point of change of volatile compounds might be at the end of sublimation period. In addition, E-nose could clearly discriminate button mushroom samples subject to different drying periods, the result obtained by E-nose showed good identity compared with GCeMS.

Tian *et al*. (2016) evaluated the effects of hot air, vacuum, microwave, and microwave vacuum drying techniques on important qualities and volatile compounds of whole shiitake (Lentinus edodes) mushrooms. These four drying methods resulted in a significantly ($p < 0.05$) increase in the content of total free amino acids and the relative content of sulfur compounds of dried products. Microwave vacuum drying helped to maintain larger amounts of taste-active amino acids, and improved nutrient retention and color attributes. Furthermore, the uniform honeycomb network created by microwave vacuum drying along with a less collapsed structure of dried samples can be used to explain the observed high rehydration ratio. Therefore, microwave vacuum drying should be a potential method for obtaining high-quality dried mushrooms.

Yasmin *et al*. (2016) studied the air drying behavior of fresh and osmosed oyster mushroom. Three different temperatures (55, 60 and 65^{o}C) were used to determine the effect of temperature on drying behavior of oyster mushroom in a mechanical dryer and an Arrhenius type relationship was developed from which activation energy value of 13.48 kcal/g-mole for fresh mushroom16.47 ,15.01and 4.19 kcal/g mole for mushroom osmosed at 12^{o}C, 27^{o}C and 45^{o}C respectively were found. Combined osmotic dehydration (in 20% salt solution) and air drying results in significantly higher (4 times) drying throughput compared to fresh mushroom. The values of proximate composition of fresh mushroom are 89.56, 3.83, 0.44, 0.91 and 5.26% moisture, protein, fat, ash, and

total carbohydrate, respectively, while the corresponding values are 11.70, 31.5, 2.90, 5.92 and 47.98% moisture, protein, fat, ash and total carbohydrate for developed mushroom powder.

2.2 Post Harvest Operations of Mushroom for Drying:

2.2.1 Washing:

Immediately after harvesting and removing casing material and contamination from surface, mushrooms are generally washed thoroughly under running tap water (Mudahar and Bains, 1982)**.** However, it is recommended that mushrooms being delicate should be washed carefully and as quickly as possible in plain water to prevent excessive absorption of moisture (Yapar *et al*., 1990). Mushrooms washed for less than 30 seconds look comparable to those treated with metabisulphite solution (Kohli, 1991).

2.2.2 Slicing:

An optimum slice thickness for drying of mushrooms is an important product parameter which needs to be judged accurately to ensure uniform dried product with proper drying rates and time. Komanowsky *et al*. (1970) used cubes of 3/8 inch × 3/8 inch × 3/8 inch and 1/8 inch thick slices for different sets of experiments. The dicing was made using Urschel Model RA cutter. Chen and Chen (1974) used 1/4 inch thick slices whereas Singh *et al.* (1984) used 3/8 inch thick slices for drying. Mudahar and Bains (1982), Kar and Gupta (2003) and Lidhoo *et al*. (2008) sliced mushroom heads length wise into 4 portions and the results showed that the rehydration ratio (RR) of dehydrated sliced sample varied between 2.3 to 3.9. Fang *et al*. (1971) and Singh *et al*.(2008) cut button mushroom into slices of about 5 mm thickness and the results showed that the rehydration ratio (RR) of dehydrated sliced sample varied between 1.89 to 2.61.

2.2.3 Pretreatment of Mushroom:

Foods are subjected to a number of preliminary unit operations and pretreatments before drying. Pretreatments are important in all methods of drying to inactivate enzyme and retention of typical characteristics of the product, *etc*. However, researchers are divided on the issue of the selection of an appropriate pretreatment prior to drying.

Thermal pretreatments affect the integrity of natural tissue leading to severe effects on water loss and solid gain.

Walde *et al.* (2006) carried out dehydration of button and oyster mushroom with various pretreatments like blanching, blanching followed by soaking in potassium metabisulphite (KMS), fermented whey, curds, etc. and dried in different dryers viz, hot air cabinet dryer, fluidized bed dryer, vacuum dryer and microwave oven. For both oyster and button mushrooms using pretreatment by dipping in curds or fermented whey the time of drying was less compared to other treatments in all types of dryers. The time taken for drying from 7.5% (db) moisture to 2.0% (db) was in the order of vacuum dryer > cabinet moisture dryer > fluidized bed dryer > microwave oven. The diffusion coefficients evaluated were also found in the same order.

Jambrak *et al.* (2007) used ultrasound as a pre-treatment method prior drying of mushrooms, Brussels sprouts and cauliflower in order to achieve reduction in drying time and to understand the effect of the ultrasound in mass transfer process, where diffusivity is the limiting step in the process. Pre-treatment with 20 kHz probe and 40 kHz bath for 3 and 10 min have been compared with blanched (80 ºC/3 min) and untreated samples. The procedures used were either freeze drying or conventional drying at a temperature of 60 ºC and air velocity (v=0.3 m/s) for sonicated, blanched and untreated samples. The effect of ultrasound and blanching pre-treatments on weight and moisture loss/gain, upon drying and rehydration were investigated. The drying time after ultrasound treatment was shortened for all samples, as compared to untreated. The rehydration properties (weight gain, %) were found to be the best for freeze-dried samples which showed weight gains for mushrooms (45.3%), Brussels sprouts (21.4%) and cauliflower (51%). The rehydration properties for ultrasound treated samples were higher than those for untreated samples.

Singh *et al.* (2008) conducted an experiment to know the effect of pretreatment on drying characteristics of button mushroom. Button mushrooms of thickness 0.5, 0.7 and 0.9 cm were pretreated with different preservatives such as 0.5 % citric acid, 0.5 % KMS and 0.75 % EDTA for 10 minutes and then dehydrated in a tray dryer at 40, 45, 50 and 55°C. The qualities of dehydrated slices were evaluated on the basis of veil opening and

amino acid content. The samples treated with EDTA and dehydrated at 50°C showed good amino acid content and were recommended.

Nour *et al.* (2011) carried out dehydration of button mushrooms (Agaricus bisporus) slices with various pre-treatments like blanching, soaking in 0.5% potassium metabisulphite (KMS), soaking in 0.5% citric acid +0.5% ascorbic acid and soaking in 0.75% EDTA. Drying was done in a tray dryer at drying air temperatures of 50 ºC and 70 ºC and the drying characteristic curves were drawn. The total drying time required for drying of white button mushrooms slices pretreated with various chemicals and dehydrated at different temperature of drying air was determined. The qualities of dehydrated slices were evaluated on the basis of rehydration characteristics and colour. Drying air temperature of 50ºC was better as it resulted in dried products having better rehydration characteristics and lighter color. Pre-drying treatments had a significant effect on the whiteness and colour change of dried mushroom slices. Whiteness of blanched mushrooms was very high compared to other samples but the rehydration ratio was very low. Among the four treatments, soaking in 0.5% citric acid and 0.5% ascorbic acid has produced comparatively more acceptable product taking into account all the quality parameters.

Khan *et al.* (2014) evaluated the effects of composite chemical pretreatment on the quality of post harvest button mushrooms. Three different treatments, including (T1) control (water), (T2) 1 mmol $L^{-1}Na_2EDTA$ + 10 mmol $L^{-1}CaCl_2$ and (T3) 1 mmol $L{-}1Na_2EDTA$ + 2.5% $CaCl_2$+ 0.5% citric acid + 2.5% sorbitol were used for pretreatments. The results showed that T3-treated samples maintained good firmness & color and had less weight loss during the postharvest storage. These results suggest that the T3 treatment could be useful in preserving button mushrooms.

2.2.4 Process temperature:

In case of fruits and vegetables, there is an upper temperature limit beyond which there is a negative impact on final product quality due to browning, flavour loss, softening of tissue, *etc.* For button and oyster mushroom it was reported that enzymatic browning and flavour deterioration take place above 49^{o}C (Ponting *et al.,* 1966).This

limit is specified by the sensitivity of each particular product and is conventionally placed around 50^{o}C (Ponting *et al.*, 1966; Bongirwar and Sreenivasan, 1977; Lenart and Flink, 1984a and b; and Maguer, 1984).

2.3 Quality Evaluation of Dried Mushroom Products:

Re-hydration behavior and color are two major quality attributes of dried products most important to consumers. In general severe browning or discoloration and low re-hydrated levels reduce quality.

Kotwaliwale *et al*. (2007) monitored textural and optical properties of paddy straw mushroom (*Pleuratus spp.)* during hot air drying of mushrooms in a cabinet tray drier at different air temperatures 50, 55, 60, and 70°C. Effect of pre-drying treatments, viz. blanching and sulphitation, was also monitored. Texture AnalyserTM and HunterlabTM Colorimeter were used to determine textural and optical properties, respectively. During drying, hardness and chewiness of mushrooms were increased, while cohesiveness and springiness increased initially and decreased at the final stage of drying. Hardness of mushroom dried at higher temperature was higher. Cohesiveness decreased with increased drying temperature. Blanched and dried mushrooms had more hardness compared to other dried samples. Whiteness index of mushrooms decreased while yellowness index increased during drying. Drying temperature had an inverse effect on whiteness of mushrooms. Sulphitation helped while blanching deteriorated whiteness retention during drying.

Kulshreshtha *et al*. (2009) studied drying characteristics and quality of the dried mushrooms by fluidized bed drying method. Drying was done at drying air temperatures of 50, 70, and 90 ºC and air velocities of 1.71 and 2.13 m/s. Two batch sizes, namely, 0.5 kg and 1 kg of sliced milky mushrooms were dried. Drying characteristics and the quality of dried mushrooms were analyzed. The results indicated that the drying time decreased only marginally with increase in air velocity. Drying air temperature of 50 ºC was better as it resulted in a dried product having better rehydration characteristics, lesser shrinkage

and lighter color. Highest energy efficiency (79.74%) was observed while drying a batch size of 1 kg at a drying air temperature of 50 ºC, using an air velocity of 1.7 m/s.

Doymaz (2014) investigated the effect of pretreatment (0.5% citric acid solution) and drying air temperature (40, 50, 60, and 70 ºC) on drying characteristics of button mushroom slices in a cabinet dryer. The experimental results show that the drying temperature and pretreatment have significant effects on the moisture removal from mushroom. In addition, rehydration ratio of pretreated samples was higher than that of control ones. Four kinds of classical model were used to obtain moisture data and the logarithmic model was the best for representation of mushroom drying. The values of effective moisture diffusivity were found to range between 1.70×10^{-10} and 7.12×10^{-10} m^2/s over the temperature range studied. The activation energy was found to be 35.04 and 37.21 kJ/mol for control and pretreated samples, respectively.

Hasan and Medany (2014) carried out study to evaluate the effect of pretreatments prior drying as well as drying temperature on quality of the dried mushroom. Rehydration ratio and color of the dried product are the most effective parameter for judging and evaluating the drying process. *Pleurotus ostreatus* and *Pleurotus eryngii* samples were pretreated by different solutions (NaCl, citric acid and sodium metabisulfite) at room temperature and at 96± 2 ºC. Pretreated and control mushroom samples were dried by hot air at 50, 60 and 70 ºC until reached to constant weight. The dried product was evaluated immediately after drying. *P. ostreatus* required from 7-12 h, while *P. eryngii* required 6.5- 11 h to reach moisture content around 7% depending on pretreatment and drying temperature. Control sample dried by using any tested drying temperature recorded the highest rehydration ratio compared to other pretreated samples dried at the same drying temperature. Also, steeped dried samples had higher rehydration ratio than blanched ones. Samples steeped in sodium metabisulfite (SMS) prior drying had the lowest browning index, while those blanched in NaCl or citric acid had the highest browning index values. Drying process caused a considerable decrement in protein content and a severe reduction in total microbial counts of mushroom samples. Sensory evaluation revealed that control and samples steeped in SMS or NaCl prior drying at 50 ºC got higher scores than the others. According to the results obtained it could be clearly

concluded that, steeping *P. ostreatus* and *P. eryngii* samples in NaCl, citric acid or Sodium metabisulfite (0.1% each at room temperature) for 10 min. prior drying at 50 ºC prevented browning especially with SMS. Also, steeping treatment resulted satisfactory rehydration ratio for dried products even they were lower than the untreated (control) sample.

Kumar *et al*. (2014) carried out performance study to assess the effect of pre-treatment on dehydration characteristics of mushrooms at drying temperature of 50, 60 and 70 ºC using air velocity of 1.5m/s. The study also covered the effects of parameters on the quality characteristics of the dehydrated products. Dehydration characteristics of oyster pleurotus variety of mushroom were studied. Both untreated and treated (steam blanching followed by sulphating and citric acid pre-treatment before drying) mushroom were dried in the thin layer set up at each of the drying air temperature 50, 60, and 70 ºC for the air velocity of 1.5 m/s. In thin layer drying mushroom dried under constant rate period for the short time at the beginning, subsequently it dried under falling rate period for the rest of the time. Rate of drying increases with the increase of drying air temperature of both treated and untreated mushrooms at particular air velocity. The quality characteristics of dehydrated mushrooms were analyzed. The colour and flavour of treated samples were appeared to be better. Rehydration ratio of untreated samples was found to be greater than those of the treated one. The texture of curry prepared from treated sample was a whole acceptable. Taking drying time and quality of the dehydrated product into account, a combination of drying air temperature of 60 ºC and air velocity of 1.5 m/s appears to be suitable for drying of both treated and untreated mushroom for good dehydrated products.

Aday (2015) studied the effectiveness of electrolyzed water (EW) at different concentrations (5, 25, 50 and 100 mg/L) combined with passive atmosphere packaging on the quality of mushroom. In order to understand the effect of EW on mushrooms, gas composition inside packages, weight loss, pH, whiteness and browning index, texture profile analysis (TPA), cap development, electrolyte leakage and FT-NIR analysis were performed during the twelve days of storage at 4°C. Samples washed with 25 and 50 mg/L EW consumed O_2 lower than the other treatments. Mushrooms treated with 25

mg/L EW had a significantly lower electrolyte leakage values than untreated and 5 mg/L treated mushrooms. Mushrooms treated with 25 mg/L EW had the highest whiteness index and lowest browning index. EW treatments at the concentrations of 25 and 50 mg/L maintained the textural parameters and slowed down the weight loss better than other treatments. FT-NIR analysis supported the results obtained by weight loss and electrolyte leakage. In conclusion, the results of this research support the idea that combined use of EW treatment and passive modified atmosphere packaging can be used to extend the shelf life of mushrooms.

2.3.1 Rehydration:

Mudahar and Bains (1982) reported re-hydration ratios for untreated and treated dehydrated mushrooms (*Agaricus bisporus*). They observed the re-hydration ratios of the sun-dried mushrooms in range of 2.3 to 2.6 as compared to 2.6 to 3.9 of the pre-treated hot-air dried mushrooms. The re-hydration ratio values of pre-treated mushrooms were found to be higher than those of untreated samples when dried by hot-air. They have also reported that the extent of storage had negligible effect on the re-hydration properties of mushroom.

2.3.2 Colour:

Whiteness is one of the most important quality factors associated with mushrooms (Gormley, 1975 and Burton *et al*. 1987).

Yapar *et al*. (1990) evaluated the colour of mushroom slices (*Agaricus bisporus*) in a hunter colorimeter by the L [black (0) / white (100), a [red (+) / green (-)] and b [yellow (+) / blue (-)] scales. They reported the L-value from 45.0 to 50.5 for dried product at different drying air temperatures.

Briones *et al*. (1993) assessed the quality of mushrooms (*Agaricus bisporus*) after storage by measurement of the external and internal colour (luminance) using a Hunterlab colourquest colorimeter fitted with a specimen port (diameter 9mm) and standardized with a white tile in the CIE, L*a* b* mode (colour parameters). External colour was

measured on the top of the cap and internal colour inside the tissue after slicing longitudinally 2.5 mm of the cap.

Shukla and Singh (2007) assessed the quality of mushrooms (*Agaricus bisporus*) using a Hunter scale L, a, and b. Significant changes in illuminance (80.90 to 67.31) were observed in dehydrated samples.

2.3.3 Sensory evaluation:

Sensory properties of dried foods are also important in determining quality. These include colour, taste, aroma, flavour and overall acceptability. Aroma and flavour can change due to loss of volatile organic compounds, the most common quality deterioration for dried products. Low temperature drying is used for foods that have high economic value such as flavouring agents, herbs and spices (Salunke, 1991; Singh *et al.,* 2006). Low temperature drying is important for heat sensitive products. It was found that low temperature dryer caused minimal damages to leafy vegetables during drying and thereby retained more nutrients than other dryers (Singh *et al.,* 2006).

2.4 Potential uses of Spent Mushroom Substrate:

Williams *et al*. (2001) assessed energy potential of spent mushroom substrate. Variability in SpMS composition was investigated by analysing samples from various locations. Analysis showed that SpMS has a calorific value equivalent to sewage sludge which has been fired successfully for many years. Study showed that spent mushroom substrate can be utilised as a source of energy production through anaerobic digestion.

Liang and Chiu (2007) examined the effects of the spent substrate of oyster mushroom (SpOMS) for growing wheat at different drought conditions. The SpOMS not only served as the sole fertilizer to produce normal growth and grain yield of wheat but also improved the soil quality after harvest to raise the soil organic matter, maintain the soil alkalinity and increase field capacity unlike the synthetic fertilizer amendment. Simultaneously, SpOMS treatment enhanced drought tolerance of wheat by enabling germination at 8.5% soil water content and completing sexual reproduction to grain production even at 6.3% soil water content.

Izyan *et al*. (2009) investigated potential of spent mushroom substrate from saw dust in vermicomposting through the growth and reproduction of earthworms. Five treatments in different ratios of cow dung: spent mushroom substrate was selected for study and performance were analysed. The highest percentage of growth and reproduction of earthworm were observed for 40 % cow dung and 60% SpMS treatment.

Medina *et al*. (2009) investigated the possibility of using spent mushroom substrate (SpMS) in the production of horticultural seedlings replacing part of the peat in the growing media. Three vegetable species with different salt sensitivities, the less sensitive being tomato (Lycopersicon esculentum var. Muchamiel), the moderately salt-sensitive being courgette (Cucurbita pepo L. var. Afrodite F1) and the most salt-sensitive being pepper (Capsicum annum L. var. Lamuyo F1) were grown in 12 media containing SpMS of two types of mushroom (Agaricus bisporus (SpMS-AB) and Pleurotus ostreatus (SpMS-PO)) or a mixture of both 50% (v/v) (SpMS-50), as well as peat in various ratios. The proportions of each residue in the mixtures elaborated with peat were 25%, 50%, 75% and 100% v/v residue. A substrate of 100% peat was used as control. In most of the cases, the addition of SpMS to the growing media produced an increase in the pH values, salt contents, macro and micronutrient concentrations and a decrease in the water holding capacity contents in comparison to peat, whereas great differences were found in the air capacity values between SMS-based substrates and peat. Up to 75% SpMS can be used in mixtures with peat for seed germination of the plant species studied. Regarding the most suitable SMS-based substrates for plant growth, any substrate could be used for tomato seedling production. However, all SpMS-AB-based substrates and the media containing low dose of SpMS-PO and SpMS-50 were adequate for growth of courgette and pepper.

Zhang *et al*. (2012) evaluated spent mushroom substrate (SpMS) as a growing medium for nursery seedlings. Two vegetable species, cucumber (*Cucumis sativus* L. cv. Jinchun No. 2) and tomato (*Solanum lycopersicum* L. cv. Mandy), were grown in 8 media of SpMS in various ratios with perlite or vermiculite. A mixed substrate of peat with perlite (1:1; v:v) was used as the control (CK). The experiment was arranged in a completely randomized design under greenhouse conditions. Prior to sowing, some physical and chemical properties of the growing media were determined. Results showed

that all the mixtures had desirable physical and chemical properties for their use in nursery tomato and cucumber seedlings except for the T4 (SpMS:vermiculite = 1:1; v:v) and the T8 (SpMS:perlite = 2:1; v:v) mixtures. Compared with the CK, increased plant height, leaf area, fresh weight, dry weight and index of seedling quality were found in the T3 (SpMS:vermiculite = 2:1; v:v) and T6 (SpMS:perlite = 4:1; v:v) growing media. SpMS should be considered as an alternative for the widely used but expensive and resource-limited peat in greenhouse cultivation.

Phan and Sabaratnam (2012) studied potential application of spent mushroom waste and its associated lignocellulose enzymes. This paper reviews scientific research and practical applications of SpMS (Spent Mushroom Waste) as a readily available and cheap source of enzymes for bioremediation, animal feed and energy feedstock.

Zhu *et al*. (2012) converted spent mushroom substrate into biofertilizer using a stress tolerant phosphate-solubilizing Pichia FL7. The isolate FL7 was identified as Pichia farinose with resistance against multiple environmental stresses, including 5–45 °C temperature, 3–10 pH range, 0–23% (w/v) NaCl and 0–6 M ammonium ion. Under the optimized cultivation condition, 852.8 mg/l total organic acids can be produced and pH can be reduced to 3.8 after 60 h, meanwhile, the soluble phosphate content reached 816.16 mg/l. The P. farinose was used to convert SpMS to a phosphate biofertilizer through a semi-solid fermentation (SSF) process. SpMS biofertilizer produced by P. farinose significantly improved the growth of soybean in pot experiments, demonstrating a tremendous potential in agricultural application.

Ma *et al*. (2014) obtained char from spent mushroom substrate via pyrolysis. Study found that as the pyrolysis temperature increased from 400 to 700 ºC, the char yield decreased from 45.10 to 33.79 wt.% and the higher heating value increased from 17.32 to 22.72 MJ/kg.

Tran (2016) utilized spent mushroom waste for vermicomposting using perionyxexkavatus and artificial nutrient compound. This study reported valuation of moisture and light on the growth of Perionyx exkavatus. Results showed that at 80% moisture, earthworm has the most growth rate and gain 100% clitellum development after

30 days. In natural light, growth rate and manure rate reached maximum with 5.61 mg.worm-1.day-1 and 235 mg.worm-1. ANC supplementing showed strong effects on earthworms' growth rate. Earthworms gained maximum growth rate at 20ml ANC added in three kg of substrates with over double biomass after 60 days. However, due to ANC's high acidity, with supplement volume over 25ml, there was a down trend of earthworm growth rate. ANC supplement did not show noticeable affect to manure rate of earthworms.

2.5 Biomethanation of Spent Mushroom Substrate:

Spent mushroom substrate is the soil like material remaining after a crop of mushroom. Spent mushroom substrate is high in organic matter making it desirable for use as a source of feedstock for anaerobic digestion. The composition of spent mushroom substrate may vary according to the raw material source. Table 2.1 shows the Physiochemical properties of spent mushroom substrate in comparison with cow dung, poultry droppings, wheat straw and rice straw.

Table 2.1 Physiochemical properties of spent mushroom substrate in comparison with other bio-materials used for anaerobic digestion.

Parameters	**Spent Mushroom Substrate**	**Cow Dung**	**Poultry droppings**	**Wheat Straw**	**Rice Straw**
Colour					
Colour	Brown to black	Dark Brown	Brown to green yellow or even black	Pale Yellow	Pale Yellow
Physical Properties					
Moisture Content, wb %	25-35	83	77.5	9.6	11.43±0.77
Total Solids %	65-75	17	22.5	90.4	88.57
Volatile Solids,%	85-92	79	66.72	91.1	87.2
Ash content, (g /kgTS)	80-150	210	299.52	89	127.21

Chemical properties					
C:N ratio	≤30	24	6.5	80	61.30±2.61
Nitrogen, %	1.5 to 3	1.1-1.5	4±0.04	0.65	0.5-0.8
Phosphorous ,% (P_2O_5)	0.5 to 2	0.5-1	3.02±1.0	0.23	0.16-0.27
Potassium, % (K_2O)	1 to 3	0.5-1	1.2±0.5	1.54	1.4-2.0
pH	6 to 8	6.3	7.0	7.9	7.60±0.008
Cellulose, (% of dry matter)	39.3	27.4	12.88	39.2	44.3
Hemicellulose, (% of dry matter)	12.9	12.2	11.72	26.1	30
Lignin, (% of dry matter)	7.4	13	14.16	7.5	5.6

[Dobermann and Fairhurst 2002, Ahmed et al. 2007, USDA 2011, Franzen 2012, Jusoh*et al*. 2013, Adebayo and Carrera, 2015, Strauber *et al.* 2015, Miah *et al.* 2016, Pandey *et al*. 2016]

Bisaria *et al.* (1990) utilized spent agro residues from mushroom cultivation for biogas production. Pleurotus sajor-caju were used in anaerobic digestors for production of biogas. The changes that take place in the residues during bioconversion were quantified in terms of composition of cellulose, hemicellulose, lignin, carbon and nitrogen. These “mycostraws” resulted in increased biogas production over the untreated ones, which varied from 21.5% in the case of spent bagasse to 38.8% in the case of spent paddy straw. The increased biogas generation by the spent residues seems to be due to the increased susceptibility to digestion and more favourable C/N ratio of the residues.

Mehta *et al.* (1990) cultivated Pleurotus Florida mushroom on rice straw and utilized spent rice straw for biogas production. Rice straw, used as a substrate for three successive crops of the fruiting bodies of *Pleurotus florida* having 22% protein, had

less cellulose but more nitrogen and ash than the original straw. *In vitro* digestibility using bacterial cellulase released 4.3-fold more reducing sugars per g cellulose from spent straw than from plain straw. There was 8-fold increase in biogas production from the spent straw compared with the original when used either in 3:1 (w/w) or 1:1 (w/w) combination with cattle dung

Fleming *et al.* (2006) studied feasibility of spent mushroom substrate (SMS) through anaerobic digestion and composting. Composting and anaerobic digestion proved effective for breaking down the organic matter in SMS. The biogas production (steady state period) averaged 0.72 m^3/day, and methane represented 49.3% of the total gas yield. The methane yield from the steady state system averaged 53 L CH_4/kg VS. The methane yield from the steady state system averaged 53 L CH_4/kg VS. This value is considerably less than what would be expected if livestock manure were the digested material (i.e. between 288 and 562 L CH_4/kg VS).

Kumari *et al.* (2010) studied biogas production from spent oyster mushroom substrate under ambient conditions in aspirator bottles containing one kg substrate inoculated with slurry from cattle waste based biogas plant. Biogas production from SpMS after 8 weeks of digestion was found as 19.8 L/kg. Around 21 and 27.9 percent degradation of total and volatile solids was found respectively with volumetric gas productivity of 0.135 L/day.

Kumari *et al.* (2013) utilized spent mushroom substrate as feedstock for biogas production and found better results of biogas yield. The study also deals to evaluate the agronomic efficiency of enriched slurry produced by mixing with SpMS Trichoderma inoculated enriched slurry on mustard crop grown in sandy soil. Plant height and grain yield also evaluated. Study showed significant enhancement in vegetative growth and yield of mustard in pot house and field conditions.

Lin *et al*. (2014) studied solid state anaerobic digestion (SSAD) of SpMS, wheat straw, yard trimmings, and their mixtures was investigated at different feedstock to effluent ratios. SpMS was found to be highly degradable, which resulted in inhibition of SS-AD due to volatile fatty acid (VFA) accumulation and a decrease in pH. This issue

was addressed by co-digestion of SpMS with either yard trimmings or wheat straw. SS-AD of SpMS/yard trimmings achieved a cumulative methane yield of 194 L/kg VS, which was 16 and 2 times higher than that from SpMS and yard trimmings, respectively. SS-AD of SpMS/wheat straw obtained a cumulative methane yield of 269 L/kg VS, which was 23 times as high as that from SpMS and comparable to that from wheat straw.

Nguyen and Klaus (2014) studied energy recovery from anaerobic co-digestion of pig manure and spent mushroom compost in the Mekong delta. The spent mushroom compost residue from the mushroom growing was chosen for co-digestion with pig manure in anaerobic batch and semi-continuous experiments. The results showed that in case of spent mushroom compost made up 75% of the mixed substrate, the gained biogas volume was not significantly different compared to the treatment fed solely with 100% pig manure. The average produced biogas was 4.1 L/day in the experimental conditions. The semi-continuous experiments remained in good operation up to the 90th day of the fermentation without any special agitating method application. The methane contents in both experiments were around 60%, which was significantly suitable for energy purposes. These results confirm that spent mushroom compost is possibly an acceptable material for energy recovery in the anaerobic fermentation process.

Shuang *et al.* (2014) used a dynamic mathematical model, based on the IWA Anaerobic Digestion Model No. 1 (ADM1), to predict the methane production and pH value during anaerobic co-digestion of dairy manure (DM) and spent mushroom substrate (SpMS) under different hydraulic retention times (HRT). In this model the degradation of DM was modeled according to classical ADM1, while SMS was divided into inert part as well as biodegradation parts of slowly hydrolysable fraction (SHF) and readily hydrolysable fraction (RHF). The data from lab-scale experiment was used to calibrate and validate this model. The results showed that the model was able to predict reasonably well the steady-state results of methane production and pH value at HRT of 12, 20 and 28 d. The results also indicated that the model suitability to assess the combined effects of HRT and substrate ratio on the methane production and pH value.

Wendi *et al*. (2014) studied biogas production potential of mushroom cultivation waste. The results showed that total biogas yield, biogas production potential and daily

average biogas production rate after 60 days of fermentation of mushroom cultivation waste were 1.38 m^3, 0, 12 m^3/kg TS and 0.15 m^3/(m^3.d), respectively. The methane content reached above 50% after 12 days from the start of experiment and was maintained at approximately 57% till the end of the experiment. These results fully indicated that mushroom cultivation waste containing biogas residues was good quality biogas fermentative material and anaerobic fermentation of mushroom cultivation waste could well solve the surficial incrustation problem of light materials.

Zhu *et al*. (2015) investigated performance of batch solid-state anaerobic co-digestion of spent mushroom substrates (SpMS) and corn stover (CS). Digestion with SpMS alone (SpMS/CS = 100:0) resulted in excessive volatile fatty acids (VFAs) accumulation and low methane yields during the start-up phase. Co-digestion of SpMS and CS significantly enhanced digesting performance. Compared to the digesters with 100% SpMS, the start-up phase of the digesters with SpMS/CS = 75:25 was shortened from 11 days to 4 days, and the methane yield increased by 40%. It was also observed that the peak of daily biogas yields showed up earlier in the co-digestion reactors than in the digesters with SMS alone. A similar phenomenon happened to the methane content curves. The VFAs and pH were shown to be important driving factors for determining the population of methanogenic communities (methanosaeta and methanobacteriaceae), which were obtained by using the Fluorescent *in situ* Hybridization method. The changes of the methanogenic communities, in return, affected the methane production in digesters. This study showed that co-digesting SpMS with CS is a feasible method to handle mushroom wastes and produce bioenergy.

Temu *et al*. (2016) utilized spent mushroom substrate and untreated portion of mixed palm oil waste. Study found particle size reduction (< 4 mm) resulted to increased methane yield by 66%. The untreated and biologically treated mixed palm oil wastes yielded 517 and 287 of CH_4 L/kg VS added which correspond to 80% and 64.5% of theoretical methane yield, respectively.

Mmanywa and Mshandete (2017) utilized spent mushroom substrates (SpMS) batch anaerobic bioreactors for biogas production. The best results 0.43 and 0.49 CH_4 m^3 /kg Volatile Solids (VS) added was obtained from pretreated (SpMS) 98% EFB+1%

S+1% and 39% MF (Mesocarp Fibers)+39% EFB+ (20% PK (Palm Kernel)+ 1% P+1% S palm wastes substrates formulation, respectively. The highest methane yield were 1.3-1.4 fold higher compared to methane yields 0.33- 0.34 CH_4 m^3 /kg VS registered from corresponding non-pre-treated palm oil wastes substrates formulations, mean methane content of the biogas obtained from treated SpMS was 82%, which was slightly higher than 79% recorded from untreated palm oil wastes substrates formulations.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the material and methodology adopted for designing and development of solar-biogas integrated hybrid dryer for button and oyster mushroom drying and biomethanation study of spent mushroom substrate. The complete hybrid system was fabricated in the workshop of Department of Renewable Energy Engineering, CTAE Udaipur. The experimental investigation was carried out to assess drying performance of button and oyster mushroom in the developed hybrid dryer and its economic evaluation at Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur. The study area lies at 24° 38' N – latitude, 73° 43'E – longitude and at an altitude of 582.5 m above mean sea level. The stepwise methodology adopted for the proposed research work is presented under following sub heads.

The stepwise methodology adopted for the proposed research work is presented under following sub heads

3.1 Design and development of solar-biogas integrated hybrid drying system.
3.2 Biomethanation study of spent mushroom substrate.
3.3 Development of biogas plant and field study of biogas production from selected combination of substrates.
3.4 Analysis of fresh and digested slurry sample.
3.5 Economic evaluation of solar-biogas integrated hybrid drying system.
3.6 Instrumentation and measurement

3.1 Design and Development of Solar-Biogas Integrated Hybrid Drying System:

The solar and biogas integrated hybrid dryer was designed on the basis of energy requirement to dry button and oyster mushroom, which is suitable for small farmers or rural entrepreneurs. The assumptions made to design the system are presented in Table 3.1

Table 3.1 Assumptions made for design of solar-biogas integrated hybrid dryer

Sr. No	Particulars	Specifications
1	Product	Button Mushroom & Oyster Mushroom
2	Capacity	4 kg
3	Initial moisture content (M_i)	91 %
4	Final moisture content (M_f)	8 %
5	Specific heat of product	3.99 kJ/kg °C
6	Ambient Temperature	26 °C
7	Drying efficiency	25 %
8	Drying Temperature	50°C
9	Drying Time	11 h

3.1.1 Design of Solar-Biogas Integrated Hybrid Drying System:

I. Total quantity of water in the product, M_w

It has been calculated by using following euation 3.1;

$$M_w = \left[M \times \frac{M_i}{100} \right] \qquad \text{....3.1}$$

Where, M_w = Mass of water in the product, kg

M = Mass of the wet product, kg

M_i = Initial moisture content of the product, kg

II. Bone dry mass of the product, M_d

It is the dry mass remained after complete removal of moisture from the product, it was calculated by using following equation 3.2;

$$M_d = M - M_w \qquad \text{.....3.2}$$

Where, M_d=Bone dry weight of product, kg

M= Mass of the wet product, kg

M_w= mass of the water in the product, kg

III. Mass of the water to be removed during drying , M_w

Mass of the water to be removed to bring down the moisture content of product up to the safe limit was calculated with the help of following equation 3.3.

$$M_w = \frac{M_i - M_f}{100 - M_f} \times M \qquad \ldots.3.3$$

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

M_i = Initial moisture content of product (wb %)

M_f = Final moisture content of product (wb %)

M = Mass of the wet product, kg

IV. Total energy required for drying , Q_E

Total energy required for drying of the product is the function of amount of moisture present in the product and level up to which moisture of the product is to be bringing down, it was estimated by using following equation 3.4.

$$Q_E = M \times C \times (T_d - T_a) + M_w \times \lambda \qquad \ldots.3.4$$

Where,

Q_E = Total quantity of energy required for drying, kJ

M= Mass of the wet product, kg

C= Specific heat of wet product, kJ/kg °C.

T_d = Drying air temperature, °C

T_a= Ambient air temperature, °C

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

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

V. Drying air requirement

After attaining desirable temperature, moisture from product starts evaporating; to remove the moisture from drying cabinet air passage is required. The fresh air replaced moisture content. The following methodology was adopted to estimate the required air

a) Mass of the air required for drying, M_a

$$M_a = \frac{M_w}{(H_e - H_d) \times t} \quad \text{....3.5}$$

Where, M_a = Mass of air required for drying, kg/h

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

H_e = Humidity ratio of exit air, kg of water/ kg of dry air

H_d = Humidity ratio of drying air, kg of water/kg of dry air

t = Drying time, h

b) Volumetric air flow rate required for drying, V_{ad}

$$V_a = M_a \times V_h \quad \text{....3.6}$$

Where, V_a= Volumetric air flow rate required for drying, m^3/h

M_a=Mass flow rate of drying air, kg/h

V_h = Humid volume, m^3/kg

VI. Total volume of product to be dried, V_t

$$V = \frac{M}{\rho} \quad \text{....3.7}$$

Where, V=Volume of the product to be dried, m^3

M=Mass of the wet product, kg

ρ = Density of the product to be dried, kg/m^3

VII. Dimensions of tray,

$$A_d = \frac{V_t}{T_{dl}} \quad \text{....3.8}$$

Where,

A_d= Drying area, m^2

T_{dl} = Thickness of drying layer, m

No. of trays,

$$\text{No. of trays} = \frac{Total\ drying\ area(A_d)}{Tray\ area} \quad \text{....3.9}$$

VIII. Design of Chimney,

Quantity of air needed to absorb m_w kg of water

$$Q_a = \left[\frac{M_w \times \lambda}{C_a \times \rho_a (T_e - T_a)}\right] \quad \text{....3.10}$$

Where, m_w= mass of water to be removed , kg; λ = Latent heat of vaporization, kJ/kg; C_a= Specific heat of air, kJ/kg°C; ρ_a = density of air at ambient temperature, kg/m^3; T_e= Temperature of moist air at chimney outlet, °C; T_a= ambient temperature, °C, D_a= actual draft in kg/m s^2, D_i= draft produced in kg/m s^2.

Now, Q_a amount of moist air needed to be removed in 11 h

= Q_a/ (11×60×60) m^3/s

Draft produced,

$$D_i = H \times g \times (\rho_a - \rho_e) \quad \text{....3.11}$$

Where, ρ_e = density of exit air kg/m^3; g= acceleration due to gravity 9.81 m/s^2,

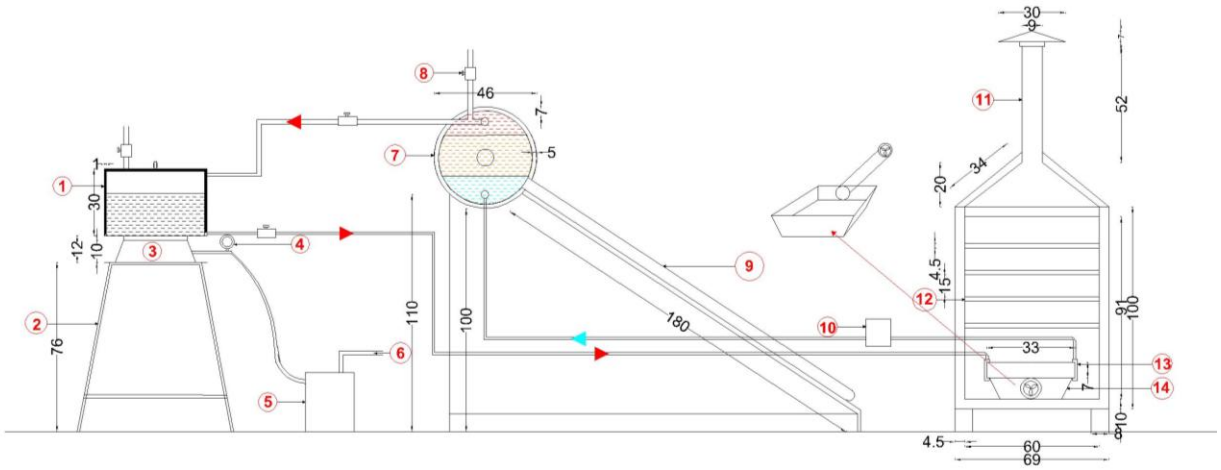
H= Height of chimney, m. But actual draft D_a= 0.80 ×D_i

$$\text{Velocity of exit air, } V = \sqrt{\frac{2D_a}{\rho_e}} \quad \text{....3.12}$$

$$Area\ of\ Chimney = \frac{Q_a}{V} \quad \text{....3.13}$$

3.1.2 Development of Solar-Biogas Integrated Hybrid Drying System:

Solar and biogas integrated hybrid dryer was developed in Department of Renewable Energy Engineering as shown in Fig 3.1. Solar energy and biogas produced from codigestion of spent button mushroom substrate and cowdung substrate were used for water heating. This hot water was circulated through radiator kept inside dryer. Ambient air was circulated at constant flow rate using 12 volt air fan over radiator to absorb heat of the hot water flowing through radiator and to dissipate absorbed heat inside dryer for drying of mushroom at constant temperature. This complete process was optimized in such a way that constant temperature of 50 °C was maintained throughout drying of mushroom.



1. Water heating chamber using biogas, 2. Stand, 3. Biogas burner, 4. Pressure gauge, 5. Biogas flow meter, 6. Biogas fuel, 7. Solar water tank, 8. Overflow pipe, 9. Evacuated tubes, 10. Water pump, 11. Dryer Chimney , 12. Tray, 13. Radiator, 14. Air duct

Fig. 3.1 Solar-Biogas Integrated Hybrid Dryer for Mushroom Drying

3.1.3 Drying of Button and Oyster Mushroom:

3.1.3.1 Selection of Raw Materials:

Mushroom of *Agaricus bisporus*(button mushroom) and *Pleurotus ostreautus* (oyster mushroom) variety, having about 87-91% moisture content (wb), were procured

on daily basis from All India Co-ordinated Research Project (AICRP) on Mushroom, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. Freshly harvested, firm, dazzling white, mature mushrooms of uniform size were manually sorted and selected as the raw material for experiment.

3.1.3.2 Sample and Solution Preparation:

The white button mushroom (*Agaricus bisporus)* and Oyster mushrooms (*Pleurotus ostreautus)* of uniform size were thoroughly washed under tap water to remove adhering impurities. They were then dried on a blotting paper, and then samples of button mushroom were cut into 5±0.5 mm thick slices with the help of sharp stainless steel knife. Oyster mushroom samples were utilized directly after washing with water and pretreatment with mixture of 0.5% citric acid and 0.5% ascorbic acid for drying. Button mushroom samples were also pretreated with mixture of 0.5% citric acid and 0.5% ascorbic acid before drying (Nour *et al.,* 2011).

3.1.3.3 Determination of Moisture Content:

Moisture content of fresh as well as dried mushroom slices were determined by method suggested by Ranganna (2000). A brief description of the method is as follows:

1. A thin layer of finely divided asbestos (Gooch grade) powder was spread into a flat bottom moisture box and dried at 110^{o}C for 1 h, cooled and weighed.
2. About 5-8 gram sample of mushroom was kept in a pre-dried and weighed moisture box. The mass of the sample was recorded as M.
3. The box was placed in oven and temperature was maintained at 100^{o}C for 18 h.
4. After drying the sample was cooled in a desiccator to room temperature and then weighed. The mass of the dried sample was recorded as $M_{d.}$
5. A single pan analytical balance of 0.001g sensitivity was used.

The moisture content of the sample was calculated by using following equation 3.14;

$$MC\,(\%db) = \frac{M - M_d}{M_d} \times 100 \qquad \ldots 3.14$$

Where, M = mass of original sample, g, M_d = mass of sample after drying, g

Fig. 3.2 Button mushroom used in investigation *(Agaricus bisporus)*

Fig. 3.3 Oyster mushroom used in investigation (*Pleurotus ostreautus)*

3.1.3.4 Availability of Solar radiations (W/m^2) and Biogas consumption (L) measurement:

Availability of solar radiations (W/m^2) were measured continuously during the process of drying of button and oyster mushroom. Biogas consumption in L was also measured using analog type of biogas flowmeter (Make:Siya Instrument).

3.1.4 Drying Characteristics:

3.1.4.1 Moisture Content During Drying:

Moisture content of mushroom slices (db) during drying experiment was determined by the following equation 3.15;

$$\text{Percent moisture content (db)} = \frac{M\theta - M_d}{M_d} \times 100 \qquad \ldots 3.15$$

Where,

M_θ = Mass of the sample at time θ, g

M_d = Mass of the dry sample, g

3.1.4.2 Drying Rate:

The moisture content data recorded during experiments were analyzed to determine the moisture lost by sample of mushroom slices in particular time interval. The drying rate of sample was calculated by following mass balance equation 3.16.

$$R = \frac{\text{Initial mass of sample - Mass of sample after time (kg)}}{\text{Time interval (min) x dm (kg)}} \qquad \ldots 3.16$$

Where,

R=Drying rate at time θ

3.1.4.3 Dry Matter:

It is the matter left after complete removal of moisture from the product. The initial moisture content of untreated and various pre-treated samples were determined by oven drying method, as described earlier. The dry matter (per cent) and mass of dry matter in sample were calculated using following equation 3.17 & 3.18:

Dry matter (dm) (%) = 100.0 – Intial Moisture Content (wb) …3.17

$$\text{Weight of dm} = \text{Initial mass of sample} \times \frac{dm\,(\%)}{100} \quad \ldots 3.18$$

3.1.5 Quality Evaluation of Dried Mushroom Product:

Quality analysis is important in food processing; control should be exercised at every stage from pre-processing to packaging, storing etc. Quality dried button mushroom and oyster mushroom samples were evaluated on the basis of its rehydration characteristics, ascorbic acid content, colour test, water activity, sensory evaluation, and its nutritional analysis (carbohydrates, proteins, fats, crude fibres, & ash content). All measurements were replicated thrice and the average readings were reported.

3.1.5.1 Rehydration Characteristics:

According to Ranganna (1986), there is no standard time for rehydration of fruits and vegetables. It varies from product to product. Rehydration time was therefore standardized through trial runs conducted for the purpose. A value of 1 hour was observed to be adequate as there was no weight gain beyond this point. The rehydration characteristics viz. rehydration ratio and coefficient of rehydration of the dried mushroom product were then determined by the method as explained by (Pokharkar and Prasad, 2002 and Jain *et al.,* 2011).

Eight 250 ml glass beakers were used for rehydration of dried mushroom samples in distilled water. The 5g dried sample was taken in each beaker, mixed with 50 ml of distilled water solution and kept in a hot water bath to maintain a temperature of 30^{o}C (Fig.3.4). Samples were withdrawn after 10 min interval up to 1 h and then sample surface was dried with filter paper and weighed to determine the moisture content.

Various rehydration characteristics were evaluated using following relations (Pokharkar, 1994);

(a) Rehydration ratio $(RR) = \frac{C}{D}$ …3.19

(b) Coefficient of rehydration $(CR) = \frac{C \times (100 - A)}{\left(D - \frac{BD}{100}\right) \times 100}$ …3.20

Where,

A = moisture content of samples before drying, IMC, (% wb)

B = moisture content of drying sample, (% wb)

C = drained weight of rehydrated sample, g

D = test weight of dehydrated samples, g

Fig. 3.4 Rehydration of button and oyster mushroom sample

3.1.5.2 Ascorbic Acid Content Estimation:

Ascorbic acid was determined by the 2, 6 dichlorophenol–indophenols tritimetric method according to AOAC method No. 967.21 (AOAC, 2000). The vitamin C content in fresh, dried and rehydrated mushroom samples was evaluated. A total of 10 ± 0.1 g of triturated sample was weighed, filtered, and diluted to a volume of 50 mL. All measures

were done in triplicate; the vitamin C content is expressed as mg AA/ 100 g dm (Miranda *et al*., 2009).

Procedure: Ascorbic acid reduces 2, 6-dichlorophenol indophenol dye to a colourless dye and itself gets oxidised to dehydro-ascorbic acid. The blue coloured compound dye changes to pink colour, in acid medium, at the end point. Oxalic acid is used as the medium for titration. 5 ml of working standard solution was pipetted into a 100 ml conical flask. 10 ml of 4% oxalic acid was added to it and the resultant solution was titrated against the dye till persistent pink colour appeared. The amount of dye consumed (V_1ml) during titration was equivalent to the amount of ascorbic acid. One g (w) of sample extracted in 100 ml (V_3) of 4 % oxalic acid was kept for an hour and centrifuged. Discarding the residue, 5 ml of supernatant was pipetted into a conical flask and 10 ml (V_4) of 4 % oxalic acid was added to it. The resultant solution was titrated against the dye till persistent pink colour appeared. Again, the volume of dye (V_2 ml) consumed in titration was recorded. Three replications were conducted to determine the exact end point.

$$\text{Ascorbic acid mg/100g dm} = \text{E}\, V_2 \frac{V_3}{V_4} \times \frac{100 \times 100}{W \times dm} \qquad \ldots.3.21$$

Where,

$$\text{E} = \frac{1}{\text{Titre}} = \frac{1}{v_1} = \text{Ascorbic acid equivalent of the dye in mg/ml},$$

dm = dry matter

3.1.5.3 Colour Analysis:

Colour is one of the most important qualities of acceptance for products, reflects sensation to the human eye. Colour is important to consumer as a mean of identification, as a method of judging quality and for its basic aesthetic value. Dried products are usually darker in colour, but darker colour does not mean better quality. Too dark may imply that the product is over dried. The advantage is that this parameter can be visually determined for assessing dryness quality. The colorimeter used in the present

investigation Hunter Lab Colorimeter (Model CFLX/DIFF, CFLX-45) is shown in Fig 3.5.

The technical specifications are presented in Appendix E. A cylindrical glass sample cup (63.5 mm in diameter x 40 mm height) was placed at the light port (31.75 mm diameter). The instrument was initially calibrated with a black as well as with standard white plate supplied with the equipment. The 3-dimensional scale L*, a* and b* were used in a Hunter Lab Colorimeter. The L* is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The a* is redness (positive a* value) and greenness (negative a* value) on a horizontal axis. A second horizontal axis is b*, that represent yellow (positive b* value) or blue (negative b* value) colour (Fig 3.6). Hunter L-value, which denotes the degree of whiteness, was chosen to represent the colour value of sample as suggested by Anantheswaran *et al*., 1986; Murumkar *et al*., 2006 and Pisalkar *et al*., 2011).

Fig. 3.5 Hunter lab colorimeter

Fig. 3.6 Colour scale representing relationship of colour index (L*, a*, b*)

3.1.5.4 Water Activity (A_w):

Water plays an important role in the stability of fresh, frozen and dried foods. It acts as a solvent for chemical, microbiological and enzymatic reactions. The water activity, a_w, is a measure of the availability of water to participate in such reactions. The water in a food exerts a vapour pressure. The extent of this pressure will depend on the amount of water present, the temperature and the composition of the food. Different food components will lower the water vapour pressure to different extents, with salts and sugars being more effective than starches or proteins. Thus two different foods with similar moisture contents may not necessarily have the same a_w. Water activity can be defined as the ratio of the vapour pressure exerted by the food to the saturated vapour pressure of water at the same temperature.

$$a_w = \frac{\text{Vapour pressure of water exerted by food}}{\text{Saturated vapour pressure of water at the same temperature}} \qquad ...3.22$$

Water activity is a function of moisture content in the food and the temperature (Ratti and Mujumdar, 1996). Bound molecule of water in food can be defined by water activity:

- Tightly bound water $a_w < 0.3$
- Moderately bound water $0.3 < a_w < 0.7$
- Loosely bound water $a_w > 0.7$
- Free water $a_w \sim 1.0$.

Most bacteria do not grow at water activities below 0.91, and most moulds cease to grow at water activities below 0.80 (Leung, 1986). By measuring water activity, it is possible to predict which micro-organisms will or will not be potential sources of spoilage. Lower water activity of a dried product implies better potential for storage.

Water activity was determined as a measure of storage stability using a Hygrolab-3 water activity meter. Two gram sample was used to cover the filling indicator of the sample cup. The filled sample cup was kept in contact with sensor probe of water activity meter and values of water activity were recorded. A digital water activity analyzer used in measuring water activity of the dried mushroom samples is shown in Fig. 3.7.

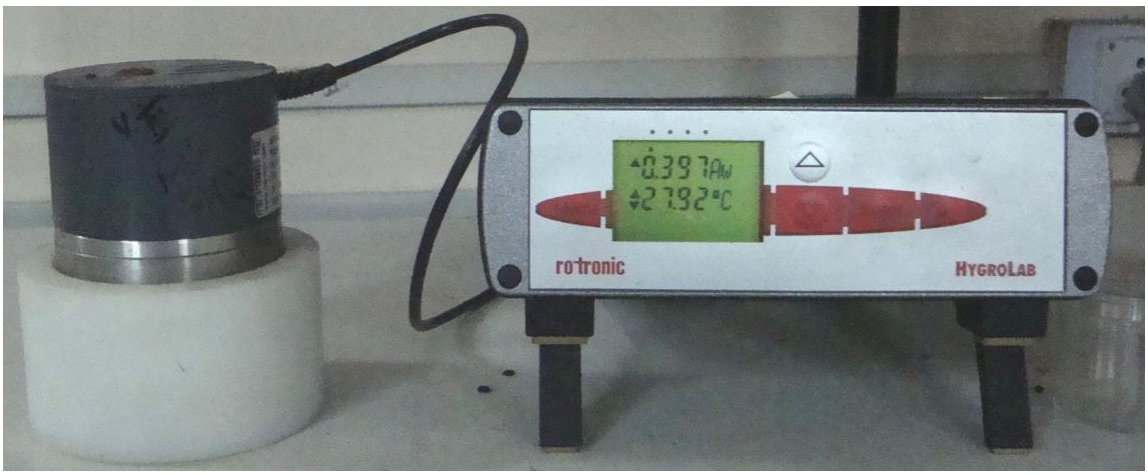


Fig 3.7 Water activity meter

3.1.5.5 Sensory Evaluation:

Sensory evaluation is important to assess the consumer's requirements. It is difficult to quantify the sensory characteristics of product 100 per cent by machine

because it is a subjective factor. To test the organoleptic characteristics, sensory evaluation was done based on numerical sensory card (Indian standard, 1971) as given in Appendix D.

The samples were evaluated for its sensory characteristics such as colour, taste, appearance and over all acceptability. The samples were served for the evaluation to ten panelists at a time. The score sheet was provided with product and panelists were requested to mark the product according to their liking. The average scores of all the panelists were computed. The independent sample t test was applied to compare between fresh button and oyster mushroom and dried product.

3.1.5.6 Crude Protein Determination:

Micro kjeldhal nitrogen distillation method is used to determine the protein content of food stuffs by estimating the nitrogen content of material and multiplying nitrogen value by 6.25 (general factor). The nitrogen present in protein or any other organic material is converted to ammonium sulphate by sulphuric acid during digestion. This salt, on steam distillation librates ammonia which is converted in boric acid solution. Ammonia forms a loose compound, ammonium borate with boric acid and titrated against standard acid.

Procedure: The 100mg of bone dried sample was weighed and transferred to micro kjeldhal flask (Fig.3.8) to which 0.5g of digested mixture (98 part K_2SO_4 +2 part $CUSO_4$) and 2ml concentrated H_2SO_4 was added and digested till it become colorless. Digested material was cooled and transferred to a distillation flask and diluted with distilled water. One sample was kept blank without test material. Ammonia was distilled by adding 10ml of 40% NAOH and ammonia librated was received in a 4% boric acid containing methyl red and methyl blue indicator. Amount of ammonia librated was determined by titrated with 0.1 N HCL. The per cent nitrogen was calculated by using following equation 3.23;

$$\% \text{ Nitrogen} = \frac{(\text{Amount of HCL} - \text{reading of blank}) \times \text{Normality of HCL} \times 14}{\text{Weighed of sample (mg)}} \times 100 \qquad \ldots.3.23$$

The protein content in sample based on nitrogen was computed using a factor of 6.25. The result is in term of crude protein as it includes non protein nitrogen also.

Fig 3.8 Kjeldahl plus digestion apparatus for protein analysis

3.1.5.7 Fat Estimation:

Fat was estimated as crude ether extract to moisture free sample by the method given by NIN (2003). Fat content of the sample was estimated on SOSC PLUS system (Fig 3.9), which works on the principle of improved Soxhlet method.

Procedure: Weighed amount of bone dried sample (5g) was placed in thimble. The thimble was inserted in the holder to be kept in an already weighed beaker and poured 80ml petroleum ether (60:80) in the beaker. The beakers were loaded in the system and the temperature was set at 100°C. The process was left to operate for 2h. The temperature was raised to the recovery temperature, which was twice the initial boiling temperature, rinsing was thus done 2-3 times in order to collect the remaining fat in the sample. Beakers were taken out and put in the hot air oven. The thimble holders were

removed from the beaker and beakers were weighed. The amount of fat present in the sample was calculated using the following equation 3.24;

$$Fat\ (g/100g) = \frac{M_2 - M_1}{M} \times 100 \qquad \ldots.3.24$$

Where, M= Mass of sample (g)

M_1= Mass of empty flask, (g)

M_2= Mass of flask with extracted fat, (g)

Fig 3.9 SOCS PLUS system for fat estimation

3.1.5.8 Ash Content Determination:

Ash of food stuff is inorganic residue that remains after burning of organic matter. Ash of button and oyster mushroom is in alkaline in nature. Alkaline ash is due to the presence of salts or organic acids that are converted to carbonates during ashing.

Estimation of total ash is an index of refinement of food and useful parameter of nutritional value of foods (NIN, 2003).

Procedure: 5g of moisture free sample was weighed in previously heated, cooled and weighed crucibles. Sample was then completely charred on the hot plate, following by heating in muffle furnace at 600°C for 5h (Fig.3.15). The crucible was cooled in desiccator and weighed. The process was repeated till constant weights were obtained and ash was almost grayish or white in color. Ash content of samples was calculated using following equation 3.25;

$$Ash\ (g/100g) = \frac{Mass\ of\ \ Ash\ (g)}{Mass\ of\ \ Sample\ Taken\ (g)} \times 100 \qquad \ldots.3.25$$

3.1.5.9 Crude Fiber Content Analysis:

Crude fibre is a loss on ignition of dried residue remaining after digestion of sample with 1.25% sulphuric acid and 1.25% sodium hydroxide solutions under the specific conditions. During the acid and subsequent alkali treatment, oxidative hydrolytic degradation of native cellulose and considerable degradation of lignin occur. The residues obtained after final filtration is weighed, incinerated, cooled and weighed again. The loss in weight gives the crude fibre content (NIN, 2003).

Procedure: 5g moisture and fat free sample was placed in 500ml beaker and boiled with 200ml of 1.25% sulphuric acid for thirty minutes. The volume was kept constant during boiling by adding hot distilled water. This was filtered through muslin cloth and residue was washed with hot distilled water till free from acid. The residue was then transferred to same beaker and boiled for thirty minute with 200ml of 1.25% sodium hydroxide solution. After boiling, mixture was filtered through muslin cloth and the residue was washed again with hot distilled water till free from alkali followed by washing with 50ml alcohol or ether. Then it was taken into a crucible and dried overnight in an oven at 80-100°C, cooled and weighed. Crucible was ignited in a muffle furnace at 600°C for 2 to 3h till it was converted into ash, and weighed to a constant weight. Crude fibre was determined by using following equation 3.26;

$$Crude\ Fibre\ \% = \frac{(M_2 - M_1) - (M_3 - M_1)}{Mass\ of\ \ Sample} \times 100 \qquad \ldots 3.26$$

Where, M_1= Mass of empty crucible, g

M_2= Mass of crucible with dry residue, g

M_3= Mass of crucible with heated residue, g

3.1.5.10 Carbohydrate Content:

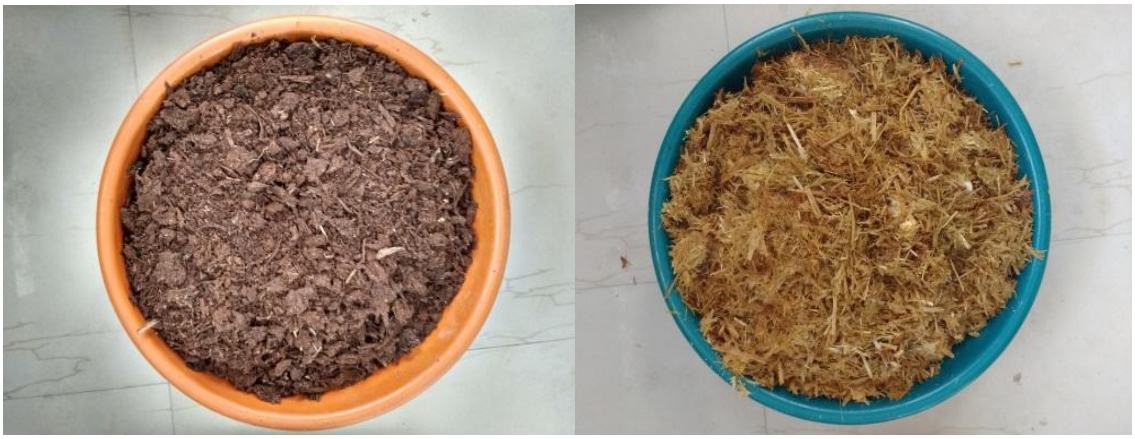
The carbohydrate content of sample on dry weight basis was calculated by difference method as given below in equation 3.27 (Jain and Mogra, 2006);

$$\text{carbohydrate(g/100g)} = 100 - (\text{crude fibre} + \text{ash} + \text{protein} + \text{fat content}) \quad \ldots 3.27$$

3.2 Biomethanation Study of Spent Mushroom Substrate:

3.2.1 Lab Study of Anaerobic Digestion of Spent Mushroom Substrate:

The anaerobic digestion of spent button mushroom waste and spent oyster mushroom waste were carried out in laboratory for a retention period of 40 days. The pictorial view of the spent mushroom substrate and laboratory setup for biomethanation study is shown in Fig. 3.10 and Fig. 3.11 respectively. The composition of spent button mushrrom substrate and spent oyster mushroom substrate is shown in Table 3.2. Physiochemical characteristics of cowdung, spent button mushroom substrate and spent oyster mushroom substrate are tabulated in Table 3.3.



a) Spent button mushroom substrate b) Spent oyster mushroom substrate

Fig 3.10 Pictorial view of spent mushroom substrate

Table 3.2. Composition of Spent Mushroom Substrate

Feed Material	Composition
Spent oyster mushroom substrate	Wheat straw+ fertilizers
Spent button mushroom substrate	Wheat straw+20% cow dung+ fertilizer

The study was performed in laboratory and the gas was collected using water displacement method. In this method airtight water filled aspirator bottle having outlet at the bottom was connected at the top to another glass reagent bottle containing organic waste material. The generated biogasfrom the organic waste material creates the pressure on water surface of the another marked glass reagent bottle. Water get displaced through outlet tube due to pressure from the generated biogas till the equilibrium of pressure balance. The water bottle was marked or graduated in milliliters. Amount of water displaced in the bottle is equal to the amount of gas formed. Total 9 treatments with 2 replications each having different ratio of spent mushroom substrate and cow dung were prepared as shown in Table 3.4 and shown in Fig.3.11a & Fig.3.11b.

Table 3.3 Physiochemical characteristics of feed material

Feed Material	MC %	TS %	VS (% of TS)	Ash (% of TS)	C %	N, %	P, %	K, %	C/N Ratio
Cow dung	81.6	18.4	78.8	22.2	28	1.1	0.7	0.75	25.45
Spent oyster mushroom waste	29	71	92.4	7.6	45.6	1.6	0.5	1.0	28.5
Spent button mushroom waste	32	68	91.2	8.8	48.8	1.96	0.6	1.2	24.89

*Note: MC= Moisture content, TS= total solids, VS= volatile solids, C= Carbon, N= total kjeldahl nitrogen, P= phosphate, K= potash, C/N= Carbon to nitrogen ratio.

Table 3.4 Different Treatments of spent mushroom substrate and cowdung combination

Waste Material	Treatments	Replication	Quantity , g			Water, ml
			SpMS	Cowdung	Slurry 9% TS	
Spent Oyster Mushroom Substrate (SpOMS)	**(T1)**25% SpOMS +75% Cow dung	O1R1	50	150	30	428
		O1R2	50	150	30	428
	(T2)50% SpOMS +50% Cow dung	O2R1	100	100	30	691
		O2R2	100	100	30	691
	(T3)75% SpOMS +25% Cow dung	O3R1	150	50	30	954
		O3R2	150	50	30	954
	(T4)100% SpOMS	O4R1	200	0	30	1217
		O4R2	200	0	30	1217
	(T5)100% Cow dung	C1R1	0	200	30	165
Spent Button Mushroom Substrate (SpBMS)	**(T6)**25% SpBMS +75% Cow dung	B1R1	50	150	30	413
		B1R2	50	150	30	413
	(T7)50% SpBMS +50% Cow dung	B2R1	100	100	30	661
		B2R2	100	100	30	661
	(T8)75% SpBMS +25% Cow dung	B3R1	150	50	30	909
		B3R2	150	50	30	909
	(T9)100% SpBMS	B4R1	200	0	30	1157
		B4R2	200	0	30	1157

Fig. 3.11a Laboratory set up for biomethanation study of spent mushroom substrate

Fig. 3.11b Laboratory set up for biomethanation study of spent mushroom substrate

The ambient temperature and biogas production was measured for the entire duration of the study on a daily basis. The ambient temperature was measured by laboratory thermometer with a least count of 0.1°C whereas the biogas production was measured by water displacement method. The displacement of water due to biogas production in each aspirator bottles was measured and used to calculate the daily biogas production at standard temperature and pressure (STP). Biogas analyzer was used as shown in Fig.3.12 for compositional analysis of the generated biogas. The generated biogas was also tested manually by simple flame test as shown in Fig.3.13. The cumulative biogas, methane and carbon dioxide production over the study period of 40 days were estimated by summation of daily biogas, methane and carbon dioxide production, respectively. Specific biogas production in terms of L/kg dm and L/kg VS were determined by using standard formulae.

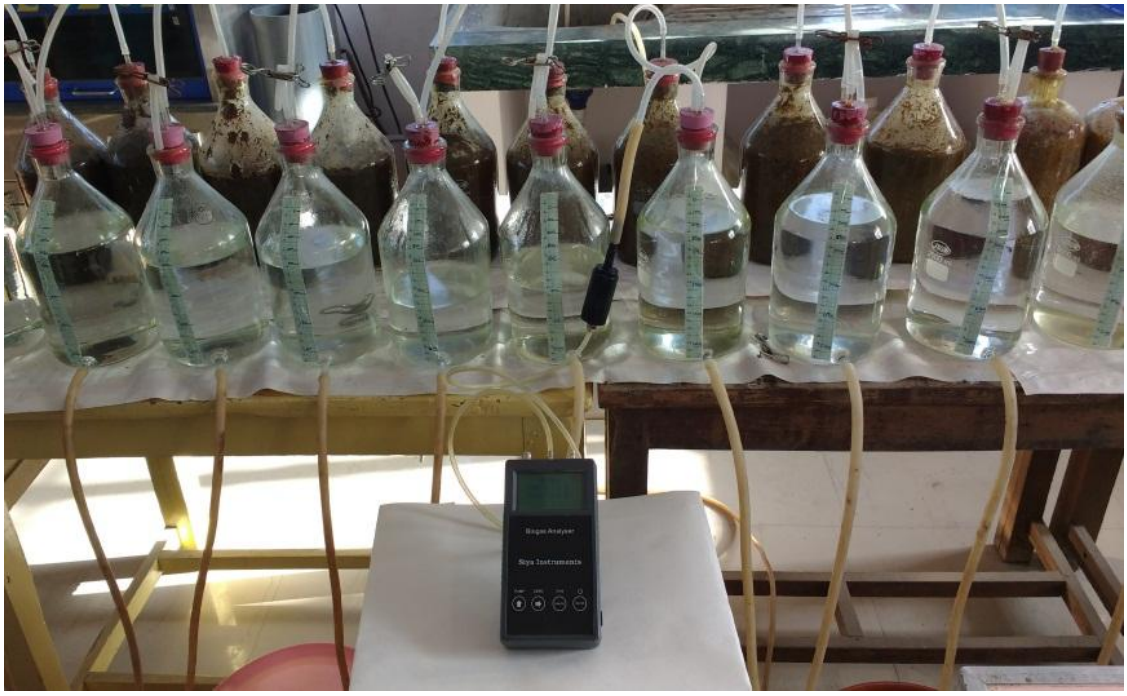


Fig 3.12 Compositional analysis of biogas

Fig 3.13 Flame test of biogas

3.2.2 Theoretical Calculations Of Biogas Production:

3.2.2.1 Biogas Production:

Observed biogas production was converted into biogas production at Standard Temperature and Pressure (STP) using Eq. (3.28). {At STP, P=1 Bar, T= 273K}

$$BV_0 = \left[\frac{273 \times BV}{273 + T} \right] \quad \text{....3.28}$$

Where,BV_0= Daily biogas production at STP (m^3 or L); BV= Daily biogas production at temperature T (m^3 or L); T=Observed biogas temperature (substrate temperature).

3.2.2.2 Specific Biogas Production:

The specific biogas production (per unit dm and VS) were calculated using Eq. (3.29) and Eq. (3.30).

$$BV_0 specific\ dm = \left[\frac{BV_0}{DMF \times TS} \right] \quad \text{....3.29}$$

$$BV_0 specificVS = \left[\frac{BV_0}{DMF \times VS} \right] \quad \text{....3.30}$$

Where,$BVo_{Specificdm}$ is the specific biogas production, L/kg dm; $BVo_{SpecificVS}$ is specific biogas production, L/kg VS; DMF is the daily mass of feed, kg; TS is the total solids content, decimal; VS is the volatile solids content, decimal.

3.2.2.3 Methane and Carbon Dioxide Production:

The daily production of methane and carbon dioxide in produced biogas were determined by using eq. 3.31 & 3.32

$$CH_4\ Yield = \left[\frac{CH_4\ Conc}{100} \right] \times BV_0 \quad \text{....3.31}$$

Where CH_4 Yield is the daily methane yield at STP, L or m^3, CH_4Conc is the methane concentration in biogas, %.

$$CO_2\ Yield = \left[\frac{CO_2\ Conc}{100} \right] \times BV_0 \quad \text{....3.32}$$

Where CO_2 Yield is the daily carbon dioxide yield at STP, L or m^3, CO_2 Conc is the carbon dioxide concentration in biogas, %.

3.2.2.4 Total Volatile Solids Mass Removal Efficiency (TVSMRE):

The total volatile solids mass removal efficiency (TVSMRE) was calculated equation 3.33 & 3.35,

$$TVSMRE = \left[\frac{TVSMR}{TVSM} \right] \times 100 \quad \text{....3.33}$$

The following relationship was used to calculate the total volatile solids mass removed (TVSMR) in the anaerobic digestion process,

Where,

$$TVSMR = \left[\frac{\left(\frac{16 \times CH_4\ Conc}{100} \right) + \left(\frac{44 \times CO_2\ Conc}{100} \right)}{22.413} \right] \times BV_0 \times DBF \quad \ldots.3.34$$

Where, TVSMR is the total volatile solids mass removed in the anaerobic digestion process, kg; TVSM is the total volatile solids input mass, kg. DBF is dry biogas factor in decimal.

The constant 16 and 44 represent the molecular weight of methane and carbon dioxide respectively. The volume of one mole of ideal gas at STP was taken as 22.413 in the above equation.

Thus for estimation of total volatile solids mass removal efficiency (TVSMRE) the equation becomes;

$$TVSMRE = \left[\frac{\left(\frac{16 \times CH_4\ Conc}{100} \right) + \left(\frac{44 \times CO_2\ Conc}{100} \right)}{22.413 \times TVSM} \right] \times BV_0 \times DBF \times 100 \quad \ldots.3.35$$

3.3 Development of Biogas Plant and Study of Biogas Production from Selected Combination of Substrates in developed Biogas Plant:

Biogas plant was developed for codigestion of selected combnation of spent mushroom substrate and cowdung combination. Biogas produced from the modified plant was measured continuously for 80 days. Daily observations of biogas production, its compositional analysis were recorded continuously for 80 days along with temperature of digester slurry. Temperature of digester slurry was measured continously using J type of thermocouple and data taker instrument. The thereotical analysis of produced biogas were made using the equations mention in section 3.2.2.

3.4 Analysis of Fresh and Digested Slurry Sample:

3.4.1 Proximate and Ultimate Analysis:

The fresh and digested slurry sample biogas plant were analyzed for total solids (TS) and volatile solids (VS) contents according to the standard methods of American

Public Health Association (APHA-AWWA-WEF, 1998).The proximate and ultimate analysis of digested slurry was carried out as per standard procedure.

3.4.1.1 Total Solid Content:

The total solid content of the feed material will be determined using standard method (APHA-AWWA-WEF, 1998). About 20-25g sample was taken in the aluminium box and placed in the oven for 24 hours at 105°C as shown in Fig.3.14. The weights of the empty box and after filling the substrate sample and before placing it on the oven were recorded. The box and the lid were placed separately in the oven. After 24 hours, the box was taken out with covered lid and placed in desiccators to cool down to ambient temperature. After some period weight of the box was measured. All the measurements of weight were made by the electronic balance. The percentage total solid content of the sample to be calculated using the following empirical equation 3.36.

$$TS = \frac{M_d}{M} \times 100 \qquad \text{…. 3.36}$$

Where, M =the initial weight of the sample, (g), and

M_d = the weight of the oven dried sample, (g).

3.4.1.2 Volatile Solids Content (VS), Non Volatile Solids Content (NVS) and Carbon(%):

The volatile solids content (VS) and non volatile solids content of the substrate material will be determined as per the standard method (APHA-AWWA-WEF, 1998). Volatile solid percentage was determined by igniting a known weight of dried samples at 580°C ± 5ºC in a muffle furnace for 6 hours (Fig.3.15) and allowed the crucible to cool partially in air and then transferred to a desiccators for final cooling. The loss in weight was taken as volatile solid fraction. The volatile solids content and non-volatile solids content of the sample to be calculated using following equations 3.37 & 3.38.

$$VS = \frac{M_d - M_{ash}}{M_d} \times 100 \qquad \text{….3.37}$$

$$NVS = \frac{M_{ash}}{M_d} \times 100 \qquad \text{….3.38}$$

Where, M_{ash} = Mass of dry ash, g

3.4.1.3 Fixed Carbon:

The fixed carbon content was the value obtained after subtracting the value of moisture content, volatile solid and ash content from the hundred per cent for balancing the value (ASTM D 3172-13).

% Fixed Carbon= 100- % of (MC+Volatile Solid+Ash) ….3.39

Fig 3.14 Oven for moisture analysis

Fig 3.15 Muffle Furnace for volatile solid and ash estimation

3.4.2 Nutritional Analysis:

3.4.2.1 Digesdahl Digestion Process:

Standard digestion process was followed for digestion of sample. The standard digestion procedure is given as follows,

Fig 3.16 Digesdahl digestion apparatus

1) Digesdahl apparatus was arranged as shown in Fig.3.16; first water circulation was started along the instrument.
2) Around 0.25 – 0.30 g sample was weighed from the digital weighing balance and then it was added in digestion flask.
3) Around 4 ml of concentrated Sulfuric acid was added to the sample, and then digestion flask was placed on boiling chip of Digesdahl apparatus.
4) Then apparatus arranged as shown in Fig.3.16 and digestion process was started.
5) During digestion continuously hydrogen peroxide (H_2O_2) was added to the flask till sample becomes colorless.
6) Around 70 ml of distilled water was added in the sample and it is allowed to cool down.
7) Equal amount of deionized water was digested in Digesdahl apparatus for reference. So that the sample can be digested as deionized water.
8) Nessler method (method 8075) was followed to determine nitrogen content.

9) Sample was placed in Hach apparatus and single wavelength program is followed to determine nitrogen content present in the slurry.

3.4.2.2 Nitrogen Content:

The nitrogen content was determined by method 8075 (Hach *et.al*, 1987). The equipments and chemicals required for analysis are boiling chips, silica carbide, cylinder graduated mixing, hydrogen peroxide, mineral stabilizer, nessler reagent, polyvinyl alcohol dispersing agent, potassium hydroxide standard solution, sulfuric acid, TKN indicator, pipet, safety shield and sample cell. The stepwise procedure to determine nitrogen content is as follows.

1. First of all the program 399 Nitrogen, TKN in Hach spectrophotometer was started. Multi-cell adapter with the 1 inch square cell holder facing user was inserted.
2. Prepared sample: The sample amount as described in the Kjeldahl digestion apparatus instruction manual was digested.
3. Blank Preparation: An equal amount of deionized water as the blank was also digested.
4. The appropriate analysis volume of the digested sample given in manual was selected. Analysis volume from the sample was taken out using pipette and was blanked into separate 25 ml mixing graduated cylinders.
5. One drop of TKN indicator to each cylinder was added. If the aliquot was greater than 1 ml drops of 8.0 N KOH to each cylinder was added until the first flash of blue color appears. Cylinder was inverted after each addition.
6. 1.0 N KOH to each cylinder was added, one drop at a time, mixing after each addition was done. It was continued until the first permanent blue color appears.
7. Both cylinders were filled to the 20-ml mark with deionized water.
8. Three drops of mineral stabilizer to each cylinder was added, stopper was used and inverted several times to mix.
9. Three drops of polyvinyl alcohol dispersing agent to each cylinder was added stopper was used and inverted several times to mix.
10. Both cylinders were filled to the 25-ml marked with deionized water stopper was used and inverted several times to mix.

11. 1.0 ml of Nessler's reagent was filled to each cylinder using pipette stopper was used and inverted repeatedly. It was noticed that the solution was not hazy. (Any haze (turbidity) would cause incorrect results).
12. A two minute reaction period was begun. When the timer expired, the contents of each cylinder were poured into separate square sample cells.
13. The blank was wiped and inserted into the cell holder with the line facing the user. The wavelength was set at 440 nm. After closing lid ZERO was pressed on the display, it was showing: 0 mg/L TKN.
14. The prepared sample was wiped and inserted into the cell holder with the fill line facing the user. Results were in mg/L TKN.

Calculations:

$$TKN = \frac{75 \text{ X } A}{B \text{ X } C} \text{ X } 100 \qquad \ldots.3.40$$

Where,

A = mg/L read from the display.

B = gm (or ml of water) sample taken for digest.

C = ml analysis volume of digested sample.

3.4.2.3 Phosphate Content:

Phosphate content was determined by method 8190 adapted from standard methods for the examination of water and wastewater (Hach *et.al*, 1987). The result of the reactive phosphorous test after the digestion was included in the orthophosphate and acid-hydrolysable phosphate. The condensed phosphate concentration was determined by subtracting the result of an orthophosphate test from the result. The chemicals required for analysis were potassium per sulfate powder pillows, sodium hydroxide solution, sulfuric acid solution, deionized water, graduated cylinder, Erlenmeyer flask and hot plate. The stepwise procedure to determine phosphate content is as follows.

1. A graduated cylinder was used to measure 25 ml of sample and the sample was poured into a 125 ml Erlenmeyer flask.
2. Potassium per sulfate powder pillow was added and swirled to mix.
3. 2.0 ml of 5.25 N sulfuric acid solutions was added to the flask.

4. Flask was placed on a hot plate and boiled gently for 30 minutes, but not till dry. Sample was concentrated to less than 20-mL for best recovery. After concentration, volume was maintained near 20-mL by adding small amounts of deionized water.
5. Sample was cooled to room temperature.
6. 2.0-mL of 5.0 N Sodium Hydroxide solutions was added to the flask and swirled to mix.
7. Sample was poured into a 25-mL graduated cylinder and the volume was adjusted to 25-mL with deionized water risings from the flask.
8. A reactive phosphorous test of the expected total phosphorous concentration range was preceded. The color development time was extended to 10 minutes for the PhosVer 3 method.

3.4.2.4 Potash Content:

Potash content was determined by method 8049 (Hach *et.al*, 1987). The equipments and chemicals required for analysis were potassium reagent 1 powder pillow, potassium reagent 2 powder pillows, potassium reagent 3 powder pillows, potassium standard solution, 100-mg/L, clippers, mixing cylinders, volumetric flask, pipette, sample cells and deionized water. The stepwise procedure to determine potash content is as follows.

1. Test was selected. Spectrophotometer was programmed as the procedure was performed for the first time.
2. Multi-cell adapter with the 1 inch square cell holder facing the user was inserted.
3. Graduated mixing cylinder was filled with 25 ml of sample.
4. Potassium 1 reagent pillow and contents one potassium 2 reagent pillow were added and stopper was used and inverted several times to mix.
5. Contents of one potassium 3 reagent pillow were added after the solution cleared. Stopper was used and the solution was shaken for 30 seconds.
6. TIMER>OK was pressed. A three minute reaction period was begun.

7. Prepared sample**:** At least 10-ml of the solution from the cylinder was poured into a square sample cell.
8. Blank preparation**:** When the timer was expired, second square sample cell was filled with 10-ml of sample.
9. The blank was wiped and inserted into the cell holder with the fill line facing the user.
10. ZERO was pressed. The display was showing 0.0 mg/LK.
11. Within seven minutes after the timer expired, the prepared sample was wiped and inserted into the cell holder with the fill line facing the user. Results were in mg/LK.

3.5 Economic Evaluation of Solar-Biogas Integrated Hybrid Drying System:

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 has been made to evaluate economics of the designed solar-biogas integrated hybrid system. The capital cost, variable cost, fixed cost, total cost, revenue and net profit are the basic components for an economic analysis of any business. Different economic indicators were used in economic analysis.

Economic analysis of the system carried out by employing following indicators

1. Net present worth(NPW)
2. Benefit-cost ratio(BCR)
3. Internal rate of return(IRR)
4. Payback period(PBP)

3.5.1 Net Present Worth:

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 principals for the investment. The present value of the future returns can be calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. The interest rate was assumed as the discount rate for discounting purpose.

A project returns the same benefit in each of several years and we need to know the present worth of that future income stream to know how much it is justified in investing today to receive that income stream.

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 streams from that of the benefit stream. To obtain the incremental net benefit gross cost is subtracted from gross benefit or the investment cost from the net benefit

The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \qquad \ldots.3.41$$

Where, C_t = Cost in each year

B_t = Benefit in each year

t = 1, 2, 3.....n

i = Discount rate

3.5.2 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 is to accept projects for a benefit cost ratio of one 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 the goods and service 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 costs, operation and

maintenance and replacement costs. Benefit cost ratio is the present value of the benefits to the present value of the cost.

The mathematical benefit-cost ratio can be expressed as,

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} B_t}{\sum_{t=1}^{t=n} C_t} \qquad \ldots.3.42$$

Where, C_t = Cost in each year

B_t = Benefit in each year

t = 1, 2, 3.....n

i = Discount rate, %

3.5.3 Internal Rate of Return:

Another way of using the incremental net benefit stream or incremental cash flow for measuring the worth of a project is to find the discount rate that makes the net present worth of the incremental net benefit stream or incremental cash flow equal to zero. This discount rate is called the internal rate of return. It is the maximum interest that a project could pay for the resources used if the project is to recover its investment and operating costs and still break even. It is the rate of return on capital outstanding per period while it is invested in the project. The internal rate of return is a very useful measure of project worth.

The internal rate of return can be found out by systematic procedure of trial and error to find that discount rate which will make the net present worth of the incremental net benefit stream equal to zero.

Internal rate of return is the discount rate i such that

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0 \qquad \ldots.3.43$$

3.5.4 Payback Period:

It is perhaps the simplest method of looking at one or more investment projects. It measures the time required to recover investment costs. It will be estimated by adding net cash flow in the project until the cumulative net cash flow equal to initial investment.

3.6 Instrumentation and Measurement:

The various instruments and accessories used for performance testing of developed solar –biogas integrated dryer are tabulated in Table 3.5.

Table 3.5 Instruments used for the study

Sr. No.	Instrument	Model	Specification
1.	Hot Air Oven	Khera Instruments (Delhi),	Temperature range: Ambient to 350°C Percentage Uncertainty: ±0.9%
2.	Moisture Analyzer	Sartorius, MA 35	Temperature range: 30-200 °C Moisture content: 0.2 to 100% Percentage Uncertainty : ±0.6%
3.	Weighing Balance	Sartorius, BSA224S-CW	Capacity: 220 g Readability: 0.1 mg Uncertainty range: ±0.001g
4.	Weighing Balance	Khera Instruments (Delhi),	Capacity: 300 kg Readability: 20 g Uncertainty range: ± 0.02 kg
5.	Thermocouple	Analog and Digital Instrumentation (Baroda)	Capacity: 1000˚C Uncertainty range: ± 1.5°C
6.	Digital Temperature Scanner	Analog and Digital Instrumentation (Baroda) DTSC-3508	Capacity: 1200˚C Uncertainty range: ± 1°C
7.	Anemometer	Lutron, AM-4204	Velocity range: 0.2 to 20 m/s Percentage Uncertainty : ±0.65%
8.	Data Taker	Manufacture: Data Taker, Model No: DT82E, Thermocoulples used: J/K type	For temperature measurement at various points inside dryer. Automatic recording of temperature and data storage. Percentage Uncertainty : ±0.7%

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter deals with the results of the investigation carried out on the design and development of solar-biogas integrated improved hybrid drying system including biomethanation study of spent mushroom substrate. Biomethanation study comprises of lab study of codigestion of spent mushroom substrate sample and cowdung in different proportions, identification of suitable combination of spent mushroom substrate and cowdung based on results of lab study, development of biogas plant for the identified substrate ratio, and field study of biogas production. The study also includes utilization of produced biogas and solar water heater for drying of button and oyster mushroom and economic evaluation of developed hybrid drying system based on its benefit cost ratio, payback period, net present worth and internal rate of return.

4.1 Design and Development of Solar- Biogas Integrated Dryer:

Design of drying system was done as per the methodology mention in section 3.1 of the previous chapter. The assumptions made and calculations are mentioned in Appendix A. Solar biogas integrated hybrid dryer was made up of solar water heater, biogas plant and cabinet tray dryer. Solar and biogas integrated hybrid dryer was developed in Department of Renewable Energy Engineering, CTAE Udaipur as shown in Fig 4.1. Solar energy and biogas produced from codigestion of spent button mushroom substrate and cowdung substrate were used for water heating. This hot water was circulated through radiator which was kept inside dryer. Schematic diagram of radiator and its parts are shown in following Fig. 4.2, Fig. 4.3, and Fig. 4.4. Ambient air was circulated at constant flow rate of 0.255 m/s using air fan over radiator to absorb heat from the hot water flowing through radiator tube and to dissipate this absorbed heat inside dryer for drying of mushroom at constant temperature. This complete process was optimized in such a way that constant temperature of 50 °C was maintained throughout drying of mushroom. Technical specifications of the hybrid dryer are mentioned below in Table 4.1.

Fig. 4.1 Hybrid System for Drying of Mushroom

Table 4.1 Technical Specifications of hybrid dryer

Particulars	Details
Dimensions of dryer	Width (outside): 69 cm, Width (Inside): 60 cm, Height (outside): 100 cm, Height (inside): 91cm Thickness: 24 gauge (0.56mm)
Tray dimensions:	Width: 45 cm, Length: 60cm, Thickness:4.5 cm No. of Trays: 4
Chimney dimensions	Height: 52 cm excluding cap, Height including cap: 59 cm, Diameter: 13 cm, Thickness: 26 gauge (0.48mm)
Radiator dimensions	**Radiator Dimensions:** Length: 44cm, Width: 33 cm, Height: 7cm. **Tube Dimensions:** Length: 33 cm, Width: 10 cm, height: 3 mm. **Fin Dimensions:** Height: 32 cm, Width: 10 mm, Thickness: 36 gauge (0.19 mm)

Solar Water Heater Specifications	Capacity: 100 LPD, Evacuated tube type solar collector. Specifications mentioned in Appendix G.
Biogas heated water chamber dimensions	Capacity: 40 LPD
Flow Rate of ambient air	12 volt air fan was used with adjusted flow rate of 0.255 m/s

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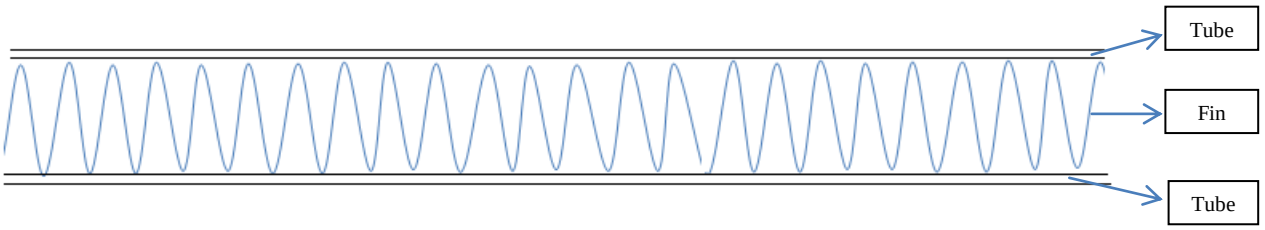


Fig. 4.2 Actual fin geometry of radiator

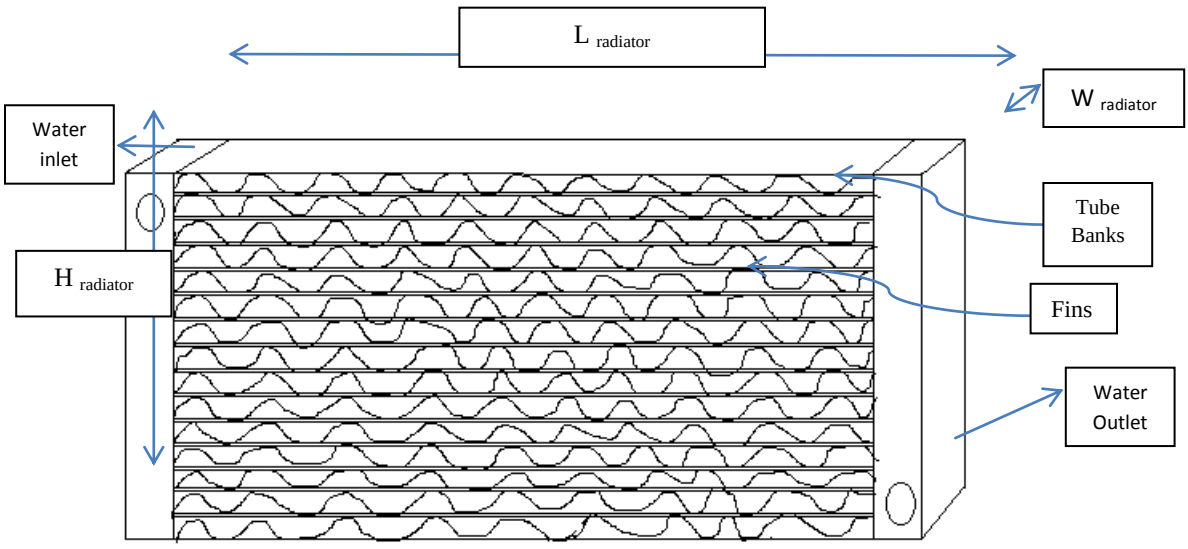


Fig. 4.3 Schematic of radiator

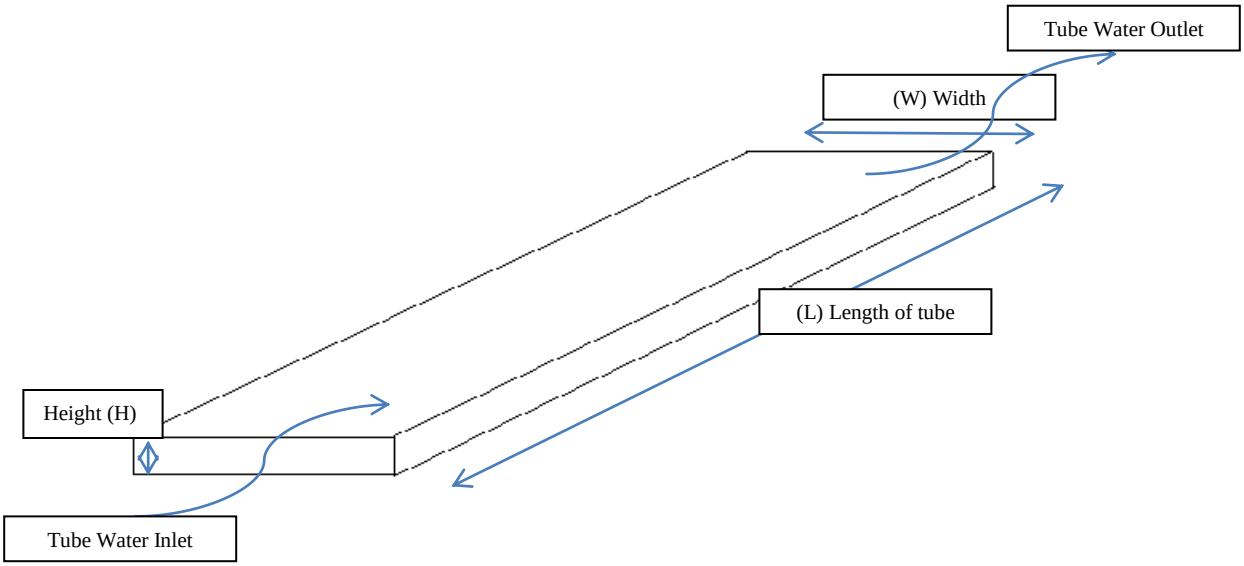


Fig. 4.4 Schematic of single tube of radiator

4.2 Biomethanation Study of Spent Mushroom Substrate:

Biomethanation study of spent mushroom substrate was carried out in the laboratory as per the methodology discussed in section 3.2. Biomethanation study of spent button mushroom substrate as well as spent oyster mushroom substrate was carried out in codigestion with cowdung. Total 9 treatments with 2 replications of each were prepared as shown in Table 3.3 of previous chapter. The daily biogas production from each selected treatment were analyzed and recorded continuously for 40 days. The observations of lab study were recorded from 20th May 2015 to 28th June 2015. The results obtained from the selected treatments are discussed in following subsections and mentioned in Appendix J whereas uncertainty analysis of biogas production from selected treatment is mentioned in Appendix K.

4.2.1 Biogas Production From Various Treatments:

Results of treatment T1 having 25 % spent oyster mushroom substrate and 75 % cow dung is shown in Fig. 4.5. Initially sample was prepared by mixing 50 g of spent oyster mushroom waste with 150 g of cow dung, 30 g of slurry as inoculum along with 428 ml of water. Two samples of this treatment were prepared for biomethanation study. Biogas production from these samples was measured continuously for a period of 40 days. Fig. 4.5 shows variation of biogas production in ml and specific biogas production

in L/kg dm and L/kg VS with respect to days of biomethanation. The biogas production was maximum during 15th to 30th day of digestion process and after 30th day the decrease in biogas production was observed. The total biogas production from treatment T1 was 6.78 L and biogas production at STP was observed as 6.17 L. The total specific biogas production from codigestion of spent oyster mushroom substrate and cow dung substrate (25% SpOMS +75% Cow dung) within 40 days of biomethanation period was observed as 97.76 L/kg dm and 113.09 L/kg VS respectively.

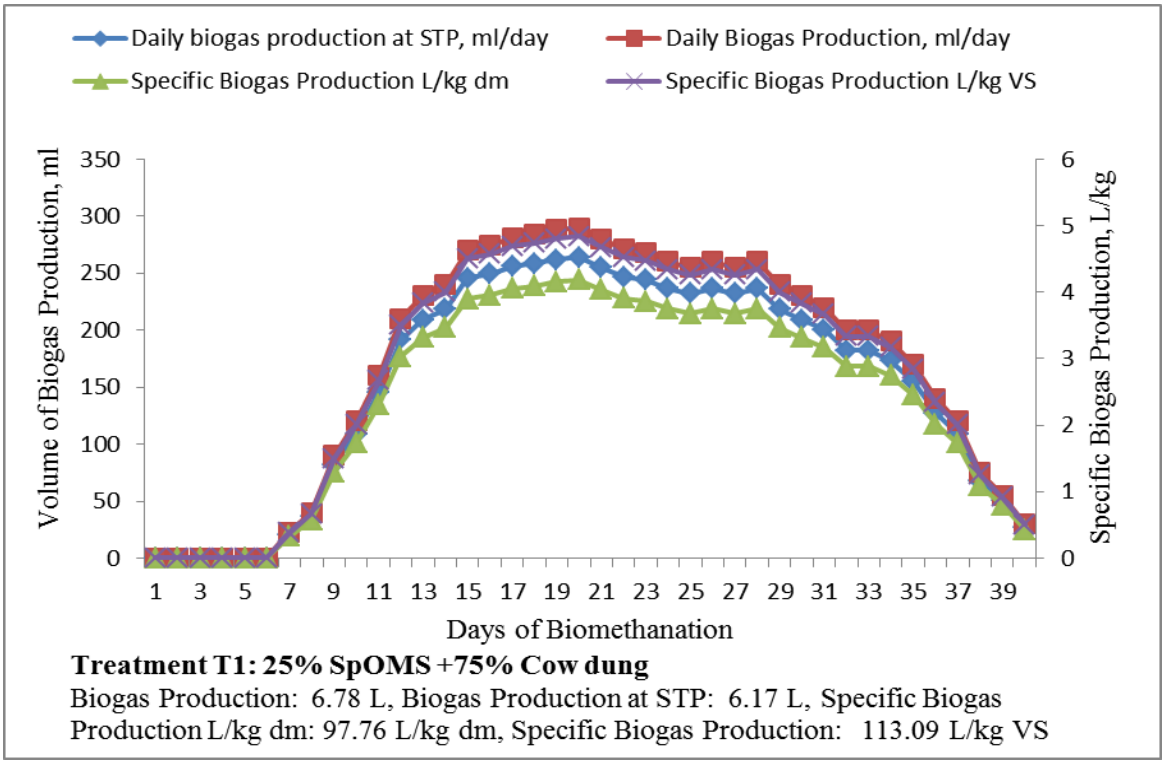


Fig. 4.5 Treatment T1: 25% SpOMS +75% Cow dung

Results of treatment T2 having 50 % spent oyster mushroom substrate and 50 % cow dung is shown in Fig. 4.6. Initially sample was prepared by mixing 100 g of spent oyster mushroom waste with 100 g of cow dung, 30 g of slurry as inoculum along with 691 ml of water. Two samples of this treatment were prepared for biomethanation study and poured in 2 L aspirator bottle. Fig. 4.6 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T2 was 5.673 L and biogas production at STP was observed as 5.16 L. The total specific biogas production from codigestion of spent button mushroom substrate and cow dung substrate (50% SpOMS

+50% Cow dung) during 40 days of retention period was observed as 57.75 L/kg dm and 64.45 L/kg VS respectively.

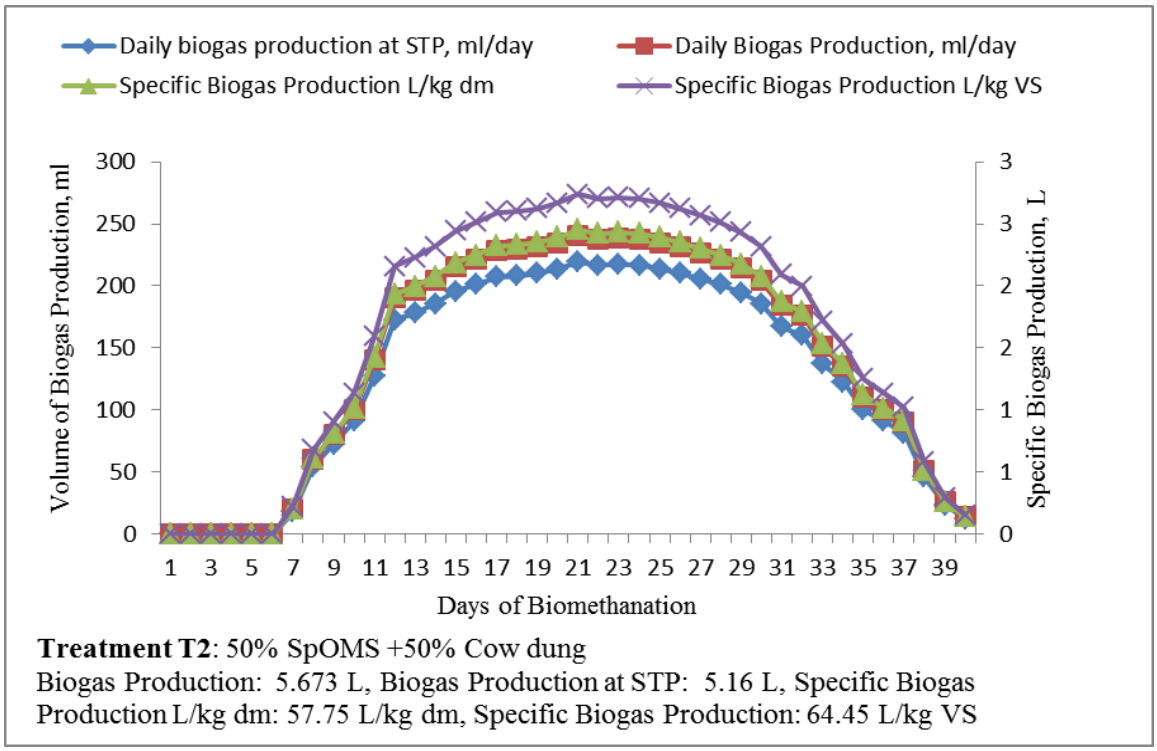


Fig. 4.6 Treatment T2: 50% SpOMS +50% Cow dung

Results of treatment T3 having 75 % spent oyster mushroom substrate and 25 % cow dung is shown in Fig. 4.7. Initially sample was prepared by mixing 150 g of spent oyster mushroom waste with 50 g of cow dung, 30 g of digested slurry as inoculums material along with 954 ml of water. Two replications of this treatment were prepared and poured in 2 L aspirator bottle for biomethanation study. Fig. 4.7 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T3 was 3.678 L and biogas production at STP was observed as 3.347 L. The total specific biogas production from codigestion of spent oyster mushroom substrate and cow dung substrate (75% SpOMS +25% Cow dung) during 40 days of retention period was observed as 28.93 L/kg dm and 31.68 L/kg VS respectively.

Results of treatment T4 having 100 % spent oyster mushroom substrate is shown in Fig. 4.8. Initially sample was prepared by mixing 200 g of spent oyster mushroom substrate and 30 g of digested slurry as inoculums material along with 1217 ml of water.

Two replications of this treatment were prepared in 2 L aspirator bottle for biomethanation study. Fig. 4.8 shows variation of biogas production in ml and specific biogas production in L/kg TS and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T4 was 1.13 L and biogas production at STP was observed as 1.02 L. The total specific biogas production from spent button mushroom substrate (100% SpOMW) during 40 days of retention period was observed as 7.21 L/kg dm and 7.81 L/kg VS respectively.

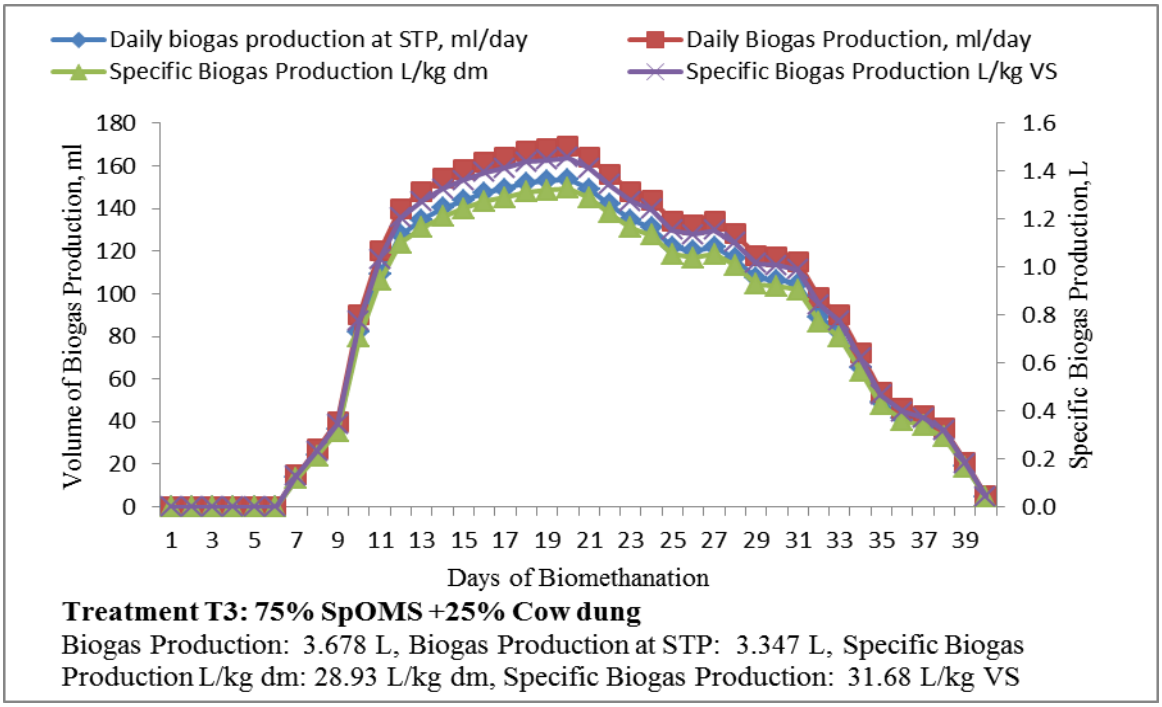
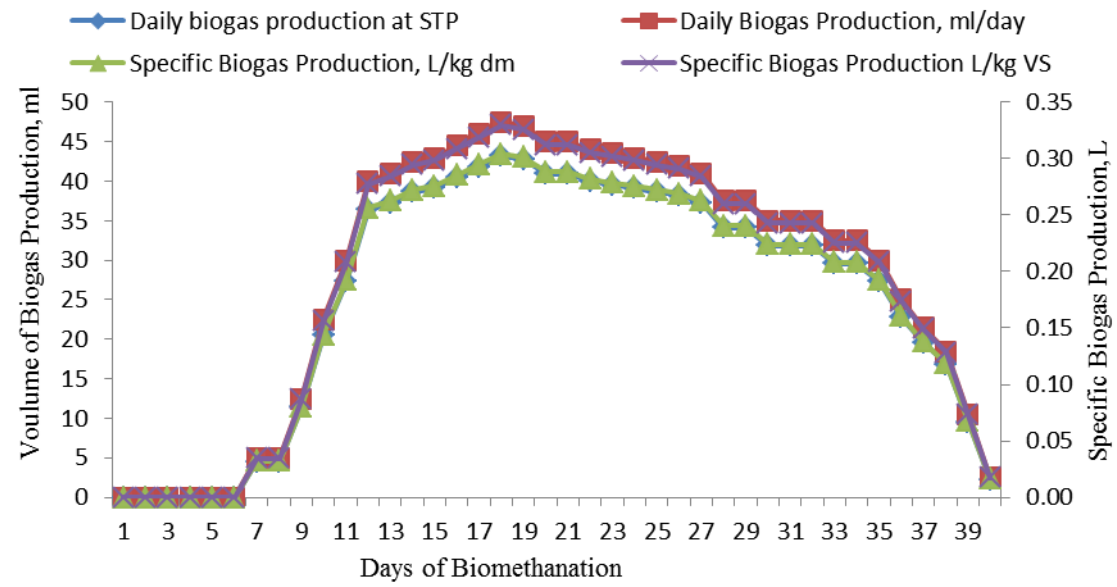


Fig. 4.7 Treatment T3: 75% SpOMS +25% Cow dung

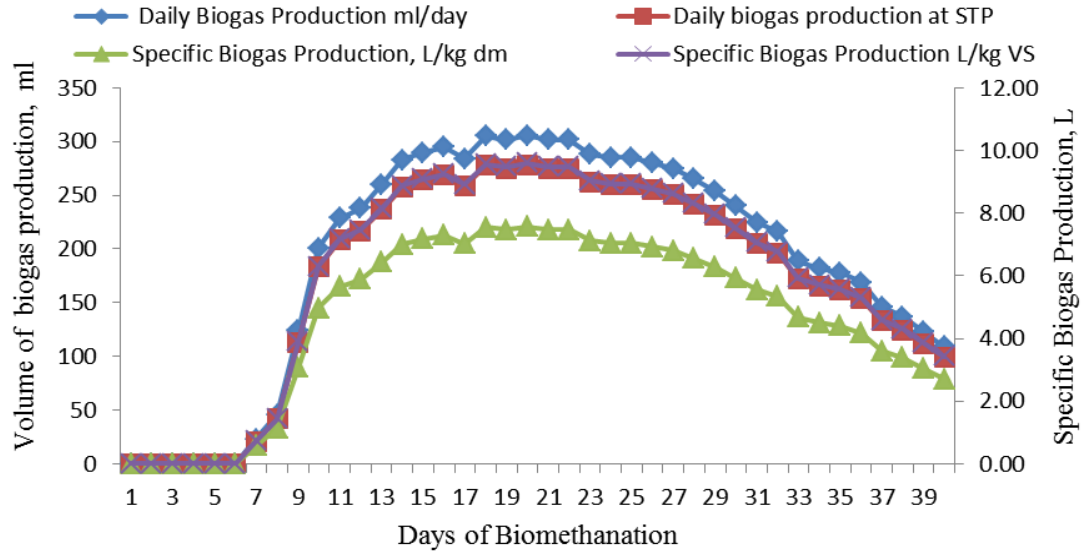
Biomethanation results of treatment T5 having 100 % cow dung substrate is shown in Fig. 4.9. Initially sample was prepared by mixing 200 g of cow dung substrate and 30 g of digested slurry as inoculums material along with 165 ml of water. Two replications of this treatment were prepared in 2 L aspirator bottle for biomethanation study. Fig. 4.9 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T5 was 7.636 L and biogas production at STP was observed as 6.95 L. The total specific biogas production from cow dung substrate (100% cow dung) during 40 days of retention period was observed as 188.83 L/kg dm and 239.63 L/kg VS respectively.



Treatment T4: 100% SpOMS

Biogas Production: 1.13 L, Biogas Production at STP: 1.02 L, Specific Biogas Production L/kg TS: 7.21 L/kg dm, Specific Biogas Production: 7.81 L/kg VS

Fig 4.8 Treatment T4: 100% SpOMS



Treatment T5: 100% Cow dung

Biogas Production: 7.636 L, Biogas Production at STP: 6.95 L, Specific Biogas Production L/kg dm: 188.83 L/kg dm, Specific Biogas Production: 239.63 L/kg VS

Fig. 4.9 Treatment T5: 100% Cow dung

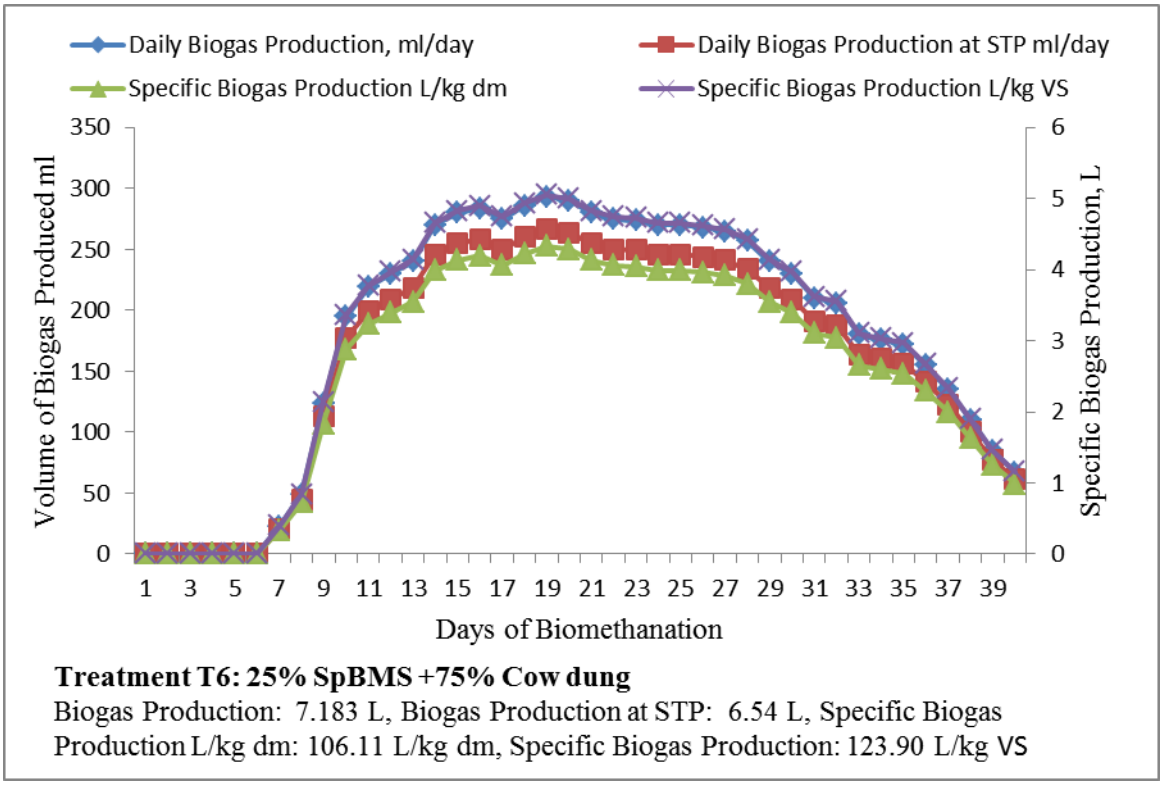


Fig. 4.10 Treatment 6: 25% SpBMS +75% Cow dung

Results of treatment T6 having 25 % spent button mushroom substrate and 75 % cow dung is shown in Fig. 4.10. Initially sample was prepared by mixing 50 g of spent button mushroom waste with 150 g of cow dung, 30 g of slurry as inoculum along with 413 ml of water. Two samples of this treatment were prepared for biomethanation study. Biogas production from these samples was measured for 40 days of biomethanation. Fig. 4.10 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T6 was 7.183 L and biogas production at STP was observed as 6.54 L. The total specific biogas production from codigestion of spent button mushroom substrate and cow dung substrate (25% SpBMS +75% Cow dung) within 40 days of biomethanation period was observed as 106.11 L/kg dm and 123.90 L/kg VS respectively.

Results of treatment T7 having 50 % spent button mushroom substrate and 50 % cow dung is shown in Fig. 4.11. Initially sample was prepared by mixing 100 g of spent button mushroom waste with 100 g of cow dung, 30 g of slurry as inoculum along with

661 ml of water. Two samples of this treatment were prepared for biomethanation study and poured in 2 L aspirator bottle. Fig. 4.11 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T7 was 6.27 L and biogas production at STP was observed as 5.71 L. The total specific biogas production from codigestion of spent oyster mushroom substrate and cow dung substrate (50% SpBMS +50% Cow dung) during 40 days of retention period was observed as 66.08 L/kg dm and 74.62 L/kg VS respectively.

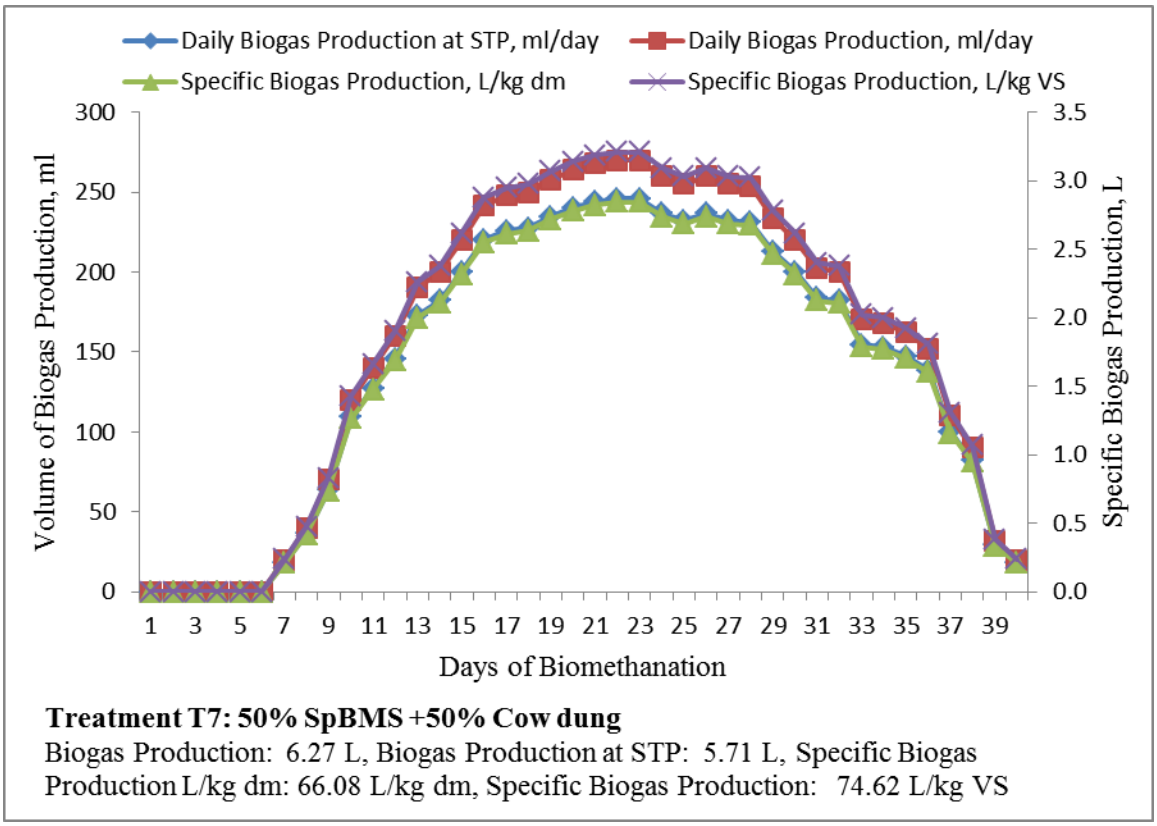
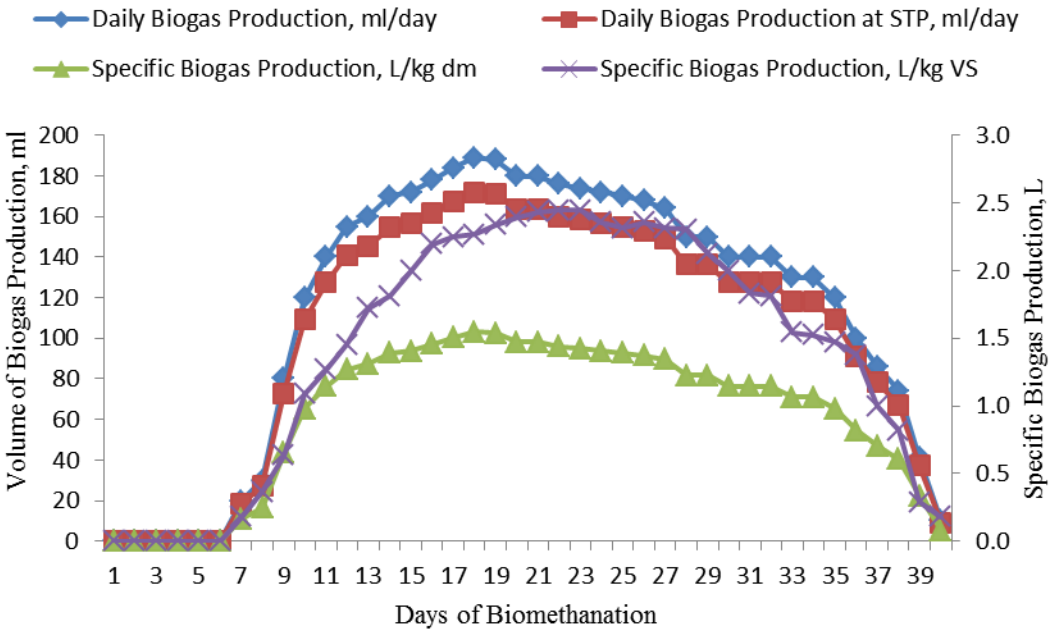


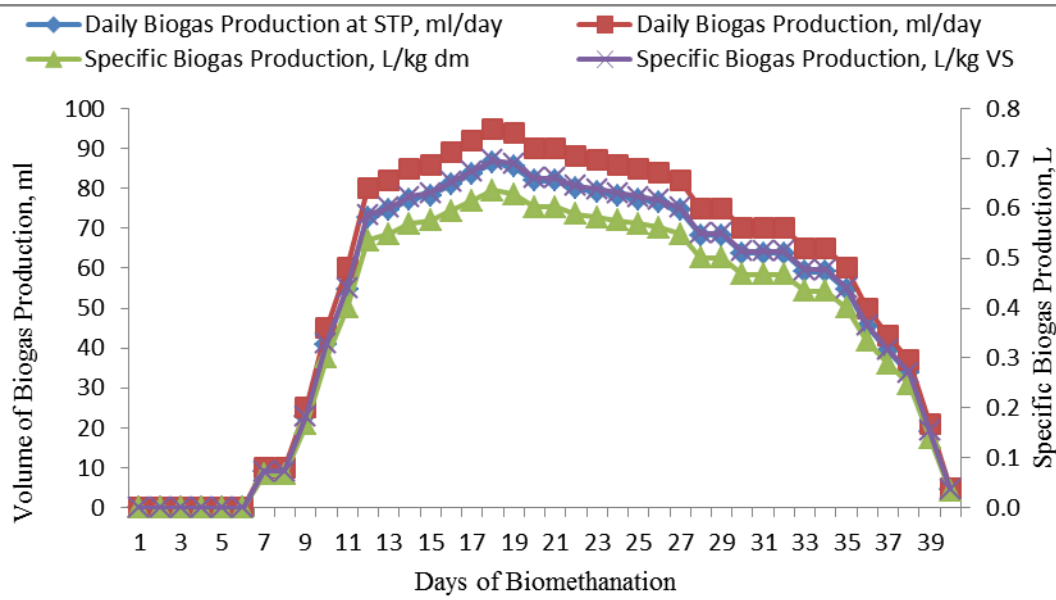
Fig. 4.11 Treatment T7: 50% SpBMS +50% Cow dung

Results of treatment T8 having 75 % spent button mushroom substrate and 25 % cow dung is shown in Fig. 4.12. Initially sample was prepared by mixing 150 g of spent button mushroom waste with 50 g of cow dung, 30 g of slurry as inoculum along with 909 ml of water. Two samples of this treatment were prepared for biomethanation study and poured in 2 L aspirator bottle.



Treatment T8: 75% SpBMW +25% Cow dung
Biogas Production: 4.581 L, Biogas Production at STP: 4.17 L, Specific Biogas Production L/kg dm: 37.49 L/kg dm, Specific Biogas Production: 56.94 L/kg VS

Fig. 4.12 Treatment T8: 75% SpBMS +25% Cow dung



Treatment T9: 100% SpBMW
Biogas Production: 2.251 L, Biogas Production at STP: 2.05 L, Specific Biogas Production L/kg dm: 15.06 L/kg dm, Specific Biogas Production: 16.52 L/kg VS

Fig. 4.13 Treatment T9: 100% SpBMW

Fig. 4.12 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T8 was 4.581 L and biogas production at STP was observed as 4.17 L. The total specific biogas production from codigestion of spent button mushroom substrate and cow dung substrate (75% SpBMS +25% Cow dung) during 40 days of retention period was observed as 37.49 L/kg dm and 56.94 L/kg VS respectively.

Results of treatment T9 having 100 % spent button mushroom substrate is shown in Fig. 4.13. Initially sample was prepared by mixing 200 g of spent button mushroom waste, 30 g of slurry as inoculum along with 1157 ml of water. Two samples of this treatment were prepared and poured in 2 L aspirator bottle. Fig. 4.13 shows variation of biogas production in ml and specific biogas production in L/kg dm and L/kg VS with respect to days of biomethanation. The total biogas production from treatment T9 was 2.251 L and biogas production at STP was observed as 2.05 L. The total specific biogas production from spent oyster mushroom substrate (100% SpBMS) during 40 days of retention period was observed as 15.06 L/kg dm and 16.52 L/kg VS respectively.

Total biogas production from biomethanation of spent mushroom substrate and cow dung in different proportion was measured in laboratory and tabulated in Table 4.2 The treatment T6 showed maximum biogas production with spent button mushroom waste as ingredient of feeding material.

Comparative performance of biogas production from various treatments of spent mushroom waste and cow dung is shown in Fig. 4.14. It showed that the biogas production from treatment T6 (25% SpBMS+75% Cowdung) was less than the control treatment T5 (100% Cowdung) but it was always more than other treatments having spent mushroom waste in various proportions with cowdung throughout biomethanation period. From Fig. 4.14 and Fig. 4.15 it was cleared that the treatment T6 showed maximum daily biogas production in ml and daily biogas production at STP in ml as compared to other treatments. The total biogas production within 40 days of biomethanation from treatment T6 was 7.183 L whereas from treatment T5 it was 7.636L.The total biogas production at STP from T6 was about 6.54 L in 40 days whereas

for T5 it was 6.95 L. The total specific biogas production in L/kg dm and L/kg VS from treatment T6 within 40 days of biomethanation period was observed as 106.11 L/kg dm and 123.90 L/kg VS respectively whereas from treatment T5 it was 188.83 L/kg dm and 239.63 L/kg VS respectively. Compare to control treatment T5 (100% CD), the biogas production of the treatments T1 (25% SpOMS+ 75% CD), T2 (50% SpOMS+ 50% CD), T3 (75% SpOMS+ 25% CD) and T4 (100% SpOMS) was found only 88.78%, 74.29%, 48.16% and 14.56 % respectively. Similarly biogas production of the treatments T6 (25% SpBMS+ 75%CD), T7 (50% SpBMS+50% CD), T8 (75% SpBMS+ 25% CD) and T9 (100% SpBMS) was found 94.06%, 82.11%, 59.99% and 29.47% respectively as compare to control treatment T5 (100% CD). Similar results were found by Nguyen and Klaus (2014), from the anaerobic co-digestion of pig manure and spent mushroom compost in the Mekong delta. It was cleared from the results that the combination of 25% SpBMS+75% CD provides alternate material for biogas production along with 100% cowdung substrate. Although cumulative biogas production throughout biomethanation period from treatment T6 was found lower as compare to the control treatment T5 (100% cowdung) but its utilization for anaerobic digestion and biogas production helps to reduce greenhouse gas emissions and solve waste disposal problem.

Table 4.2 Biogas production from different treatments throughout 40 days of HRT

Treatment	Biogas production in L	Biogas production at STP in L	Biogas production L/kg dm	Biogas production L/kg VS
T1	6.78	6.17	97.76	113.09
T2	5.673	5.16	57.75	64.45
T3	3.678	3.347	28.93	31.68
T4	1.13	1.02	7.21	7.81
T5	7.636	6.95	188.83	239.63
T6	7.183	6.54	106.11	123.90
T7	6.27	5.71	66.08	74.62
T8	4.581	4.17	37.49	56.94
T9	2.251	2.05	15.06	16.52

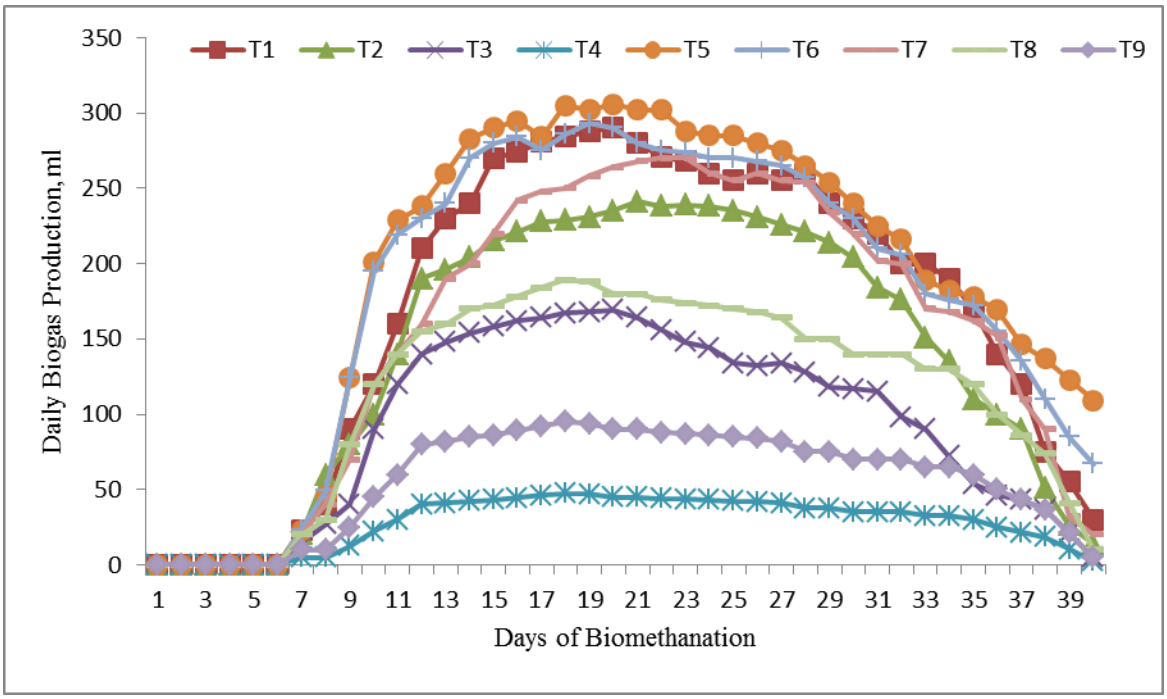


Fig. 4.14 Biogas Production, ml

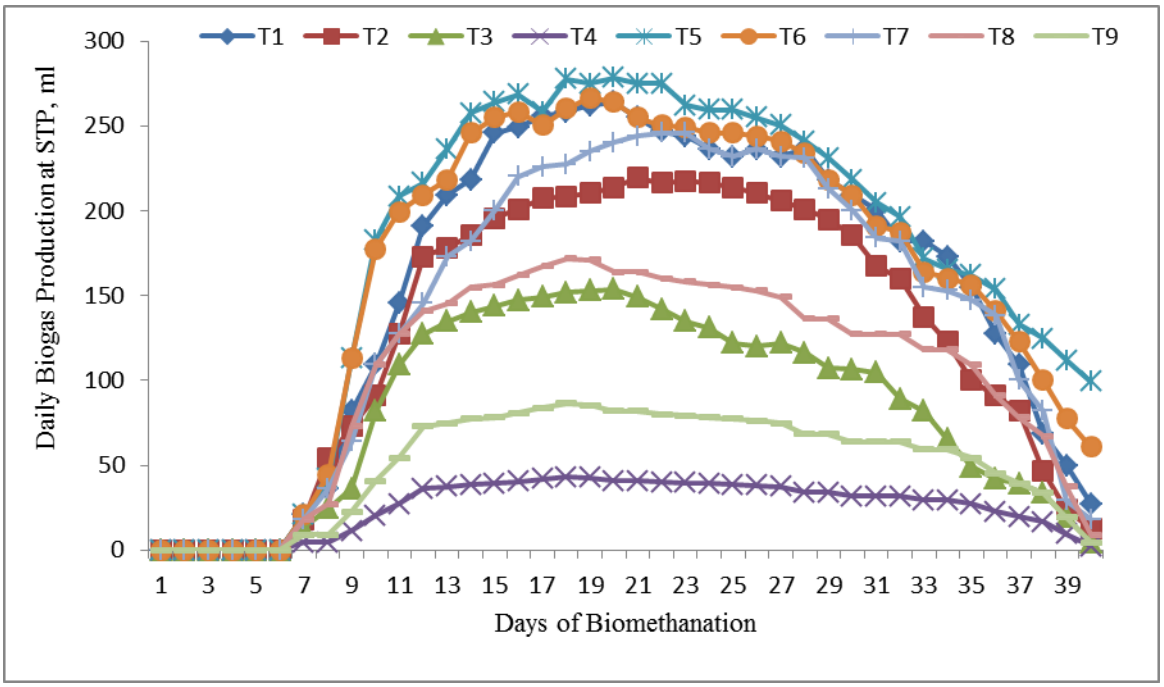


Fig. 4.15 Daily biogas production at STP, ml

4.2.2 Analysis of Biogas Composition:

Compositions of produced biogas from each treatment were analyzed using biogas analyzer after every 10 days of interval as shown in Table 4.3. Initially the percentage of methane was low and it increased along with digestion time and stabilized after 20 days of biomethanation. It was observed from table 4.3 that percentage of methane was increased after third week of biomethanation therefore it can be inferred that methanogenic stage was started after 21 days of biomethanation. CH_4 & CO_2 percentage was found approximately similar in all treatments; although methane percentage was found comparatively better in treatment T6 after control treatment T5. After stabilization CH_4 percentage was varying in between 56% to 57% in T6 whereas CO_2 percentage was varying in between 34% to 38%. The higher percentage of methane in the produced biogas indicates better combustion quality. Apart from methane and carbon dioxide various other combustible and noncombustible gases are present in the biogas like H_2, N_2, and H_2S along with water vapour but composition of all these gases were not analyzed by biogas analyzer used in the laboratory study.

Table 4.3 Analysis of biogas composition

Days	Biogas composition (%)	T1	T2	T3	T4	T5	T6	T7	T8	T9
10	CH_4	33.8	31.8	29.8	24	35.4	34	32	30	28
	CO_2	45.4	46	46.8	48.4	43.4	44.5	45.8	46	47.20
20	CH_4	39.5	38.7	38.20	36.54	41.8	39.7	39.1	38.5	37.5
	CO_2	38	38.7	39.1	39.5	37.1	38.1	38.5	39	39.3
30	CH_4	55.1	54	53.6	53	55.8	56.5	54.5	53.8	53
	CO_2	35.6	35.5	36	37	35.3	34.6	35	35.8	36.2
40	CH_4	55.4	55.8	54.6	53.12	56.8	57.1	56.4	54.8	53.4
	CO_2	35.4	34	35.32	36	34.1	34.2	34	35.1	36

4.2.3 Analysis of Undigested Substrate and Digested Slurry:

Undigested and digested samples of each treatment were analyzed in microbiology laboratory of DREE, CTAE Udaipur. The results of total solids and volatile solids before and after digestion along with pH of digested sample of each treatment are shown below in Table 4.4 whereas nutrient content analysis of each sample is depicted in Table 4.5.

From Table 4.4, it was cleared that percentage reduction in total solids and volatile solids was highest in control treatment T5, after that the percentage reduction was highest in treatment T6. In T6, percentage reduction in total solid and total volatile solids was 11.6% and 13.55% respectively. Higher percentage reduction in total solids and volatile solids indicates more biogas production in treatment T6 as compared to other selected treatments. After anaerobic digestion, pH of digested samples of various treatments were measured and tabulated in Table 4.4. It was observed that pH varies in the range of 7.1 to 7.3.

Table 4.4 Quantity of total solid and volatile solid content in samples of various treatments

Treatment	pH, AD	Total Solids (TS, g)			% R in TS	Volatile Solids (VS, g)			%R in VS
		BD	AD	BD-AD		BD	AD	BD-AD	
T1	7.2	63.1	56.16	6.941	11	54.55	47.61	6.94	12.72
T2	7.1	89.4	82.78	6.616	7.4	82.57	75.95	6.62	8.01
T3	7.2	115.7	110.84	4.859	4.2	105.65	100.79	4.86	4.60
T4	7.3	142	138.59	3.408	2.4	131.21	127.80	3.41	2.60
T5	7.2	36.8	29.07	7.728	21	29.00	21.27	7.73	26.65

T6	7.2	61.6	54.45	7.146	11.6	52.75	45.61	7.14	13.55
T7	7.1	86.4	79.66	6.739	7.8	76.50	69.76	6.74	8.81
T8	7.2	111.2	106.20	5.004	4.5	100.27	95.27	5	4.99
T9	7.1	136	132.33	3.672	2.7	124.03	120.36	3.67	2.96

The input substrate and digested slurry from every selected treatment were analyzed in laboratory to determine the changes in the nutrients like total nitrogen, phosphate and potash. The samples were collected after completion of 40 days of hydraulic retention time and analyzed in laboratory. The results obtained are shown in the Table 4.5.

Table 4.5 Nutrient content analysis of samples

Treatment	N, %			P, %			K, %		
	BD	**AD**	**Increase**	**BD**	**AD**	**Increase**	**BD**	**AD**	**Increase**
T1	1.25	1.43	12.59	0.65	0.89	26.97	0.812	0.93	12.69
T2	1.35	1.52	11.18	0.625	0.82	23.78	0.875	0.98	10.71
T3	1.48	1.64	9.76	0.53	0.65	18.46	1.087	1.2	9.42
T4	1.6	1.72	6.98	0.5	0.59	15.25	1	1.09	8.26
T5	1.1	1.35	18.52	0.7	0.99	29.29	0.74	0.88	15.91
T6	1.36	1.56	12.82	0.67	0.94	28.72	0.87	1	13.00
T7	1.53	1.74	12.07	0.65	0.87	25.30	0.975	1.1	11.36
T8	1.75	1.96	10.71	0.63	0.79	20.25	1.08	1.2	10.00
T9	1.96	2.11	7.11	0.6	0.72	16.67	1.2	1.31	8.40

***Note**: N= Total kjeldhal nitrogen, P= phosphate and K= potash.

From Table 4.5, it is clear that percentage increase in N, P, & K was found maximum in treatment T5 (100 % cowdung), after that the percentage increase was found maximum in treatment T6. In T6, N, P, & K were increased from 1.36%, 0.67%, and 0.87% to 1.56%, 0.94% and 1% respectively. The percentage of total nitrogen and potash was highest in the substrate of treatment T9 which was around 1.96% and 1.2% respectively, after digestion this percentage was increased to 2.11% and 1.31% respectively. The percentage of phosphate was found maximum in the substrate of T5 which increased after digestion from 0.7% to 0.99%.

4.2.4 Design and Development of Biogas Plant for Biomethanation of Spent Mushroom Substrate and Cowdung:

Biogas plant of $2m^3$ was developed for the codigestion of 25% SpBMS +75% cow dung substrate. The designs of the various parts of developed biogas plant are shown in Fig. 4.16, Fig.4.17, Fig.4.18, and Fig.4.19. The developed plant in pictorial view is shown in Fig. 4.20. The dome has provided with additional stirring mechanism to break the scum formation inside digester as shown in Fig. 4.16. The developed plant was further evaluated continuously for 80 days by daily feeding a mixture of 12.5 kg of spent button mushroom substrate and 37.5 kg of fresh cowdung with 100 kg of water. 100 kg of water with 50 kg of selected substrate (12.5 kg SpBMS +37.5 kg cow dung) was mixed daily to maintain 10% solid content of material.

The various parameters used in designing of biogas plant were as follows,

W= Weight of waste/substrate fed per day (kg/day)

G= Gas production rate (m^3/day)

V_s= Active slurry volume in the digester (m^3)

V_d= Dome volume (m^3)

H= Height of cylindrical portion of the digester up to the top edge of the outlet opening (m)

D= Diameter of the digester (m)

d_h= Height of the dome (m)

r= radius of the dome (m)

Various design parameters can be estimated with the help of following equation

4.2.4.1 Gas Production Rate (G):

From lab study it was found that 0.2 kg of undigested mixture of spent button mushroom substrate and cow dung (25% SpBMS +75% Cow dung) can produce 7.183 L of biogas. Therefore from 50 kg of this substrate when mixed with 100 kg of water will generate approximately around 1.795 $m^3$of biogas production.

$$G=1.795\ m^3/day$$

Active slurry volume Vs: Vs which is related to the HRT can be determined by following equation,

$$Vs = HRT * \left[\frac{W_{sb}}{\rho_{sb}} + \frac{W_w}{\rho_w} \right]$$

Whereas, W_{sb} is weight of substrate 50 kg, Ww is weight of water mixed with substrate 100 kg, ρ_{sb} is the density of substrate 2325 kg/m^3, and ρw is the density of water 1000 kg/m^3.

Considering 40 days of HRT period and 50 kg/day of substrate feeding along with 100 kg of water,

$$V_s=4.86\ m^3$$

4.2.4.2 Estimation of Height and Diameter of Digester:

For a cylindrical shaped digester of diameter (D) and height (H) requisite volume of the digester was calculated using following equation. Knowing the active slurry volume from the previous equation, H was determined from the following equation,

$$(\Pi/4)\ D^2.\ H=V_s$$

Considering cylindrical shaped digester with diameter (D) to depth or height (H) ratio as 1:2.5.

$$(\Pi/4)\ D^2.\ H=4.86$$

$$(\Pi/4)\ D^2.\ 3.4=4.86\ \ldots\ldots(\ *\text{Assuming height H=3.4 m})$$

$$D=1.35\ m$$

4.2.4.3 Estimation of Gas Holder Size/ Dome Volume:

Based on the presumption that gas is to be used regularly and withdrawn at more or less constant rate therefore gas holder needs to have only half the volume of estimated daily gas production. Thus for daily biogas production of 2 m^3/day, gasholder needs to have a capacity of only 1 m^3. For a proper movement of drum, 5 inch gap was kept in between movable dome and inner wall of digester. Therefore in total gasholder diameter was 10 inches (approx 25 cm) smaller than digester diameter. Hence diameter of gasholder/dome was kept as 1.1 m. The height of gasholder is thus given by;

$$Height\ of\ \ gasholder = \frac{Volume}{Area}$$

$$Height\ of\ \ gasholder = \frac{1 \times 4}{\Pi \times \left(1.1^2\right)}$$

Height of gasholder = 1.1 m

Gasholder diameter = 1.1 m

Gasholder height = 1.1 m

4.2.4.4 Basic Components of Developed Biogas Plant for Codigestion of SpBMS and Cowdung:

The basic components of developed biogas plants are:

1) Digester or fermentation chamber,
2) Plant dome/Gas holder or gas storage chamber
3) Inlet (pipe or tank),
4) Outlet (pipe or tank),
5) Mixing tank,
6) Gas outlet pipe.

Materials utilized for the development of 2m^3 plant are tabulated in Appendix H.

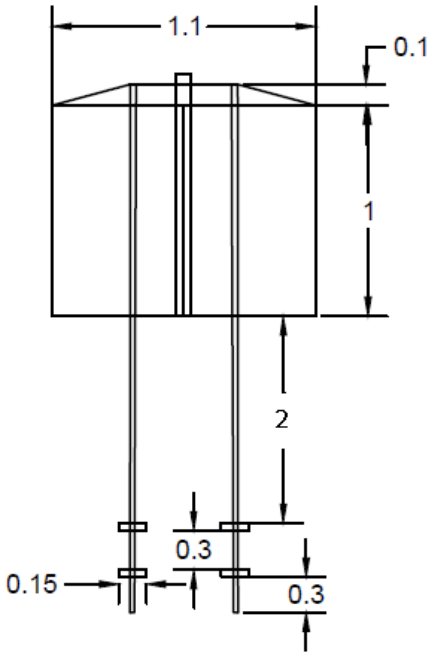


Fig. 4.16 Dome/Gas holder of developed biogas plant

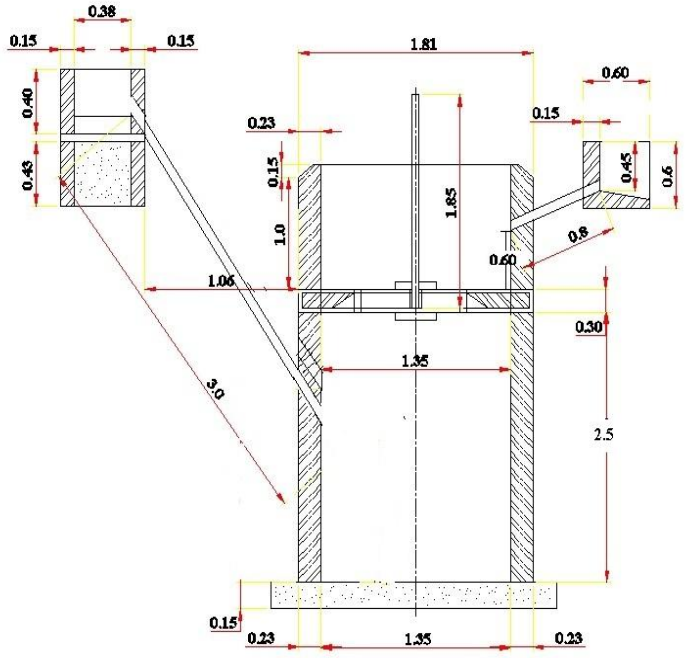


Fig. 4.17 Digester of developed biogas plant

All dimensions of Fig 4.16 and 4.17 are in meter.

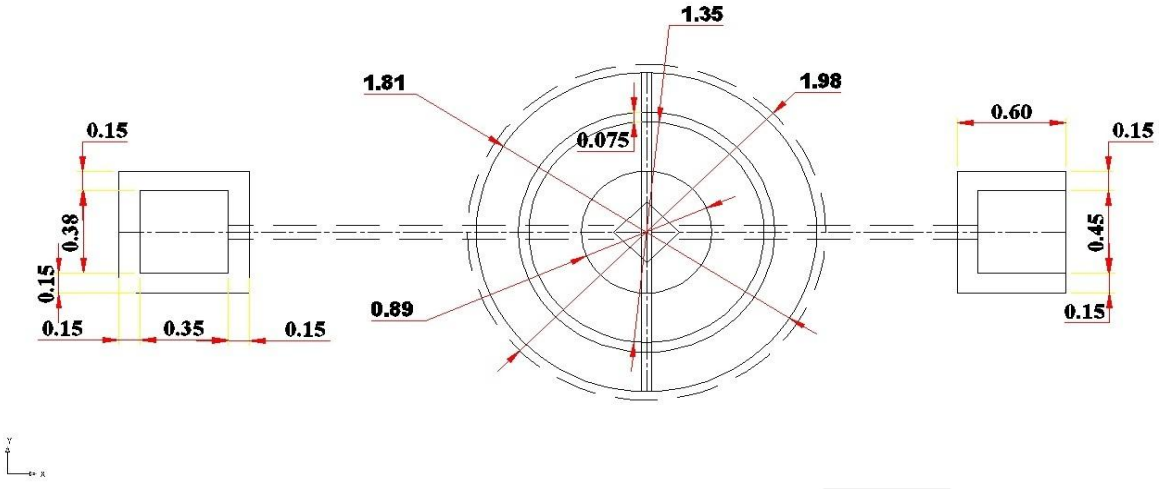


Fig. 4.18 Top view of developed biogas plant

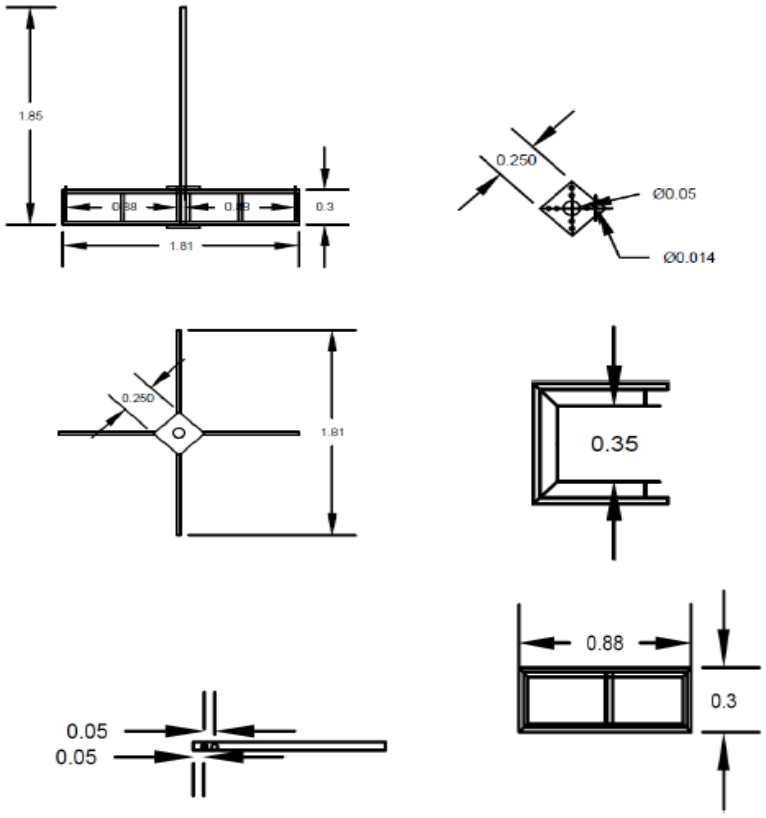


Fig. 4.19 Design of central guide frame of biogas plant

All dimensions of Fig 4.18 and 4.19 are in meter.

Fig. 4.20 Developed biogas plant for codigestion of spent button mushroom substrate and cow dung

4.2.5 Field Study of Biogas Production from Codigestion of Spent Button Mushroom Substrate and Cowdung:

Biogas produced from the developed plant was measured continuously for 80 days from the day it was fed with spent button mushroom substrate and cow dung mixture in the proportion of 1:3. The hydraulic retention time (HRT) of the modified biogas plant was 40 days, so the observations of produced biogas were recorded daily throughout two cycles of HRT (80 days). The observations were recorded from 4th February, 2016 to 23rd April, 2016. The volume of biogas generated was measured by using biogas flowmeter. Results obtained from the anaerobic codigestion of spent button

mushroom substrate and cowdung substrate are tabulated in Appendix I whereas uncertainty analysis of the biogas production measurement is mentioned in Appendix L.

4.2.5.1 Daily Biogas Production:

Fig. 4.21 shows the relationship between the daily biogas production yield, daily biogas production at STP and substrate temperature with respect to days of biomethanation for codigestion of spent button mushroom substrate (SpBMS) and cowdung (CD) (25% SpBMS+75%CD) at feeding rate of 15.4 kg dm/day. The average daily biogas production during 80 days of biomethanation period was observed as 1.852 m^3/day (Appendix I1). It was observed that biogas production was started from seventh day and biogas production rate became stable after fifteenth (15^{th}) day of digestion process. The substrate temperature during anaerobic digestion of spent button mushroom substrate and cowdung was observed in the range of 31.5 °C to 37.9 °C. The observed substrate temperature indicates that the digester was operating in mesophilic temperature range. It has been reported that mesophilic methanogens are more active in the temperature range of 20-45°C and the biogas production reaches maximum when substrate temperature inside digester is maintained around 35°C. (Zeeman *et al.,* 1983). Furthermore it has been also reported by Deublein and Steinhauser, 2008 that at 30-35 °C substrate temperature, methanogens are more active. Results obtained are tabulated in Appendix I1.

4.2.5.2 Methane and Carbon Dioxide Content of Produced Biogas:

Methane and carbon dioxide contents in produced biogas were measured daily by using a GASBOARD- 3200P portable biogas analyzer. Fig. 4.22 shows the variation of methane and carbon dioxide content in the produced biogas from codigestion of spent button mushroom substrate (SpBMS) and cowdung (CD). Initially the percentage of methane in the biogas was not so high and it increases slowly from 16.9 to 46.2% from 7^{th} to 24^{th} day of biomethanation. After 25^{th} day the methane composition in the biogas becomes stable and it varies in the range of 48.5 to 57.3%. It was found average 55.54% methane production per day after stabilization throughout biomethanation period of 80 days. It was found average 34.91% of carbon dioxide production per day during biomethanation period of 80 days. The observed values of methane concentration in the

produced biogas from codigestion of spent button mushroom substrate and cow dung have showed significantly similarity in the methane content range of biogas produced from cattle dung only.

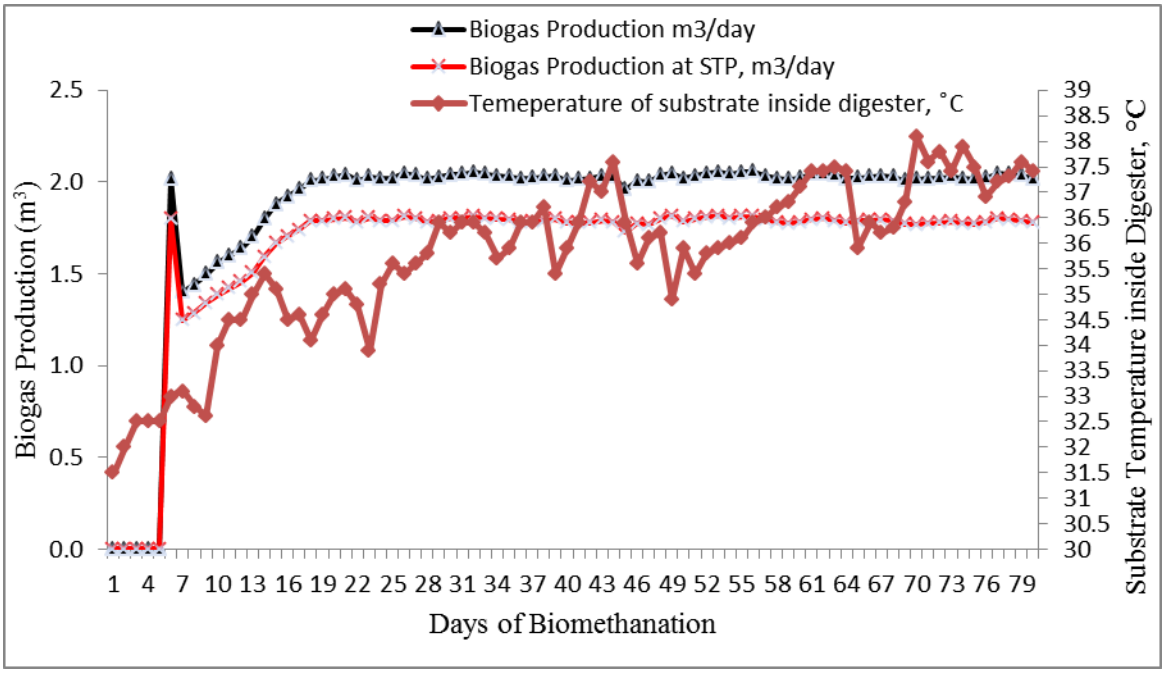


Fig. 4.21 Biogas production in m^3/day from codigestion of spent button mushroom substrate and cow dung

4.2.5.3 Specific Methane Production Rate:

The variation in the specific methane production rate in L/kg dm and L/kg VS over period of biomethanation is shown in Fig. 4.23. The range of specific methane production in L/kg dm varies from 19.37 to 67.36 L/kg dm during 80 days of biomethanation period whereas the range of specific methane production in L/kg VS varies from 22.62 to 78.65 L/kg VS. The average specific methane production yield over 80 days period was recorded as 54.058 L/kg dm and 63.12 L/kg VS. (Appendix I1). Similar results of specific methane production in L/kg dm and L/kg VS were found by Felming *et al.*, 2006.

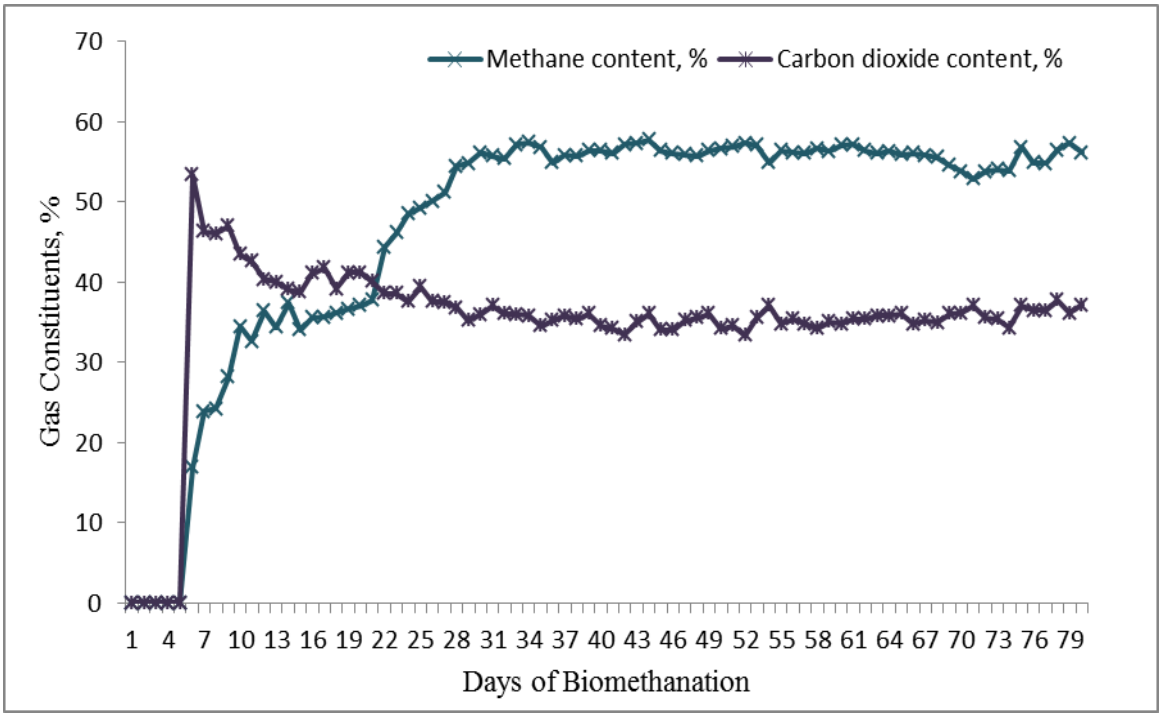


Fig. 4.22 Variation of methane and carbon dioxide percentage in produced biogas

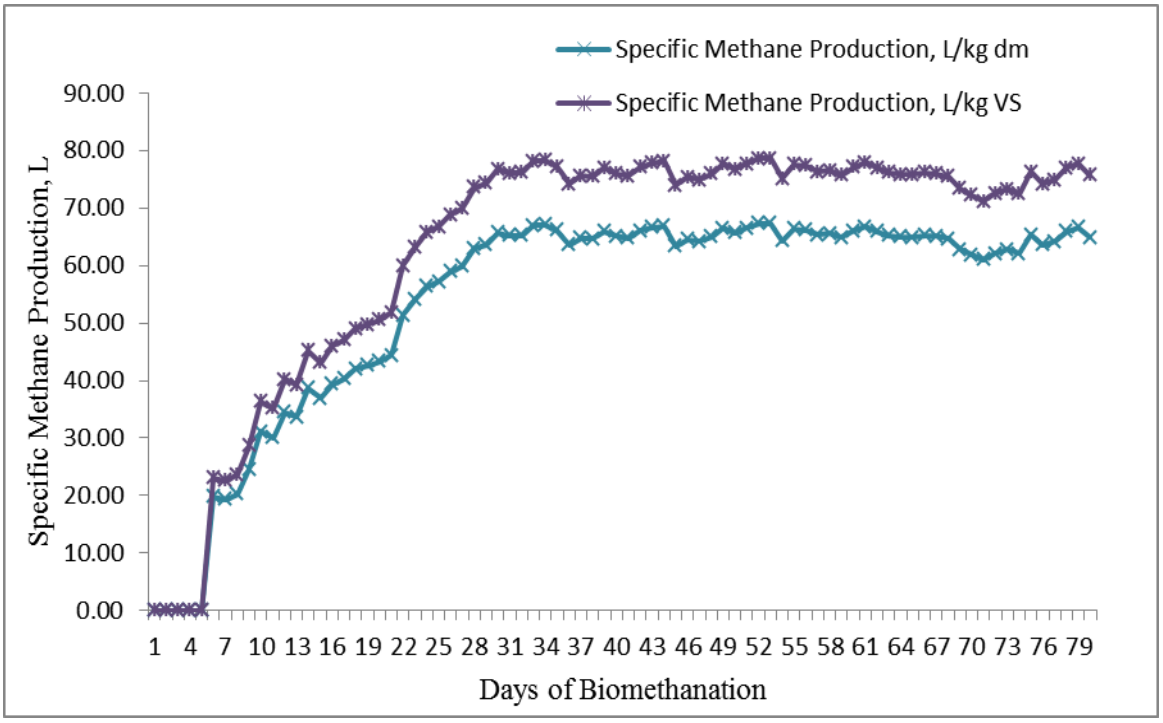


Fig. 4.23 Specific methane production, L/kg of dm and L/kg of V

4.2.5.4 Cumulative Biogas Production:

Fig. 4.24 shows cumulative biogas production in m^3, cumulative biogas production at STP in m^3 and substrate temperature inside digester (°C) over 80 days of biomethanation period from codigestion study of spent button mushroom substrate and cowdung. The cumulative biogas production and cumulative biogas production at STP was found to be 148.185 m^3 and 130.908 m^3 respectively with substrate temperature varying in between 31.5 °C to 37.9 °C. Results obtained are tabulated in Appendix I2.

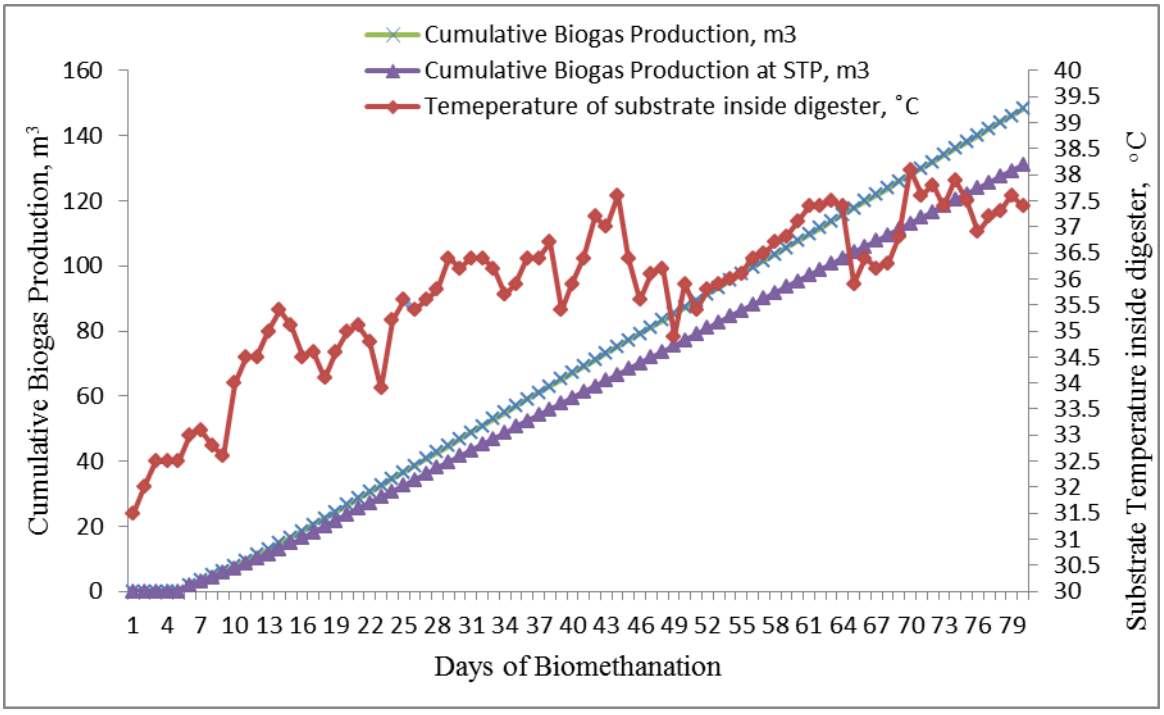


Fig. 4.24 Cumulative biogas production in m^3 from codigestion of cow dung and spent button mushroom substrate

4.2.5.5 Specific Biogas Production Rate:

The variation in specific biogas production yield per unit dm and per unit VS from codigestion of spent button mushroom substrate and cowdung is depicted in Fig. 4.25. The observed range of specific biogas production yield in L/kg dm and L/kg VS with spent button mushroom substrate and cowdung substrate (25% SpBMS+75%CD) within 80 days of biomethanation period was observed in the range of 81.078–117.56

L/kg dm and 94.66–137.27 L/kg VS respectively. The average specific biogas production yield over 80 days period was recorded as 106.25 L/kg dm and 124.06 L/kg VS respectively. Results obtained are tabulated in Appendix I1.

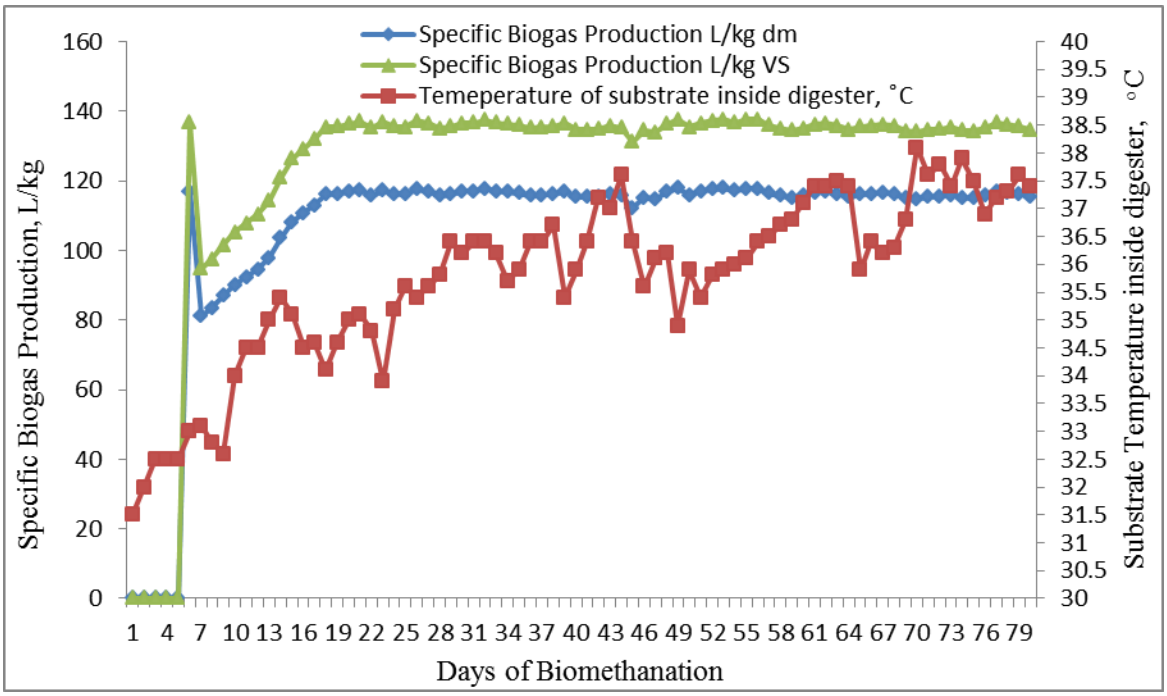


Fig. 4.25 Specific biogas production in L/kg from codigestion of spent button mushroom substrate and cow dung

4.2.5.6 Cumulative Biogas, Methane and Carbon Dioxide Production at STP:

Fig. 4.26 shows cumulative biogas, methane and carbon dioxide production at STP over 80 days of biomethanation period from codigestion study of spent button mushroom substrate and cowdung. The cumulative biogas, methane and carbon dioxide production at STP were found as 130.908 m^3, 66.60 m^3 and 48.549 m^3, respectively with substrate temperature varying in between 31.5 °C to 37.9 °C. Results obtained are tabulated in Appendix I2.

4.2.5.7 Total Volatile Solids Mass Removal Efficiency of the Anaerobic Digestion Process (TVSMRE):

Total volatile solid mass was calculated from the observed amount of methane and carbon dioxide present in the dry biogas volume at STP. Initial volatile solid mass was calculated from observed initial volatile solid percentage of total solids. These

parameters were calculated daily and total volatile solid mass loss and TVS mass removal efficiency were calculated and shown in Fig. 4.27. Results of TVSMRE are tabulated in Appendix I3.

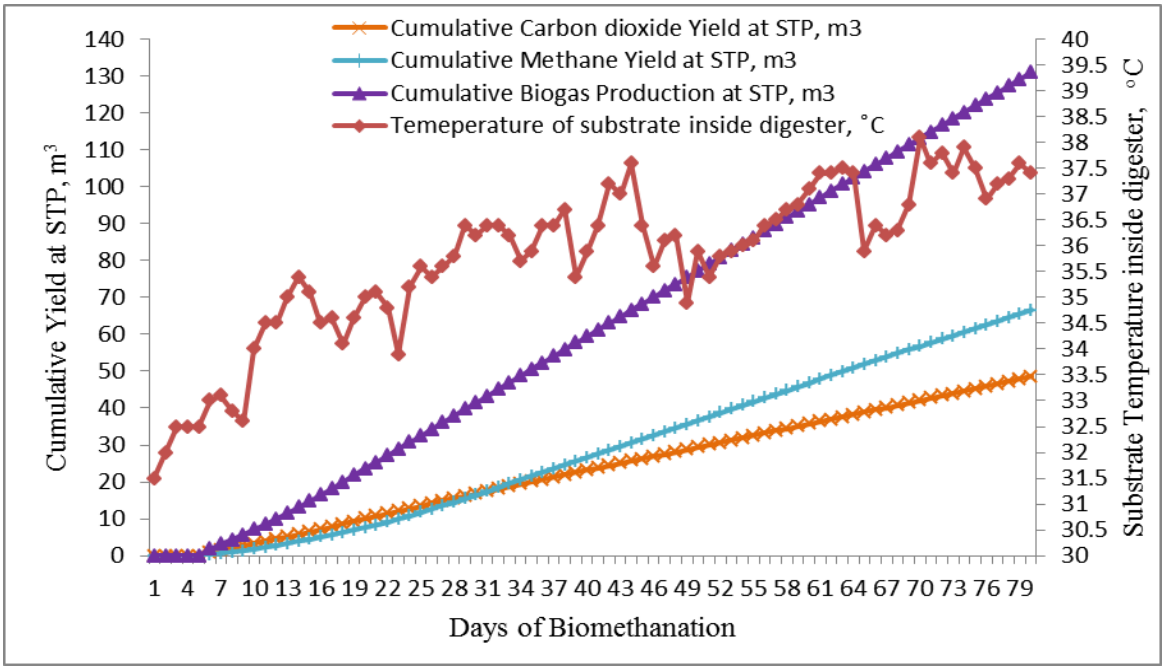


Fig. 4.26 Cumulative biogas, methane and carbon dioxide yield at STP, m^3

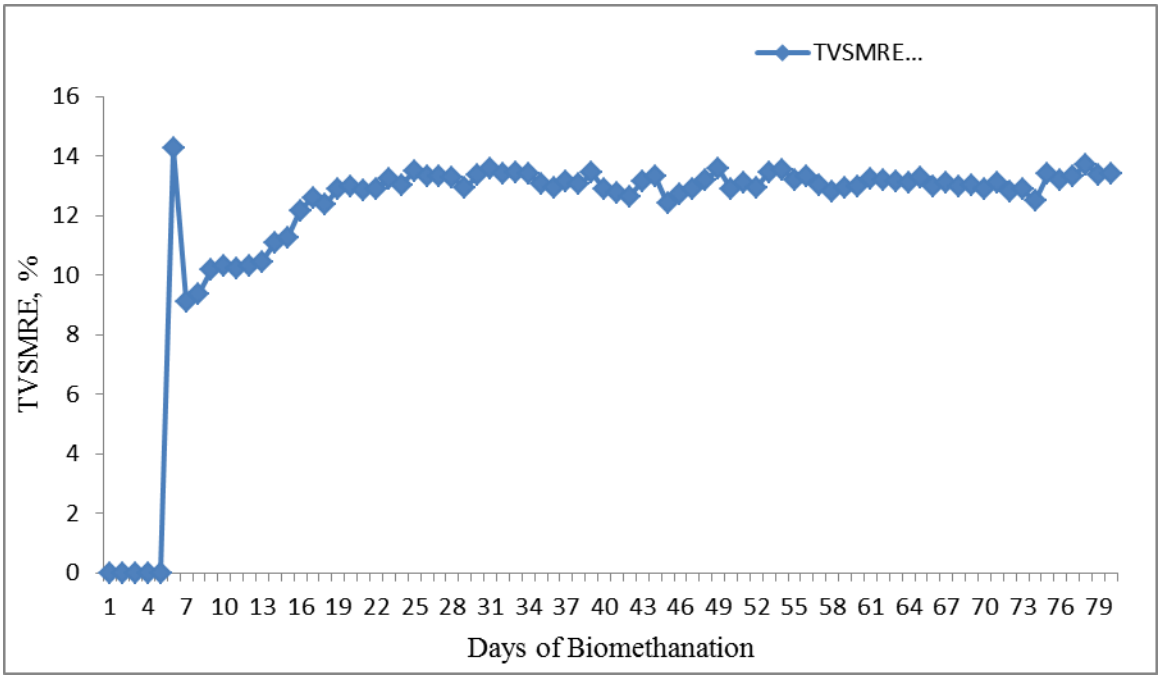


Fig. 4.27 Variation of TVSMRE from codigestion of spent button mushroom substrate and cow dung

Fig. 4.27 shows the variation in total volatile solids mass removal efficiency of the anaerobic digestion process of spent button mushroom substrate and cowdung mixture (1 SpBMS: 3 CD). The total volatile solid mass removal efficiency (TVSMRE) over a period of 80 days of biomethanation time was found to be in the range of 5.271 to 15.778 %. The average total volatile solid mass removal efficiency (TVSMRE) of the substrate over 80 day's biomethanation is 12.813 %. Total volatile solid mass fed per day was about 13.18 kg and daily total volatile solid mass removal on an average was 1.68 kg/day.

4.2.5.8 Analysis of Undigested Substrate and Digested Slurry:

4.2.5.8.1 Total Solid, Volatile Solids, pH and Organic Carbon Content:

Total solids, total volatile solids, pH and organic carbon content of digested slurry were estimated in the laboratory at every 10 days of interval. Table 4.6 shows the various estimated values of these parameters. Daily 50 kg substrate (12.5kg SpBMS+37.5 cowdung) was mixed with 100 kg of water to maintained 10% of total solidity. It was observed from the results that average total solid in the digested slurry after 40 days of biomethanation was 8.43 %. Similarly, the average volatile solid of digested slurry after 40 days was observed as 70.46 % of total solids. Average 15.65 % reduction in total solids and 17.59 % reduction in volatile solids were observed after 40 days of biomethanation.

Portable digital pH meter was used to measure the pH of the inlet charge and digested slurry. It was observed that the average pH of inlet charge was 6.68 and that of outlet slurry was 7.14.

In the same manner organic carbon content was also calculated at interval of 10 days interval. Average organic carbon content in undigested substrate was 38.56 %. It was observed from the results that average organic carbon content in the digested slurry after 40 days of biomethanation was 32.42 %. Average 16.37 % reduction in the organic carbon content was observed.

Table 4.6 Total solids, volatile solids, pH and organic carbon content before and after digestion

Day of Observation	TS (%)			VS (%)			pH		Organic Carbon (%)		
	I	O	R	I	O	R	I	O	I	O	R
1	10	9.997	0.03	85.64	85.6	0.05	6.8	7.0	38.00	37.75	0.66
10	10	9.224	7.76	85.71	78	9.00	6.6	7.2	38.20	34.10	10.73
20	10	8.813	11.87	86.12	74.15	13.90	6.7	7.1	38.42	34.00	11.50
30	10	8.608	13.92	84.97	71.2	16.21	6.6	7.2	38.64	33.50	13.30
40	10	8.458	15.42	86.10	71.1	17.42	6.7	7.1	38.68	32.50	15.98
50	10	8.438	15.62	85.12	70.21	17.52	6.7	7.2	38.60	32.30	16.32
60	10	8.435	15.65	85.40	70.4	17.56	6.6	7.1	39.20	32.80	16.33
70	10	8.422	15.78	85.44	70.3	17.72	6.7	7.2	38.45	32.10	16.51
80	10	8.420	15.80	85.47	70.3	17.74	6.7	7.2	38.90	32.40	16.71

Note: I = Inlet, O = Outlet, R= Reduction.

4.2.5.8.2 Nutrient Content:

The inlet charge and digested slurry were analyzed to determine the changes in the nutrients like total nitrogen, phosphate and potash. The samples were collected and analyzed at an interval of 10 days and results obtained are shown in the Table 4.7. Initially average 1.35 % of total nitrogen was found in the feedstock before digestion whereas 1.50 % of total nitrogen was found after digestion of sample. It was observed that on an average 0.65 % phosphate was found in inlet charge while it was 0.795 % in the digested slurry of the plant throughout 80 days of biomethanation. Average 14.72 % and 30.5 % increase in the total nitrogen and phosphate content was observed respectively. Potash content in the inlet charge was 0.87 % while it was 0.964 % in the outlet slurry throughout 80 days of biomethanation. After 40 days of biomethanation average 13.76 % increase in potash content was observed. After 40 days of biomethanation period average N, P, & K were increased from 1.372%, 0.654% and

0.878% to 1.574%, 0.852% and 0.996% respectively. The increase in percentage of N, P, and K was due to removal of carbohydrates in the form of methane and carbon dioxide during the process of biomethanation.

Table 4.7 Nutrient content of slurry before and after digestion

Day of Observation	N , %			P, %			K, %		
	BD	AD	Increase	BD	AD	Increase	BD	AD	Increase
1	1.31	1.31	0	0.64	0.64	0	0.86	0.86	0
10	1.34	1.41	5.22	0.63	0.68	7.93	0.87	0.91	4.59
20	1.35	1.47	8.88	0.67	0.78	16.41	0.85	0.93	9.41
30	1.32	1.52	13.16	0.65	0.80	23.07	0.89	1	12.35
40	1.37	1.56	13.86	0.66	0.85	28.78	0.85	0.96	12.94
50	1.4	1.60	14.28	0.67	0.85	29.85	0.87	0.97	13.21
60	1.37	1.57	14.59	0.66	0.86	30.30	0.89	1.01	13.48
70	1.37	1.58	15.32	0.65	0.85	30.76	0.9	1.03	14.44
80	1.35	1.56	15.55	0.64	0.85	32.81	0.88	1.01	14.77

Note: BD = Before digestion, AD = After digestion.

4.3 Performance Evaluation of Developed Hybrid Dryer:

Performance evaluation of the developed dryer was carried out under no load and full load conditions. The dryer was tested initially under no load condition and later on it was tested for drying of button and oyster mushroom. The results obtained are discussed in the following subsections.

4.3.1 No Load Test:

No load test was carried out to analyze the performance of dryer. The performance of dryer was analyzed continuously for 10 hours and the results obtained from the study were tabulated in Appendix B1.

Fig. 4.28 shows variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during no load testing of dryer. From Fig. 4.29 it was observed that 141 L of biogas was consumed in morning and 139 L of biogas was consumed in the evening to maintain required average 50 °C temperature inside dryer along with average available solar radiations (W/m^2) of 549.09 W/m^2. 280 L of biogas consumption along with availability of 549.09 W/m^2 solar radiations were utilized during no load testing.

Fig. 4.30 shows variation of temperature (°C) and biogas consumption (L) with respect to time (h) during no load testing. Average 53 °C, 51.90 °C, 51.05 °C, and 49.29 °C temperature was maintained throughout drying period in tray 1, tray2, tray3, and tray 4 respectively. Tray 1 was bottom tray of the dryer, tray2 was 2^{nd} tray from the bottom; tray 3 was 3^{rd} tray from bottom whereas tray 4 was top tray of dryer. Average 43.43 °C temperature was observed at the outlet of chimney throughout drying time. The temperature data (°C) with drying time (h), solar radiations availability (W/m^2) and biogas consumption (L) was tabulated in Appendix B1.

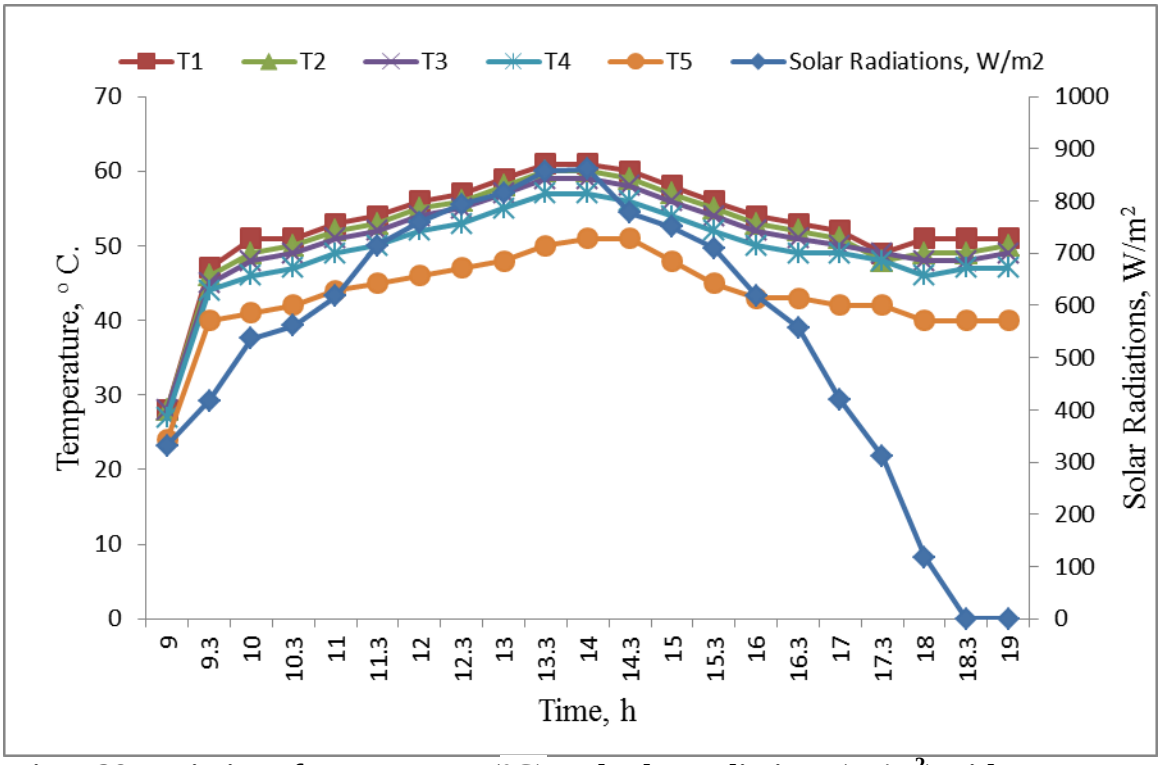


Fig. 4.28 Variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during no load test.

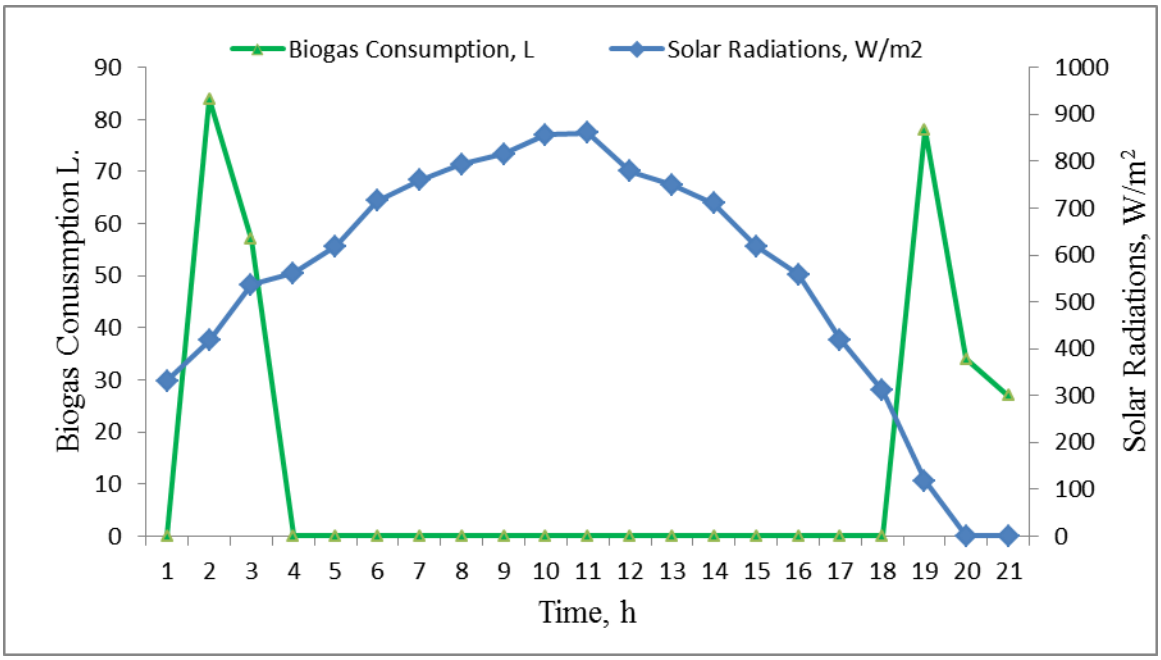


Fig. 4.29 Biogas consumption (L) and solar radiation (W/m^2) received with respect to time (h) during no load test

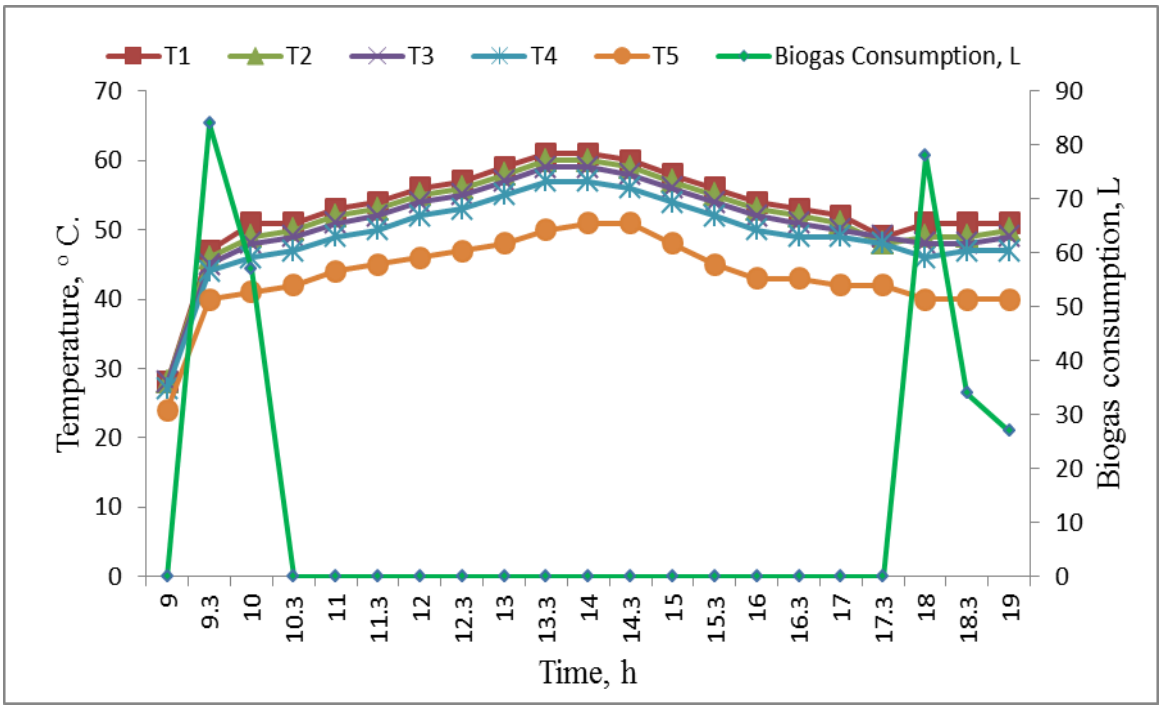


Fig. 4.30 Variation of temperature (°C) and biogas consumption (L) with respect to time (h) and during no load test.

4.3.2 Full Load Test:

Full load performance of system was evaluated by loading dryer with button mushroom and oyster mushroom product separately. Fresh products were procured from plant pathology department of Rajasthan College of Agriculture. After some pre cleaning, mushrooms were pretreated in mixture of 0.5% citric acid and 0.5% ascorbic acid to increase its storage life and quality and sliced in to appropriate size before drying. Thereafter dryer was loaded with trays containing fresh button mushroom and oyster mushroom, weighing 4 kg as shown in Fig. 4.31. Button mushroom and oyster mushroom were dried separately in the developed dryer and its drying performance were evaluated.

a) Dryer loaded with button mushroom **b) Dryer loaded with oyster mushroom**

Fig. 4.31 Dryer loaded with button and oyster mushroom

4.3.2.1 Drying of Button Mushroom (*Agaricus bisporus*):

Full load performance of system was evaluated by loading dryer after pretreatment and slicing with 4 kg of button mushroom as shown in Fig. 4.31.

It has been observed that moisture content of button mushroom was reduced with time. The button mushroom was dried from moisture content of 91% (wb) to 8.26 % (wb) in 11 hours with average solar radiations availability of 560 W/m^2 and biogas consumption of 700 L. Average 50.87 °C, 50.09 °C, 49.22 °C, and 48.26 °C temperature was maintained throughout drying period in tray 1, tray2, tray3, and tray 4 respectively. Tray 1 was bottom tray of the dryer, tray2 was 2^{nd} tray from the bottom; tray 3 was 3^{rd}

tray from bottom whereas tray 4 was top tray of dryer. Average 43.13 °C temperature was observed at the outlet of chimney throughout drying time. The temperature data (°C) with drying time (h), solar radiations availability (W/m^2) and biogas consumption (L) was depicted in Appendix B2. Fig. 4.32 shows variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during drying of button mushroom. From Fig. 4.32 it was clear that availability of solar radiation was low in morning and evening and was peak in afternoon.

From Fig. 4.33 it was observed that 165 L of biogas was consumed in morning when availability of solar radiations (W/m^2) was insufficient to maintain average 50 °C inside dryer. It was observed that after 4pm availability of solar radiations (W/m^2) was lower which was insufficient to maintain average 50°C temperature therefore 535 L of biogas was consumed during this drying period to maintain required temperature inside dryer.

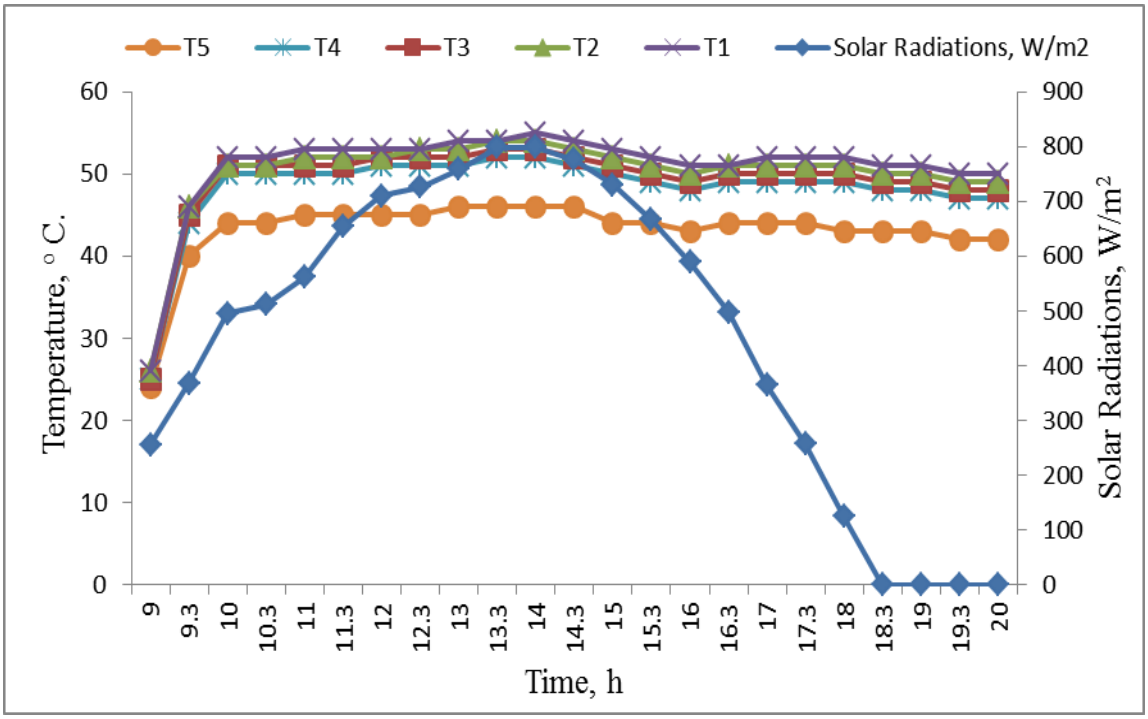


Fig. 4.32 Variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during drying of button mushroom.

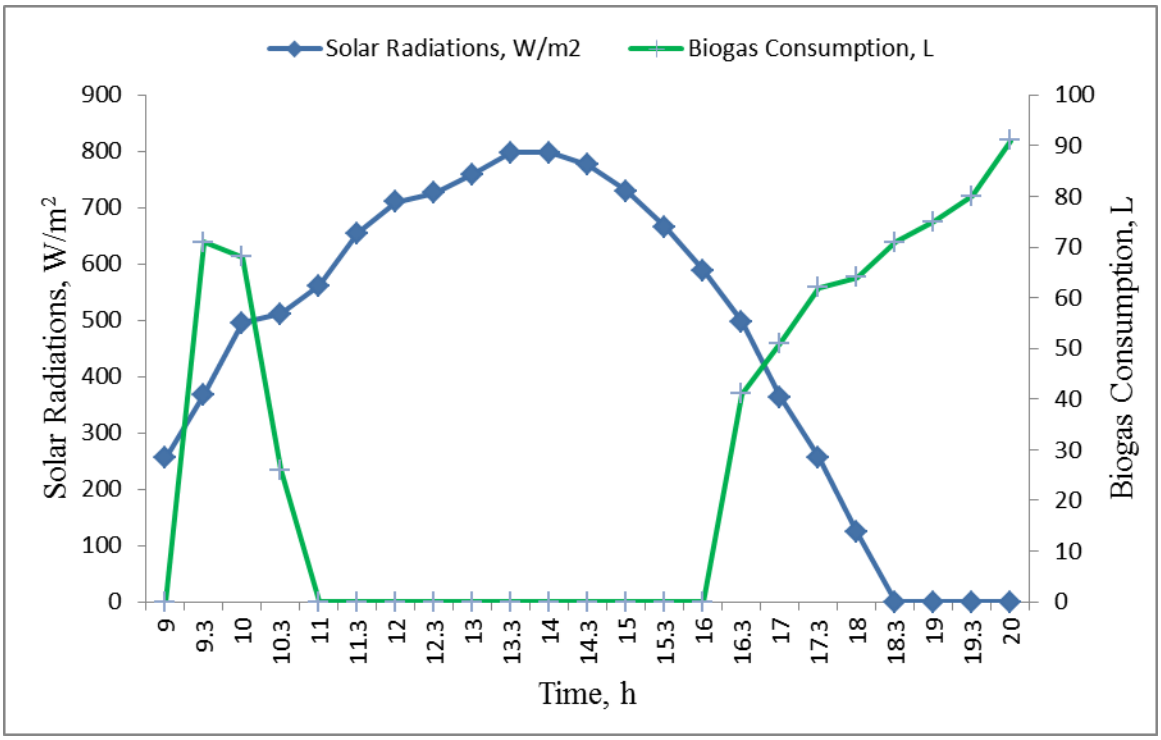


Fig. 4.33 Biogas consumption (L) and availability of solar radiations (W/m^2) with respect to time (h)

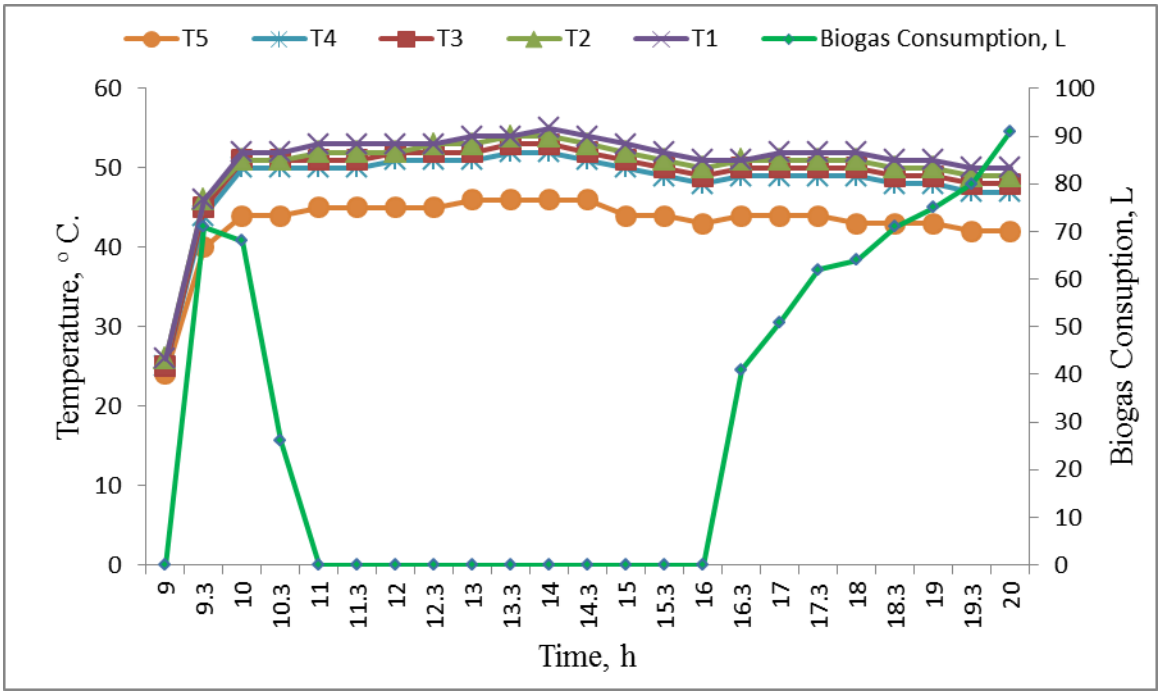


Fig. 4.34 Variation of temperature (°C) and biogas consumption (L) with respect to time (h) during drying of button mushroom.

Fig. 4.34 shows variation of temperature (°C) and biogas consumption (L) with respect to time (h) during drying of button mushroom. From Fig. 4.34 it was cleared that initially temperature inside dryer was low therefore biogas was consumed along with solar radiations to boost temperature up to 50 °C from initial low temperature. After 10am, average 50°C temperature was maintained inside dryer throughout drying period. Dried button mushroom with moisture content of 8.26% (wb) was shown in Fig 4.35.

Fig. 4.36 reveals the moisture removal rate from button mushroom. The drying behavior follows the typical drying curves for the button mushroom. Button mushroom was dried from moisture content of 91% (wb) to 8.26 % (wb) within 11 hours. Initially moisture content was decreased drastically with high drying rate up to initial 4 hours of drying period later on drying was took place slowly with nearly constant drying rate. From Fig. 4.36 it was also cleared that moisture content of button mushroom in the tray1 (bottom tray of dryer) was decreased with faster drying rate as compare to tray2 (2^{nd} tray from bottom). Likewise moisture content of the product in tray 2 was decreasing in faster rate than product in tray 3. Product in tray 4 was drying at slower rate as compare to product in other tray1, tray 2, and tray 3.

Fig. 4.35 Dried button mushroom (*Agaricus bisporus*)

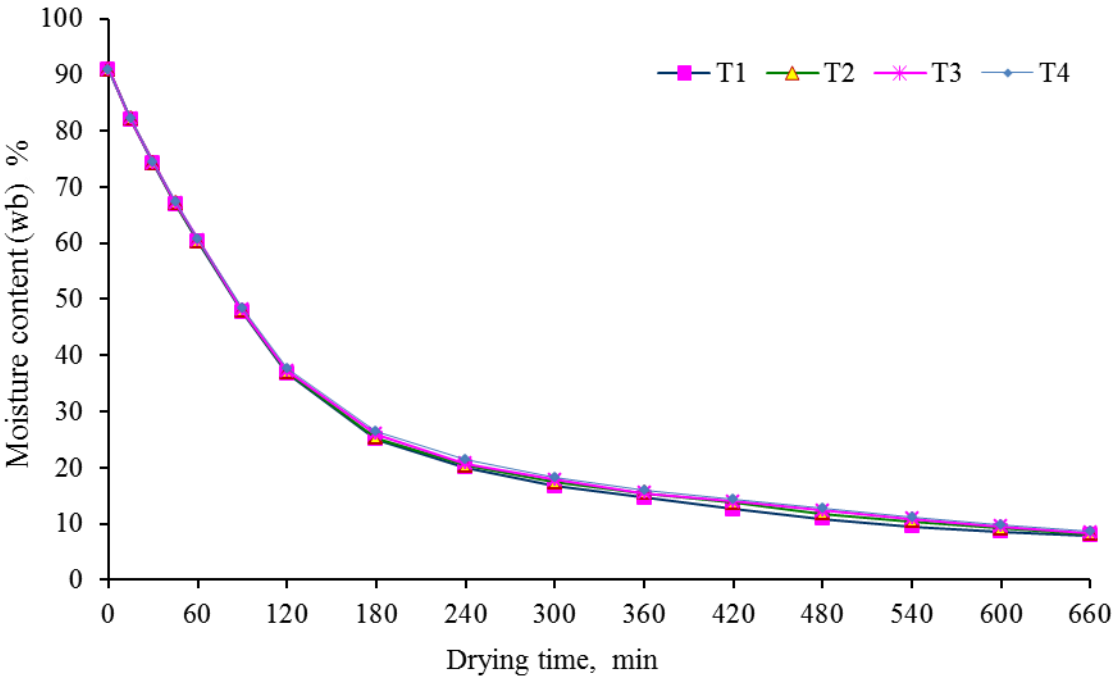


Fig. 4.36 Variation of moisture content of button mushroom with drying time

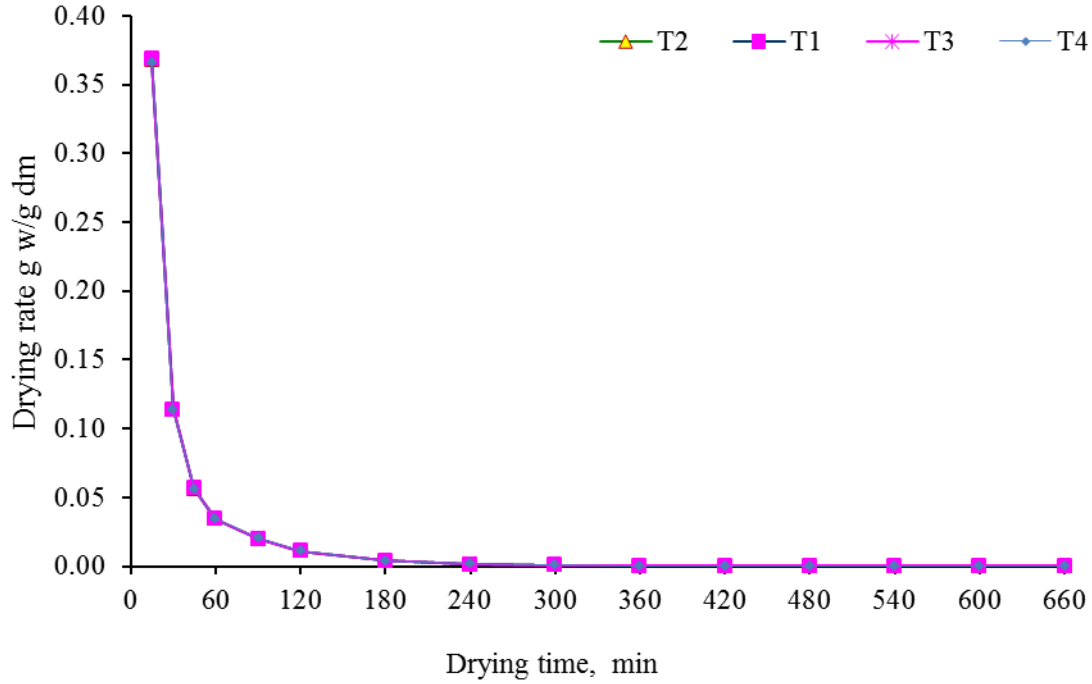


Fig. 4.37 Drying rate of button mushroom with drying time

From Fig. 4.37 it was found that drying rate during process varies from 0.368 to 0.000139 g of water evaporated/g of dry matter for tray1, 0.368 to 0.000213 g of water evaporated/g of dry matter for tray 2 whereas for tray 3 it was 0.367 to 0.000231 g of water/g of dm and for tray 4 it was 0.366 to 0.000231 g of water/g of dm. It was observed from Fig. 4.37 that during initial three hours of operation graph remains steeper that means during initial three hours moisture removal rate was higher. After initial three hours of drying the drying rate curve was near to perfect horizontal line, it reveals that drying rate decreases rapidly and remains nearly constant for remaining drying hours.

Fig. 4.38 shows variation of drying rate with respect to moisture content in percentage (wb). It was cleared from the vertical line in Fig. 4.38 that initially moisture content was decreasing with higher drying rate as drying proceeds. Initially drying rate was high and it was decreases rapidly with reduction of moisture content. Moisture content in tray 1 was reduced from 91 % (wb) to 7.93% (wb) whereas drying rate was reduced from 0.368 to 0.000139 g of water evaporated/g of dry matter. Moisture content in tray 2 was reduced from 91 % (wb) to 8.07% (wb) whereas drying rate was reduced from 0.368 to 0.000213 g of water evaporated/g of dry matter. Moisture content in tray 3 was reduced from 91 % (wb) to 8.40% (wb) whereas drying rate was reduced from 0.367 to 0.000231g of water evaporated/g of dry matter. Moisture content in tray 4 was reduced from 91 % (wb) to 8.63% (wb) whereas drying rate was reduced from 0.366 to 0.000231 g of water evaporated/g of dry matter. Drying data of button mushroom obtained are tabulated in Appendix C1, C2, C3 and C4.

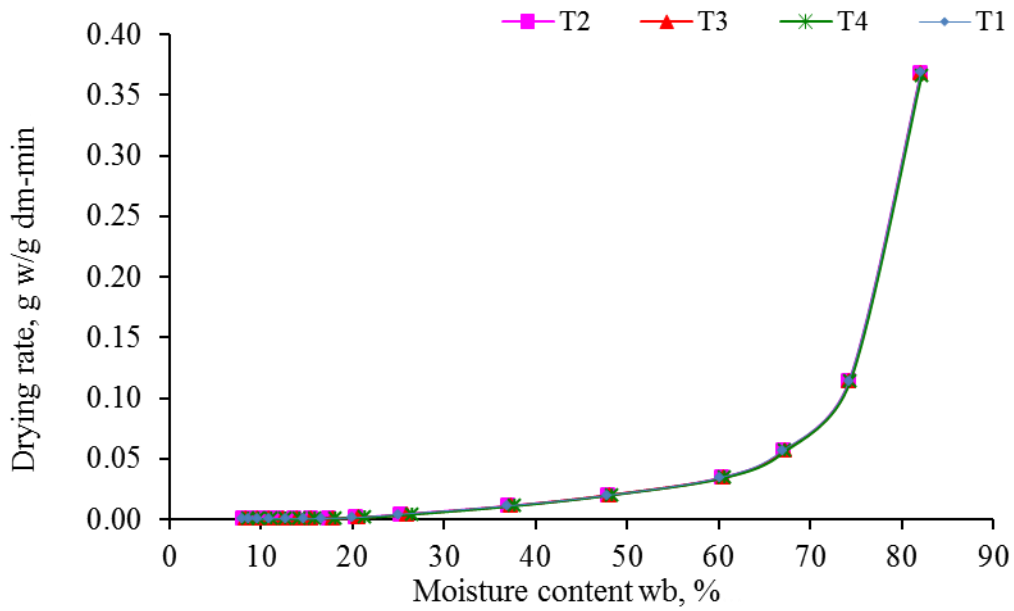


Fig. 4.38 Drying rate of button mushroom with moisture content (wb%)

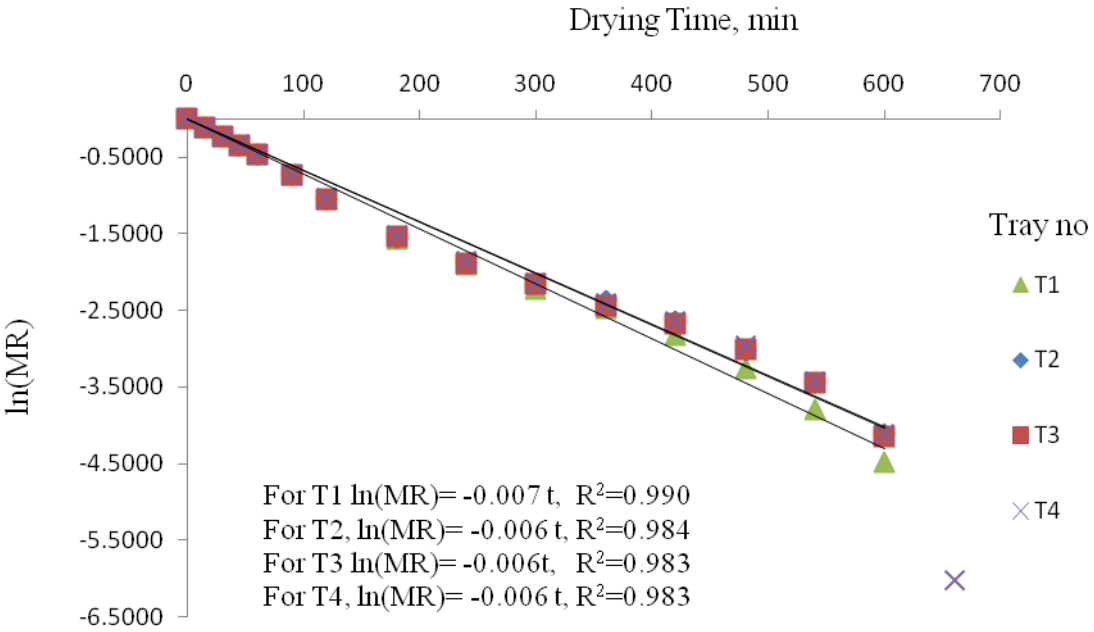


Fig. 4.39 Variation in ln (MR) with drying time (t) at different tray during drying of button mushroom

Drying data of button mushroom drying was also analyzed based on logarithmic equation of moisture ratio as shown below.

MR= exp (-kt), where k is drying constant and t is time.

ln(MR)= -kt

The data was plotted on log graph with log (MR) on Y-axis and time t on X-axis as shown in Fig. 4.39 whereas data tabulated in Appendix M. Linear line was fitted and the value of k was found. The variation in ln (MR) with drying time for each tray was found to be linear with inverse slope as it has been presented in Fig. 4.39. At all levels straights lines were fitted satisfactory with coefficient of determination R^2> 0.98 was observed for drying of button oyster mushroom.

4.3.2.2 Drying of Oyster Mushroom (*Pleurotus ostreatus*):

Full load performance of system was carried out by loading dryer with cleaned and pretreated 4 kg of oyster mushroom as shown in Fig. 4.31.

It has been observed that moisture content of oyster mushroom was reduced with time. The oyster mushroom was dried from moisture content of 90% (wb) to 8.41 % (wb) in 10 hours with average solar radiations availability of 578.37 W/m^2 and biogas consumption of 600 L. Average 51 °C, 50.14 °C, 49.29 °C, and 48.76 °C temperature was maintained throughout drying period in tray 1, tray2, tray3, and tray 4 respectively. Tray 1 was bottom tray of the dryer, tray2 was 2nd tray from the bottom; tray 3 was 3rd tray from bottom whereas tray 4 was top tray of dryer. Average 42.14 °C temperature was observed at the outlet of chimney throughout drying time. The temperature data (°C) with drying time (h), solar radiations availability (W/m^2) and biogas consumption (L) was depicted in Appendix B3. Fig. 4.40 shows variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during drying of oyster mushroom. From Fig 4.39 it was clear that availability of solar radiation was low in morning and evening and was peak in afternoon.

From Fig. 4.41 it was observed that 192 L of biogas was consumed in morning when availability of solar radiations (W/m^2) was insufficient to maintain average 50 °C inside dryer. It was observed that after 4 pm availability of solar radiations (W/m^2) was lower which was insufficient to maintain average 50°C temperature therefore 408 L of biogas was consumed during this drying period to maintain required temperature inside dryer.

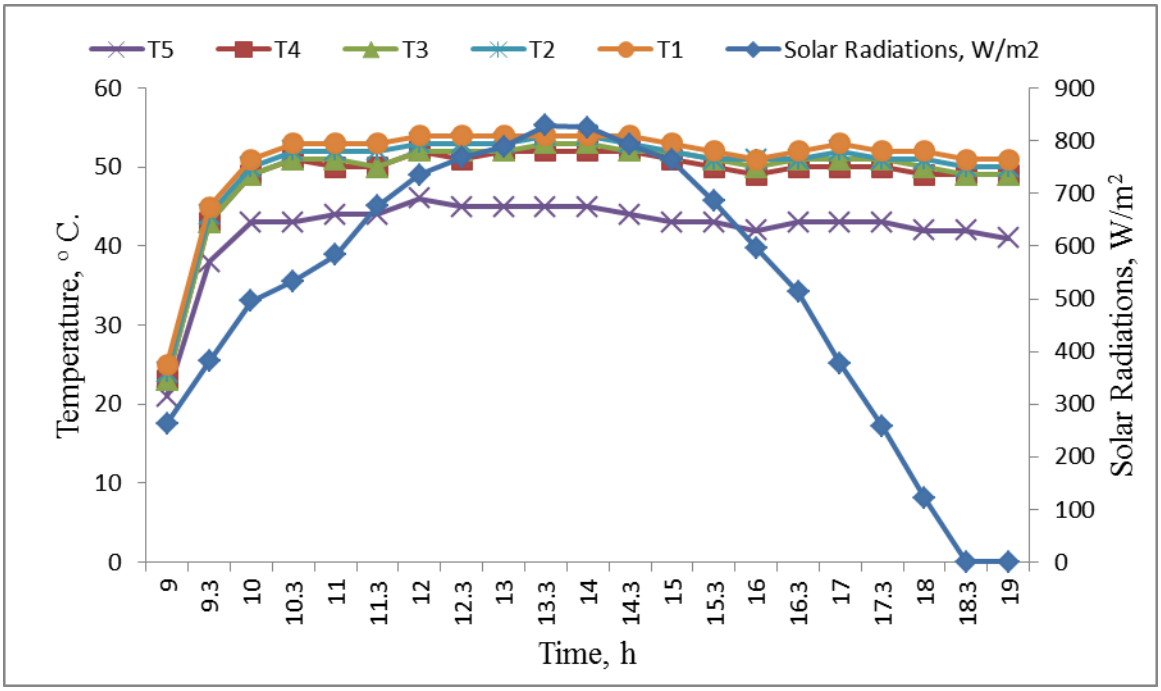


Fig. 4.40 Variation of temperature (°C) and solar radiations (W/m^2) with respect to time (h) during drying of oyster mushroom.

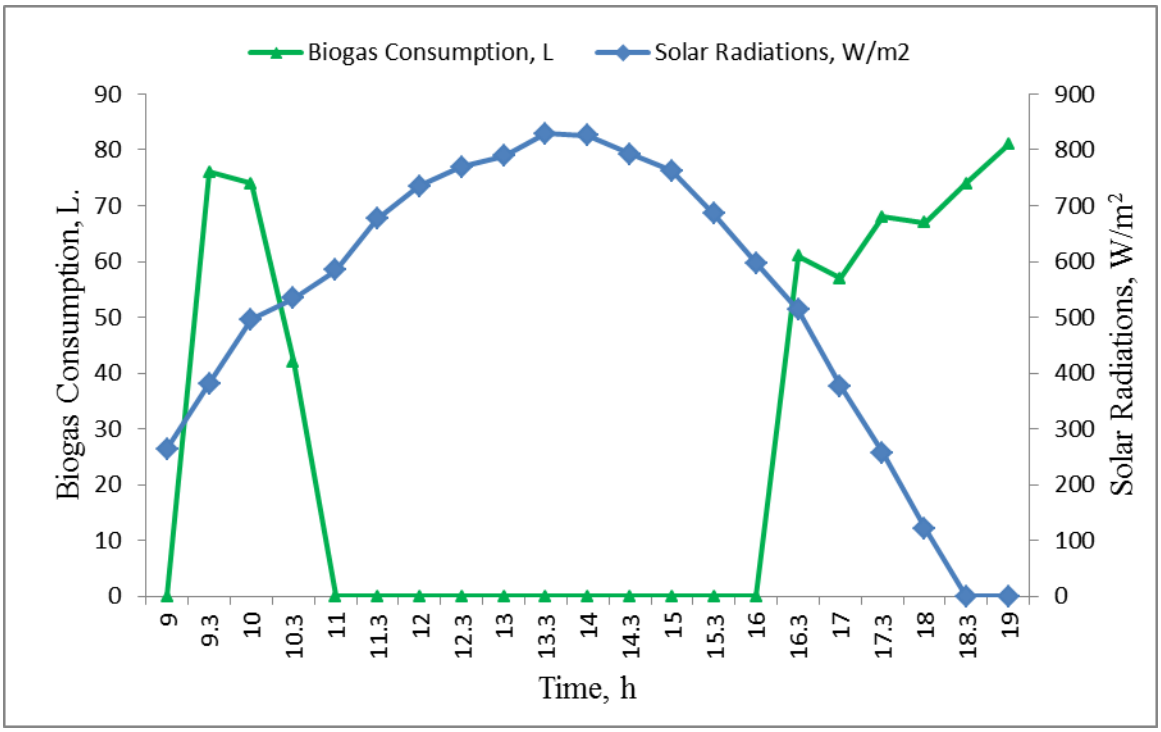


Fig. 4.41 Biogas consumption (L) and solar radiation (W/m^2) received with respect to time (h) during oyster mushroom drying.

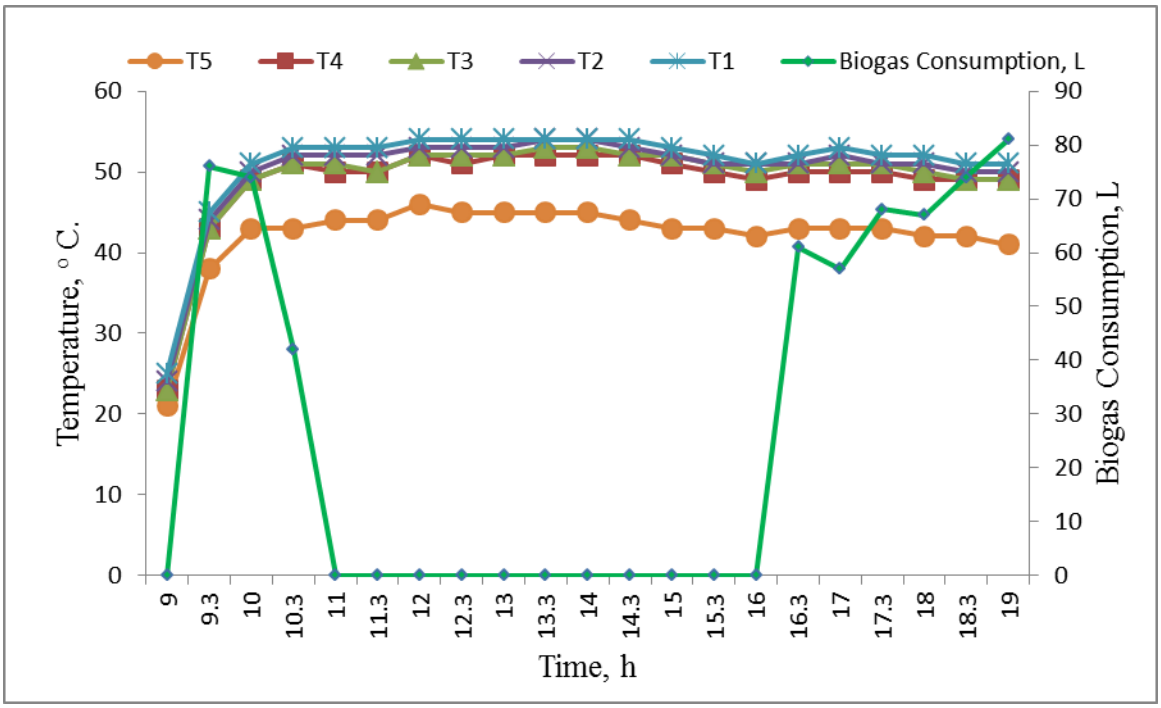


Fig. 4.42 Variation of temperature (°C) and biogas consumption (L) with respect to time (h) and during drying of oyster mushroom.

Fig. 4.42 shows variation of temperature (°C) and biogas consumption (L) with respect to time (h) during drying of oyster mushroom. From Fig. 4.42 it was cleared that initially temperature inside dryer was low therefore biogas was consumed along with solar radiations to boost temperature up to 50 °C from initial low temperature. After 10am, average 50°C temperature was maintained inside dryer throughout drying period. Dried oyster mushroom with moisture content of 8.41% (wb) was shown in Fig 4.43.

Fig. 4.44 reveals the moisture removal rate from oyster mushroom. It has been observed that moisture content of oyster mushroom reduced with time. The oyster mushroom was dried from moisture content of 90% (wb) to 8.41 % (wb) in 10 hours. The drying behavior follows the typical drying curves for the oyster mushroom as shown in Fig. 4.44.

Fig. 4.43 Dried oyster mushroom (*Pleurotus Ostreatus*)

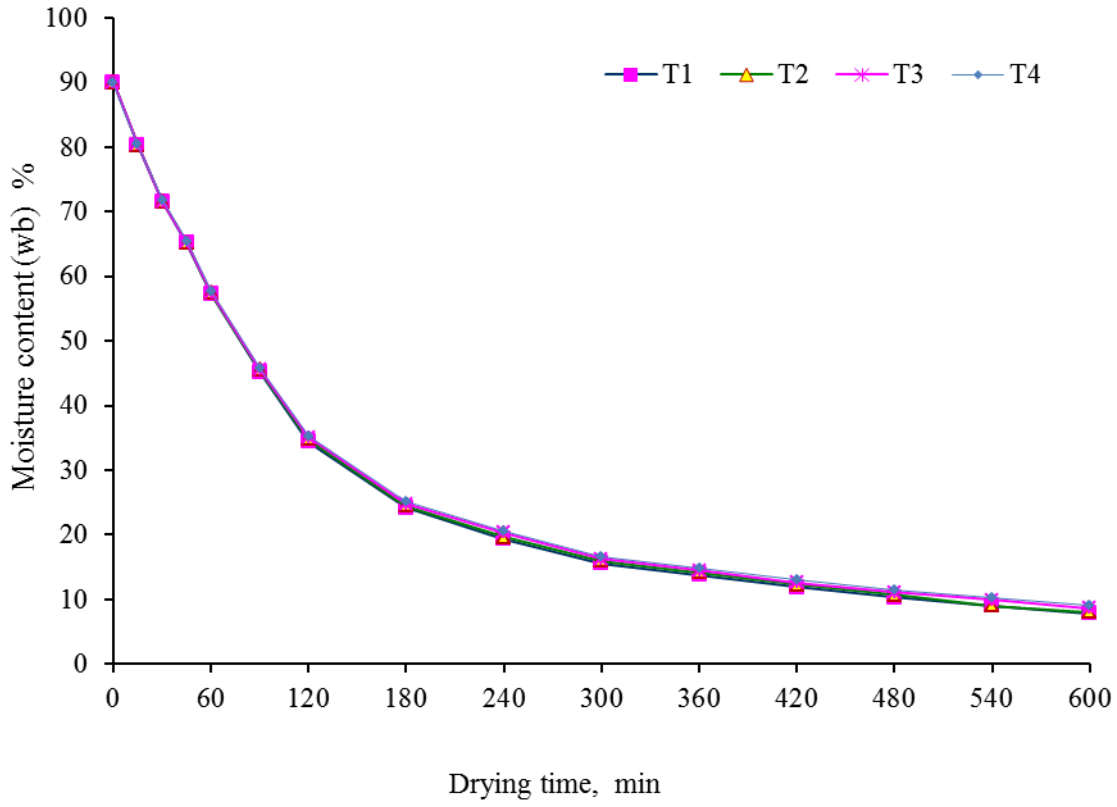


Fig. 4.44 Variation of moisture content of oyster mushroom with drying time

The drying rate for oyster mushroom was found using difference in moisture content in given time interval and expressed as g of water evaporated per g dry matter per hour. From Fig. 4.45 it was found that drying rate during process varies from 0.328 to 0.000250 g of water evaporated/g of dry matter for tray1 whereas for tray 2 & tray 3 it was 0.327 to 0.000208 g of water/g of dm and 0.327 to 0.000250 g of water/g of dm for tray 4 it was 0.326 to 0.000250 g of water/g of dm. The Fig. 4.45 also shows that the during initial three hours of operation graph remains steeper, that means during initial three hours moisture removal rate was higher. After some initial hours graph shows the near to perfect horizontal line, it reveals that drying rate decreases rapidly and remains nearly constant for remaining drying hours. After four hours of drying equilibrium condition reached and after that it was observed that very less amount of water was removed.

Fig. 4.46 shows variation of drying rate with respect to moisture content in percentage (wb). It was cleared from the vertical line in Fig. 4.46 that initially moisture

content was decreasing with higher drying rate as drying proceeds. Initially drying rate was high and it was decreases rapidly with reduction of moisture content. Moisture content in tray 1 was reduced from 90 % (wb) to 7.83% (wb) whereas drying rate was reduced from 0.328 to 0.000250 g of water evaporated/g of dry matter. Moisture content in tray 2 was reduced from 90 % (wb) to 8.05% (wb) whereas drying rate was reduced from 0.367 to 0.000208 g of water evaporated/g of dry matter. Moisture content in tray 3 was reduced from 90 % (wb) to 8.68% (wb) whereas drying rate was reduced from 0.327 to 0.000250g of water evaporated/g of dry matter. Moisture content in tray 4 was reduced from 90 % (wb) to 9.09% (wb) whereas drying rate was reduced from 0.326 to 0.000250 g of water evaporated/g of dry matter. Drying data of oyster mushroom obtained are tabulated in Appendix C5, C6, C7 and C8.

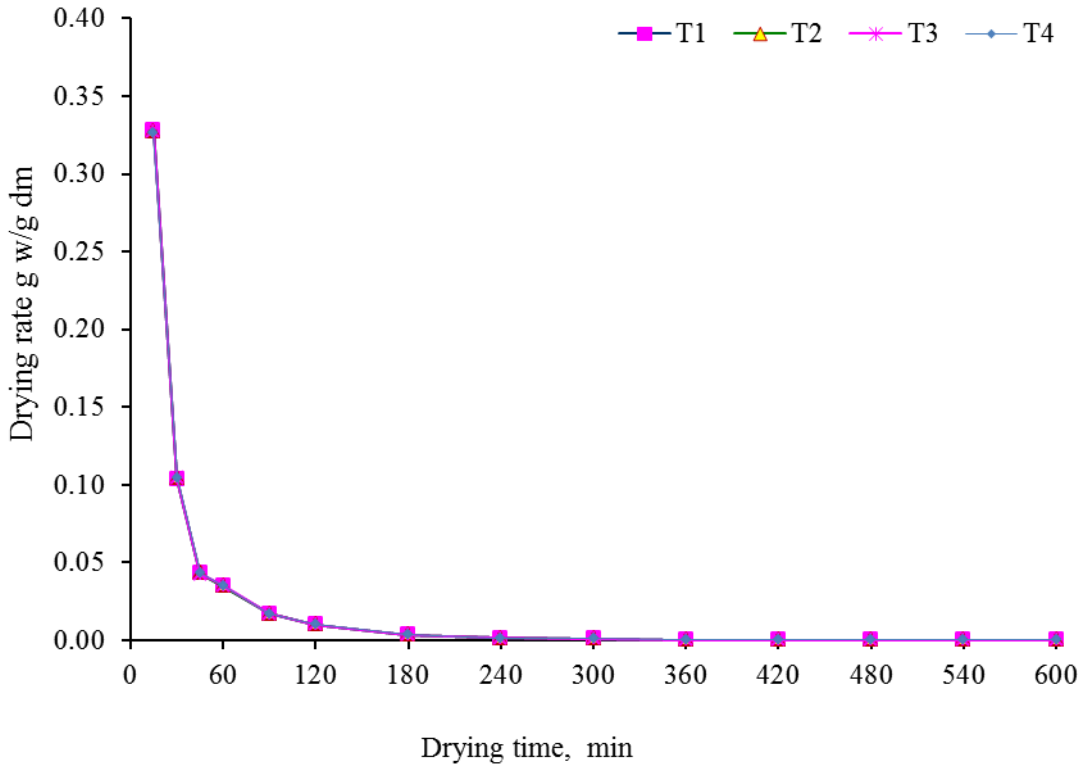


Fig. 4.45 Drying rate of oyster mushroom with drying time

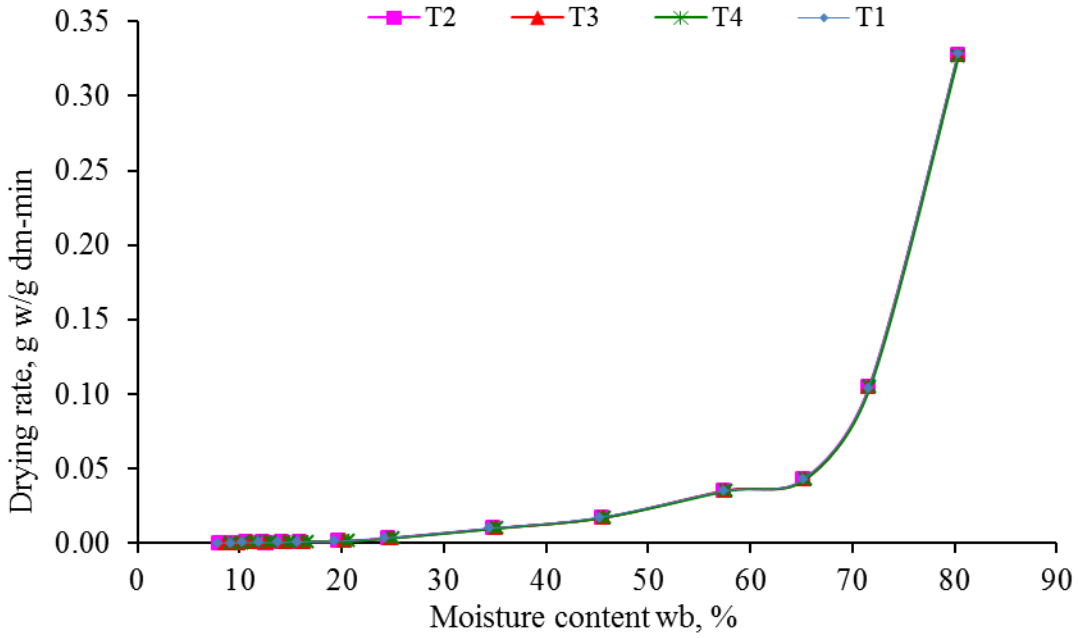


Fig. 4.46 Drying rate of oyster mushroom with moisture content (wb%)

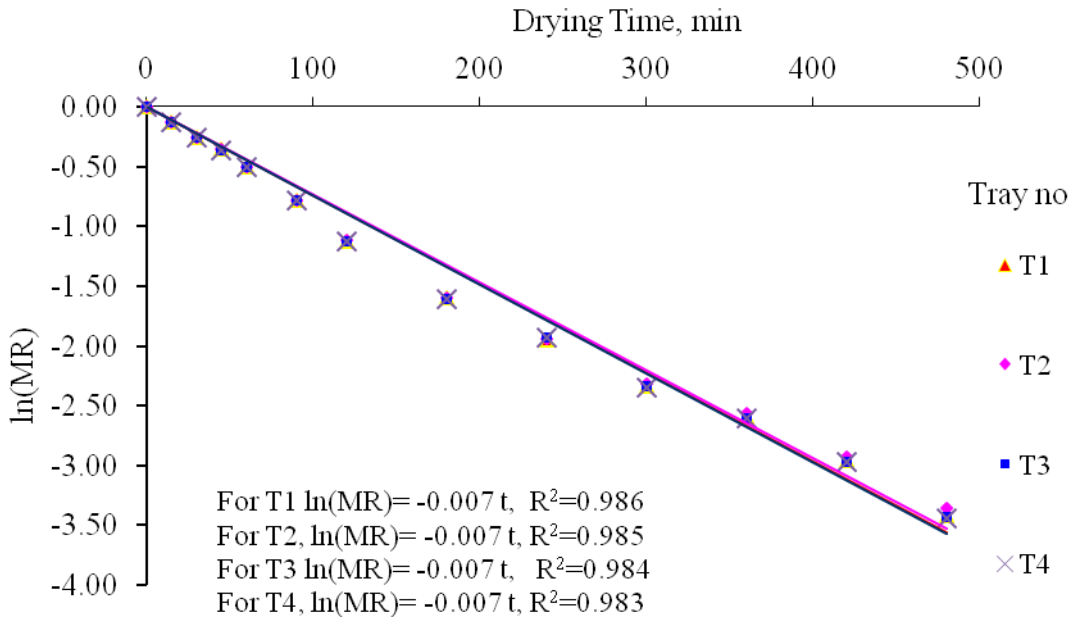


Fig. 4.47 Variation in ln (MR) with drying time (t) at different tray during drying of oyster mushroom

Oyster mushroom drying data was also analyzed based on logarithmic equation of moisture ratio (Appendix M). The data was plotted on log graph with log (MR) on Y-axis and time t on X-axis as shown in Fig. 4.47. Linear line was fitted and the value of k was found. The variation in ln (MR) with drying time for each tray was found linear with inverse slope as presented in Fig. 4.47. At all levels straights lines were fitted satisfactory with coefficient of determination $R^2 > 0.98$ was observed for drying of oyster mushroom.

4.4 Physiochemical Characteristics of the Dried Product:

4.4.1 Rehydration Characteristics:

The reconstitution qualities of dried button and oyster mushroom samples (optimized conditions) were determined by conducting re-hydration tests as described in section 3.1.5.2. The dried samples were immersed in distilled water solution and heated constantly using heat bath at 30 °C and the mass of the products after every 10 minutes intervals up to one hour were measured. The data pertaining to moisture content of the sample during the rehydration tests are reported in Table 4.8. The dehydrated sample absorbed water during rehydration and became soft. Three replications of each sample were rehydrated to avoid any experimental error and average values are reported in Table 4.8.

The initial moisture content of the button mushroom and oyster mushroom sample was 9.14% (db) and 8.97 % (db). From Table 4.8 it was cleared that moisture content of the button mushroom and oyster mushroom was increased to 198.2% (db) and 177.2% (db) respectively during rehydration test when immersed in water for 1 h. Rehydrated button mushroom sample and oyster mushroom sample was shown in Fig. 4.48 & Fig. 4.49 respectively.

The rehydration ratio and coefficient of rehydration of dried button and oyster mushroom samples were determined using equations 3.19 and 3.20. The rehydration ratio of the button mushroom and oyster mushroom was increased to 2.73 and 2.54 respectively as shown in Fig 4.48 and Table 4.9. Coefficient of rehydration after 1 h of rehydration test for button and oyster mushroom was found as 0.26 and 0.28 respectively as shown in Table 4.9 and Fig 4.49. Similar results of rehydration ratio of the pre-treated hot air dried mushrooms were found by Mudahar and Bains (1982).

Table 4.8 Moisture content of product with respect to time (min) during rehydration

Sr. No	Time, min	Moisture content of product, db %		Moisture content of product, wb %	
		Button Mushroom	Oyster Mushroom	Button Mushroom	Oyster Mushroom
1	0	9.14	8.97	8.37	8.23
2	10	121.20	116.20	54.79	53.74
3	20	143.23	134.29	58.88	57.31
4	30	163.27	149.34	62.01	59.89
5	40	179.58	162.70	64.23	61.93
6	50	191.70	172.80	65.71	63.34
7	60	198.20	177.20	66.46	63.92

Table 4.9 Rehydration ratio and coefficient of rehydration of button and oyster mushroom

Sr. No	Time ,min	Drained weight of rehydrated sample, g		Rehydration Ratio		Coefficient of Rehydration	
		Button Mushroom	Oyster Mushroom	Button Mushroom	Oyster Mushroom	Button Mushroom	Oyster Mushroom
1	0	5.00	5.00	1	1	0.10	0.11
2	10	10.12	9.91	2.02	1.98	0.20	0.22
3	20	11.14	10.74	2.23	2.15	0.22	0.23
4	30	12.06	11.43	2.41	2.29	0.24	0.25
5	40	12.80	12.05	2.56	2.41	0.25	0.26
6	50	13.36	12.51	2.67	2.50	0.26	0.27
7	60	13.33	12.71	2.73	2.54	0.26	0.28

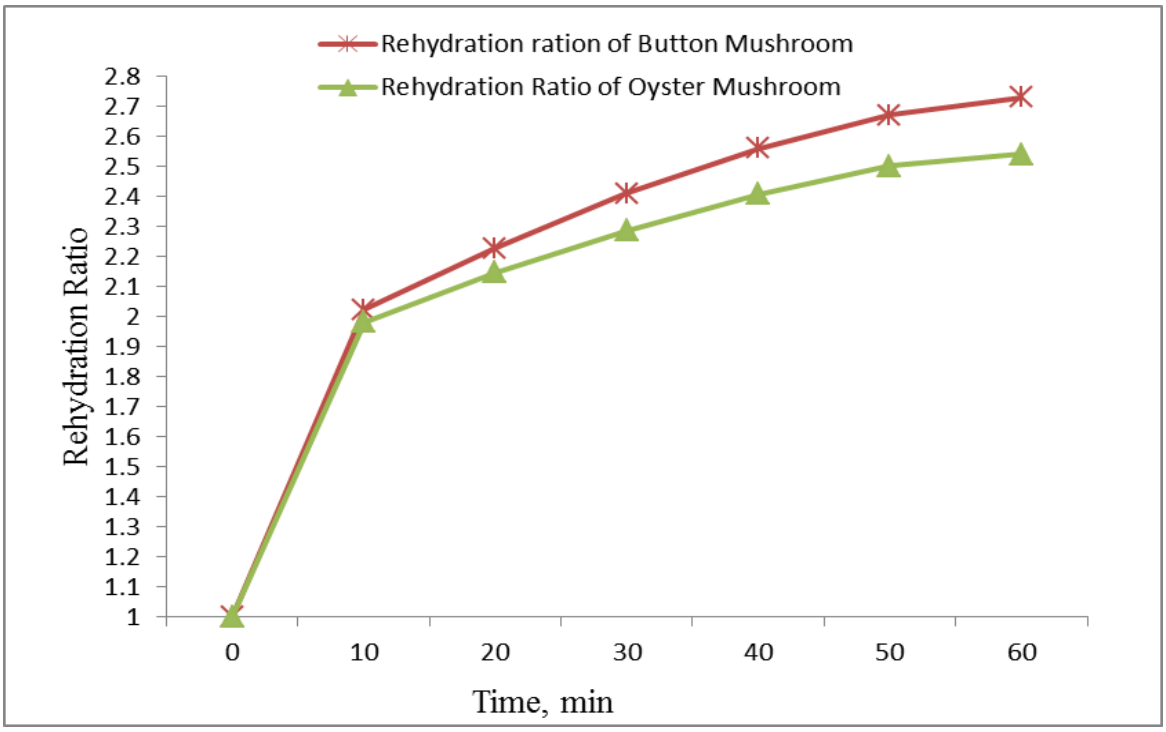


Fig. 4.48 Rehydration ratio of button and oyster mushroom

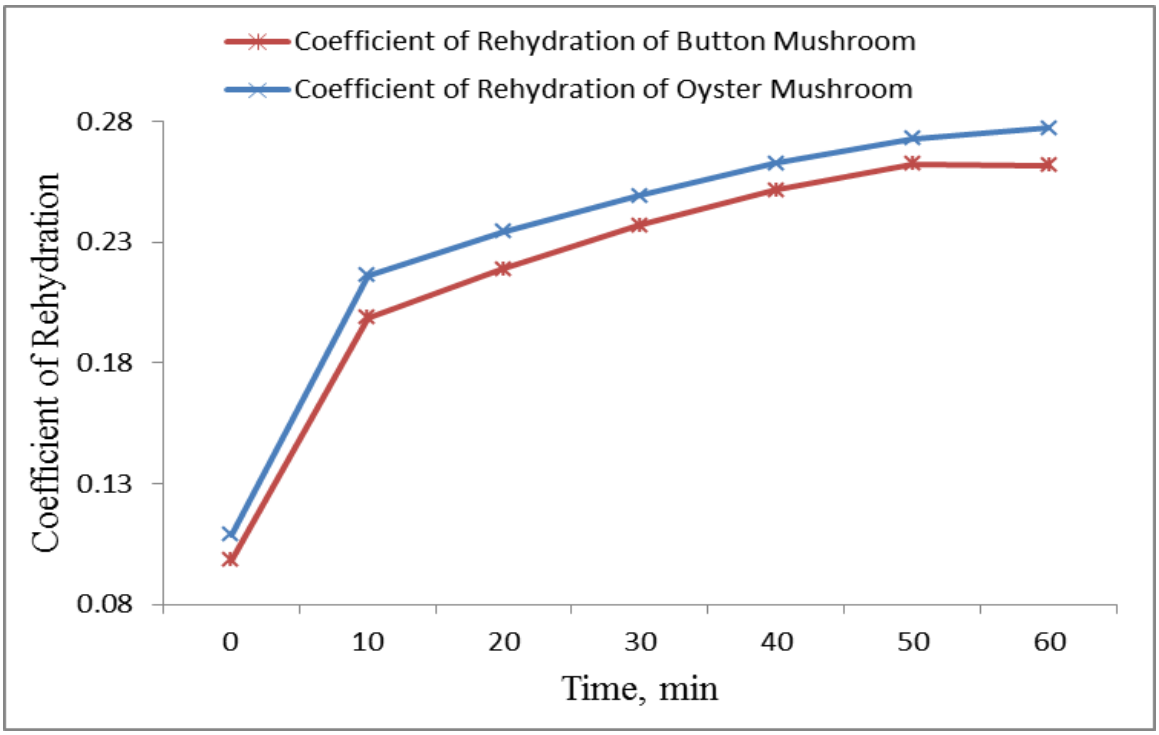


Fig. 4.49 Coefficient of rehydration of button and oyster mushroom

Fig. 4.50 Rehydrated button mushroom

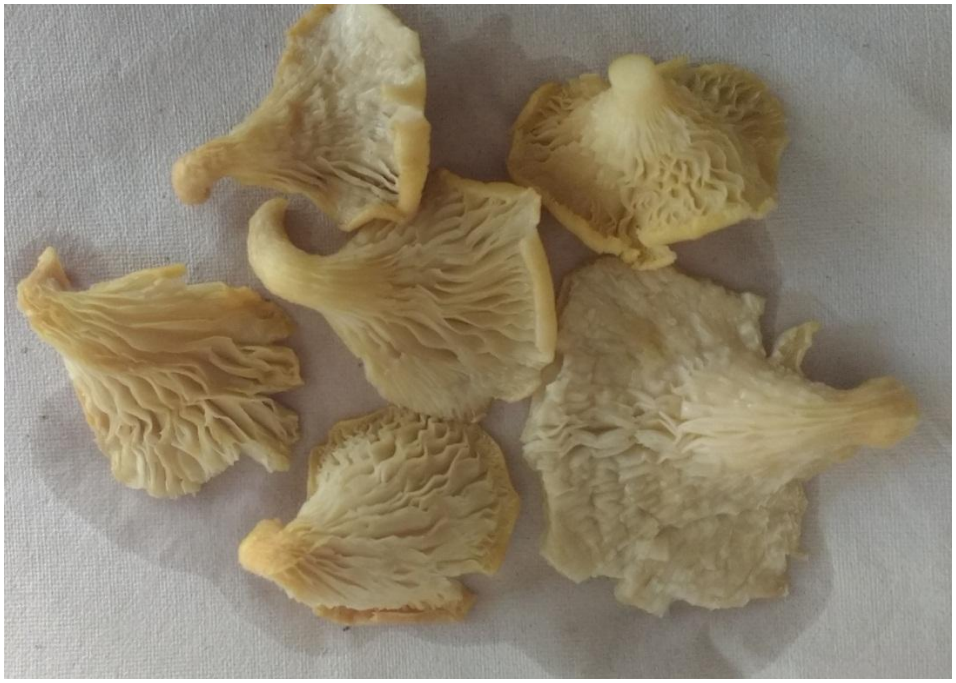


Fig. 4.51 Rehydrated oyster mushroom

4.4.2 Ascorbic Acid:

Ascorbic acid is precursor of Vitamin C and is lost during the drying process because it is heat liable nutrient. When a food is sliced and its cells are cut, the surfaces that are exposed to air, loose some vitamin C content. The retention of vitamin C depends upon the water content, salt content, the size of the sample of food material, amount of air circulation when food is dried, the level of humidity in the air entering the dryer and the air temperature and time of exposure inside the dryer.

In the present study the ascorbic acid content of fresh button mushroom sample was found as 32.3 mg/100 g dm, whereas ascorbic acid content of dried button mushroom sample was 12.83 mg/100 g dm. The ascorbic acid content of fresh oyster mushroom sample was found as 28.3 mg/100 g dm, whereas ascorbic acid content of dried oyster mushroom sample was 10.58 mg/100 g dm. It revealed from the results that ascorbic acid in the product was decreased by 60.28 per cent & 62.62 per cent in button and oyster mushroom respectively. The high loss of ascorbic acid was might be due to long period of exposure. Similar results of ascorbic acid content of fresh and dried button mushroom were found by Mehta *et.al* (2012).

4.4.3 Colour Test:

Colour is often used as an indication of quality and freshness for food products. Hence, it has become important for food processors to be able to evaluate and grade their products based on colour. Colour values measured using a Colourflex Hunterlab Colorimeter, were relative to the absolute values of perfect reflecting diffuser as measured under the same geometric conditions (ASTM method). Observations were taken at room temperature 24-28°C and 59-63 % relative humidity. Specifications of the Hunterlab colorimeter were tabulated in Appendix E.

The colour of dried button and oyster mushroom product was measured in terms of L-value (brightness/darkness). The L-value of fresh button mushroom sample was found to be 79.3 whereas L-value of dried button mushroom sample was found as 49.2. The L-value of fresh oyster mushroom sample was found to be 83.2 whereas L-value of dried oyster mushroom sample was found as 56.4. The drying air temperature of 50^{o}C was found better and recorded significant L values of dried product. Similar results were

quoted by Yepar *et al*. (1990), Murumkar *et al*. (2007), Shukla and Singh (2007) and Singh *et al*. (2008)

4.4.4 Water Activity:

The water activity of the fresh and dried samples of button and oyster mushroom samples were measured by using the methodology as mentioned in section 3.1.5.3. Water activity is a function of moisture content in the food and the temperature (Ratti and Mujumdar, 1996). Water content in the dried product provides favorable conditions to the microorganism which results in product spoilage. Therefore lower the value of water activity of product higher will be its storage potential. The specifications of the water activity meter were depicted in Appendix F.

The water activity of fresh button mushroom sample was 0.91 whereas water activity of dried button mushroom sample was found to be 0.29. Similarly water activity of fresh oyster mushroom sample was 0.90 whereas water activity of dried oyster sample was found as 0.30. It revealed from the results that button and oyster mushroom dried at 50^{o}C has relatively lower water activity and better storage potential.

Similar results of water activity were found by, Kotwaliwale *et.al* (2007), Kulshreshtha *et.al* (2009) and Mehta *et.al* (2012).

4.4.5 Sensory Evaluation:

The mean sensory score of colour, taste, appearance and over all acceptability of rehydrated button mushroom and oyster mushroom are presented in the Table 4.10. Sensory evaluation was conducted on the aspects of colour, taste, appearance and overall acceptability of rehydrated samples by a panel of 20 judges and found the score ranged from 1 to 9 which represented from “Dislike extremely” to “Like extremely” as shown in Appendix D. The values of the colour, taste, appearance and over all acceptability score of rehydrated button mushroom was found 7.14, 7.12, 6.95 and 7.07 at 50°C drying temperature and 7.35, 7.21, 7.1 and 7.22 for oyster mushroom respectively as shown in Fig. 4.50. It can be inferred from Fig 4.52 that the rehydrated button and oyster mushroom dried in developed hybrid dryer at 50°C was accepted by consumer panel and rated as liked very much.

Table 4.10 Sensory evaluation score card of button and oyster mushroom

Sr. no.	Parameter	Button Mushroom	Oyster Mushroom
1	Colour	7.14	7.35
2	Taste	7.12	7.21
3	Appearance	6.95	7.10
4	Overall Acceptability	7.07	7.22

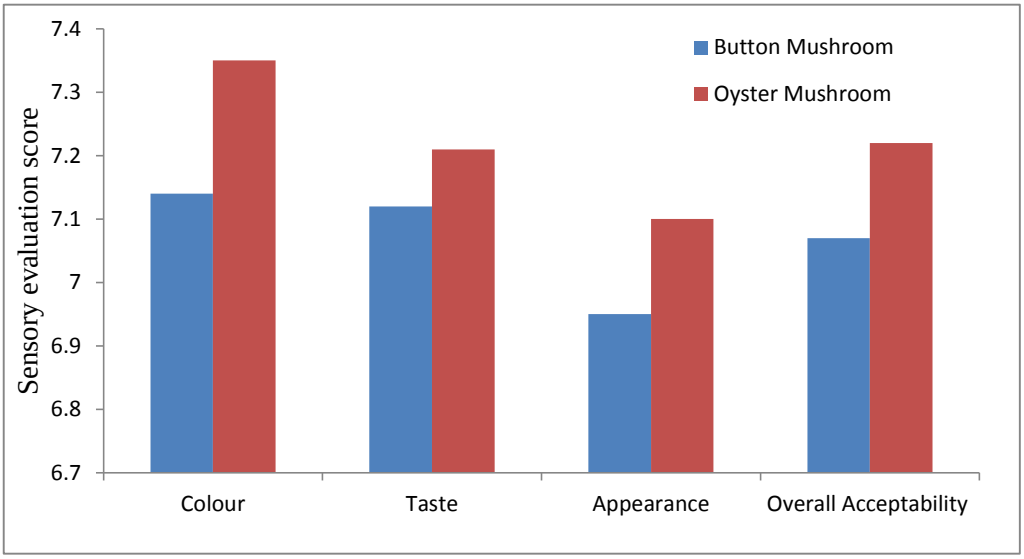


Fig. 4.52 Sensory evaluation scores of button and oyster mushroom

4.5 Nutritional Characteristics of Fresh and Dried Mushroom:

Carbohydrates, proteins, fats, crude fiber and ash content were estimated in the laboratory as per standard methodology mentioned in section 3.1.5. The results obtained from the laboratory are tabulated in following Table 4.11. It was observed that fresh as well as dried form of button and oyster mushroom contains significant quantity of proteins, crude fibers and fats. It was observed from Table 4.11 that 7.35% of protein was loosed from button mushroom during drying process whereas 9.73% of protein was loosed from oyster mushroom during drying. It was also cleared that very negligible quantity of fats and crude fiber were loosed from fresh button and oyster mushroom during drying process. Similar results of nutritional composition of fresh as well as dried button and oyster mushroom were quoted by Salunke *et.al* (2007) and Stojkovic *et.al* (2017).

Table 4.11 Nutritional composition of button and oyster mushroom

Composition, Per cent	Button Mushroom, 100 g				Oyster Mushroom, 100 g			
	Fresh		Dried		Fresh		Dried	
	%	g	%	g	%	g	%	g
Moisture content	91	91	8.25	8.25	90	90	8.41	8.41
Dry Matter	9	9	91.75	91.75	10	10	91.59	91.59
Carbohydrates	22.62	2.03	25.20	27.46	40.41	4.04	42.73	46.65
Proteins	33.57	3.02	31.10	33.89	32.2	3.22	30.59	33.39
Fats	2.47	0.22	2.46	2.68	2.54	0.25	2.52	2.75
Crude Fiber	32.10	2.89	31.97	34.84	17.59	1.76	16.86	18.40
Ash	9.24	0.83	9.26	10.09	7.26	0.73	7.30	7.97

4.6 Economics of the Drying:

4.6.1 Cost Analysis:

A cost analysis was made with Solar-biogas hybrid drying system. The analysis was made by considering the present investment and the assumptions as given below.

Following assumptions were made to carry out the economic analysis of the system

1. The operating life of biogas plant was assumed to be 20-25 years, life of solar evacuated tube water heater was assumed as 15-20 years, and life of dryer was considered as 10-12 years. Therefore for calculations we assumed 15 years life of complete hybrid drying system.
2. Repair and maintenance cost of developed hybrid system was assumed to be a 5 per cent of total capital cost per year.
3. For drying of 4 kg of button mushroom required 0.7 m^3 biogas and for drying of 4 kg of oyster mushroom required 0.6 m^3 of biogas per day. So within one year 210 m^3 biogas is required. For production of this biogas requires around 3937.5 kg of cowdung and 1312.5 kg of spent button mushroom substrate which cost around 10,500 Rs.

4. Button mushroom is available in the market from November to March and oyster mushroom is available throughout the year. Here for economic assessment we considered peak availability of 120 days for drying of button mushroom and 210 days for drying of oyster mushroom. Cost of fresh oyster mushroom: 140 Rs/kg ,Cost of button mushroom: 200 Rs/kg ,Total Cost of Mushroom: (120×200×4+ 210×140×4)= 213600 Rs/year
5. 437 gram of dried oyster mushroom and 393 gram of dried button mushroom was produced from 4 kg of fresh oyster and button mushroom respectively.*Cost of dried oyster mushroom: 2800 Rs/kg ,*Cost of dried button mushroom: 3200 Rs/kg
6. Operating period considered to be a 330 days in a year.

The results obtained were enlisted in the Table 4.11 given below for economic analysis of the system. It was observed that the investment of the Solar-biogas hybrid drying system was recovered in 14 months and 10 days only which is viable and feasible as well. The total investment and possible achievable profit is given in the Table 4.12.

The benefit-cost ratio was found to be 1.184 with a payback period of 1.194 years (14 months and 10 days only). It can be inferred that the developed Solar-biogas hybrid drying system was technically as well as economically feasible.

Table 4.12 Cash flow analysis for Solar-biogas hybrid drying system

Particulars	**Cost in Rs.**
Capital cost of hybrid dryer including cost of 100 lpd solar water heater, 2m^3 modified KVIC biogas plant, and dryer.	Rs. 90,000
Life of Hybrid System:	15 years
Repair and maintenance cost= 5% of capital cost per year	4500 Rs.
Operating days per year:	330

Cost of dung and spent mushroom substrate to operate biogas plant per year:	10500 Rs.
Cost of Fresh Mushroom per year:	213600 Rs/year
Cost of electricity per year:	4950 Rs.
Labour Cost per year: Considering one labour @ 300 Rs per day for 330 days of working operation.	99000
Total cost per year:	3,32,550 Rs.
Money value recovered from the dried button and oyster mushroom per year:	407868 Rs.
Total Net annual profit: (Money value recovered –Total cost per year)	75,318 Rs.
Pay Back Period:	**1.194 Years (14 Months and 10 days)**

4.6.2 Net Present worth (NPW):

The net present worth of the solar-biogas hybrid drying system was calculated on the basis of present investment and the interest rate considered for the system and the profit achieved in each year. The life of solar-biogas hybrid drying system was assumed as 15 years thus the NPW for the system was Rs. 4,82,875/- . The net present worth were calculated for next 15 years and presented in the Table 4.13.

4.6.3 Benefit Cost Ratio (BCR):

The benefit cost ratio of the solar-biogas hybrid drying system was calculated by dividing present worth of the benefit stream to the present worth of the cost stream. Present worth of the benefit stream after 15 years was Rs. 31,02,276.43 whereas present worth of the cost stream after 15 years was Rs. 26,19,401.74 (Table 4.13).

$$Benefit\ Cost\ Ratio = \left[\frac{3102276.43}{2619401.74}\right] = 1.184$$

Benefit cost ratio of the developed drying system was found to be 1.184.

Table 4.13 Cash outflow for Solar-biogas hybrid drying system

Year	Cash out flow (Rs.)	PW of cash outflow (Rs.)	Cash inflow (Rs.)	PW of cash inflow(Rs.)	NPW (Rs.)
0	90000	90000	0	0	-90000
1	332550	302318.18	407868	370789.09	68470.9
2	332550	274834.71	407868	337080.99	62246.3
3	332550	249849.73	407868	306437.26	56587.5
4	332550	227136.12	407868	278579.33	51443.2
5	332550	206487.38	407868	253253.93	46766.6
6	332550	187715.80	407868	230230.85	42515
7	332550	170650.73	407868	209300.77	38650
8	332550	155137.02	407868	190273.43	35136.4
9	332550	141033.66	407868	172975.84	31942.2
10	332550	128212.42	407868	157250.77	29038.3
11	332550	116556.74	407868	142955.24	26398.5
12	332550	105960.67	407868	129959.31	23998.6
13	332550	96327.88	407868	118144.83	21816.9
14	332550	87570.80	407868	107404.39	19833.6
15	332550	79609.82	407868	97640.35	18030.5
Total	**5078250**	**2619401.74**	**6118020**	**3102276.43**	**482875**

4.6.4 Pay Back Period (PBP):

Pay back period of the solar biogas hybrid drying system was estimated by adding net cash flow in the project until the cumulative net cash flow equal to initial investment. It was clear from Table 4.12 and Table 4.13 that after 1.194 years (14 months and 10 days) the cumulative net cash flow of the project equals initial investment. Therefore it can be inferred that developed system has pay back period of 1.194 years.

4.6.5 Internal rate of return for Solar-biogas hybrid drying system:

The internal rate of return for solar-biogas hybrid drying system was calculated and found to be 83.7 % for 15 years. The higher percentage of internal rate of returns indicated the good commercial return of the investment. Table 4.14 shows the calculations of IRR for solar-biogas hybrid drying system.

Table 4.14 Internal rate of return (IRR) for solar-biogas hybrid drying system

Year	Cash flow	83.6 % Discount factor		83.7 % Discount factor	
		Discount factor	Present Value	Discount factor	Present Value
0	-90000	1	-90000	1	-90000
1	75318	0.836	41022.88	0.837	41000.54
2	75318	0.836	22343.61	0.837	22319.29
3	75318	0.836	12169.72	0.837	12149.86
4	75318	0.836	6628.39	0.837	6613.969
5	75318	0.836	3610.234	0.837	3600.419
6	75318	0.836	1966.359	0.837	1959.945
7	75318	0.836	1071.001	0.837	1066.927
8	75318	0.836	583.3341	0.837	580.7986
9	75318	0.836	317.7201	0.837	316.1669
10	75318	0.836	173.0502	0.837	172.1104
11	75318	0.836	94.2539	0.837	93.69104
12	75318	0.836	51.33655	0.837	51.0022

13	75318	0.836	27.96108	0.837	27.76385
14	75318	0.836	15.22935	0.837	15.11369
15	75318	0.835	8.294852	0.837	8.227378
		NPW	**83.37936**	**NPW**	**-24.1665**
Internal rate of return (IRR)= 83.7 %					

Net present worth, benefit cost ratio, payback back period and internal rate of return of developed solar biogas hybrid drying system was tabulated below in Table 4.15.

Table 4.15 Economic Indicators of the solar-biogas hybrid drying system

S. No.	Economic Indicators	Value
1	Net present worth (NPW)	Rs. 4,82,875
2	Benefit cost ratio (BCR)	1.184
3	Pay-back period (PBP)	1.194 years
4	Internal rate of return (IRR)	83.7 %

CHAPTER V

SUMMARY AND CONCLUSIONS

The button mushroom (*Agaricus bisporus*) is the most widely cultivated and consumed mushroom throughout the world and contributing about 90 % of total country's production as against its global share of about 40 % (Rai and Arumuganthan, 2003). The oyster mushroom (*Pleurotus ostreatus)* is the second largest cultivated and consumed mushroom in India. Mushroom is a rich source of good quality proteins having most of the essential amino acids, vitamins and minerals and is popular for its delicacy and exotic flavour (Rai *et al*., 2003). Mushroom is highly perishable product and needs processing to increase its storage life. Therefore to keep mushrooms safe and unspoiled for a long time, it is vital to remove the bacteria causing fermentation. Drying is relatively inexpensive (Chen and Chen, 1974) and reduces bulk; thus, facilitates its transportation, handling and storage.When the mushroom is dried, it keeps almost all of its taste and retains other features. Solar energy is effectively available only in day time with average sunshine duration of eight hours. Mushroom is highly perishable fungal product with moisture content of around 90 %. Availability of sunshine hours for drying of button and oyster mushroom is not sufficient and therefore there is need to have some additional source of energy to dry mushroom product continuously to avoid spoilage and damage to the quality of dried product. Therefore study was undertaken to develop hybrid mushroom dryer through energy integration of solar water heater and biogas plant for continuous drying of button and oyster mushroom.

Spent mushroom substrate is a byproduct of mushroom cultivation technique. It is the organic substrate material left over after harvesting of mushroom. This spent mushroom substrate was not utilized most of the time and may be either buried openly in the environment or composted to prepare enriched organic manure. Open burning of spent mushroom substrate can cause emission of harmful greenhouse gases in the environment which may results in to global warming and climate change effects. Composting of organic manure took a long time to convert organic material in to enriched fertilizer and may create unhygienic surrounding condition. During the process of composting some sort of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) is

released in to the environment. This untapped greenhouse gases stays in the atmosphere for longer duration and contributes heavily in global warming of the earth. The utilization of spent mushroom substrate for biogas production through anaerobic digestion technology not only provides additional source of energy for drying of mushroom but its utilization can also save emission of harmful greenhouse gases in the atmosphere and solve waste disposal problem. Therefore study on biomethanation of spent mushroom substrate and development of modified biogas plant was undertaken.

Solar and biogas integrated hybrid dryer for drying of button mushroom (*Agaricus bisporus*) and oyster mushroom (*Pleurotus ostreatus*) was developed in Department of Renewable Energy Engineering, CTAE Udaipur. The white button mushroom (*Agaricus bisporus)* and Oyster mushrooms (*Pleurotus ostreautus)* of uniform size were thoroughly washed under tap water, sliced into 5±0.5 mm thick slices and pretreated with mixture of 0.5% citric acid and 0.5% ascorbic acid before drying. Solar energy and biogas produced from codigestion of spent button mushroom substrate and cowdung substrate were used for water heating. This hot water was circulated through radiator which was kept inside dryer. Ambient air was circulated at constant flow rate of 0.26 m/s using air fan over radiator to absorb heat and to dissipate through dryer for drying of mushroom at constant temperature. This complete process was optimized in such a way that constant temperature of 50 °C was maintained throughout drying of mushroom. Quality of dried button and oyster mushroom samples were also evaluated on the basis of its rehydration characteristics, ascorbic acid content, colour test, water activity, sensory evaluation, and its nutritional analysis (carbohydrates, proteins, fats, crude fibres, & ash content).

The anaerobic digestion of spent button mushroom waste and spent oyster mushroom waste were carried out in laboratory for a retention period of 40 days. The study was performed in laboratory with 9 different treatments of spent mushroom substrate and cowdung proportion. Based on results of laboratory study, biogas plant was modified for codigestion of selected combination of spent mushroom substrate and cowdung. Biogas produced from the modified plant was measured continuously for 80 days. Daily observations of biogas production, its compositional analysis and temperature of digester slurry were recorded continuously for 80 days. Economic analysis of the

complete system was also carried out with net present worth (NPW), benefit-cost ratio (BCR), internal rate of return (IRR) and payback period (PBP).

Based on the results of the investigations, the following conclusions were drawn:

Conclusions:

1. Solar water heater and biogas integrated hybrid dryer for mushroom was developed in Department of Renewable Energy Engineering. The button mushroom was dried from moisture content of 91% (wb) to 8.26 % (wb) in 11 hours with average solar radiations availability of 560 W/m^2 and biogas consumption of 700 L.
2. The oyster mushroom was dried from moisture content of 90% (wb) to 8.41 % (wb) in 10 hours with average solar radiations availability of 578.37 W/m^2 and biogas consumption of 600 L.
3. The efficiency of the developed dryer for button mushroom drying was found 25.10% whereas for oyster mushroom drying efficiency was 27.89%.
4. The biogas production was found maximum in treatment T6 when spent button mushroom substrate was mixed with cow dung in 1:3 proportions. The total biogas production from treatment T6 was 7.183 L and biogas production at STP was observed as 6.54 L. The total specific biogas production from codigestion of spent button mushroom substrate and cow dung substrate (25% SpBMS +75% Cow dung) within 40 days of biomethanation period was observed as 106.11 L/kg dm and 123.90 L/kg VS respectively.
5. After stabilization, CH_4 percentage was varying in between 54% to 57% in T6 whereas CO_2 percentage was varying in the ranges of 34% to 36%. In T6, percentage reduction in total solids and total volatile solids was 11.68% and 13.65% respectively which was maximum after control treatment T5 (100% CD).
6. The percentage increase in N, P & K was found maximum in T6 after control treatment T5. In T6, N, P, & K were increased from 1.36%, 0.67%, and 0.87% to 1.56%, 0.94% and 1% respectively.
7. On the basis of laboratory results the biogas plant was developed for codigestion of spent button mushroom substrate and cow dung (25% SpBMS +75% CD) and

implemented in Deptt. of Renewable Energy Engineering, CTAE Udaipur. Biogas produced from the developed plant was measured continuously for 80 days along with its compositional analysis.

8. The average daily biogas production during 80 days of biomethanation period was observed as 1.852 m^3/day with substrate temperature varies in the range of 31.5 °C to 37.9 °C.

9. After stabilization of biogas plant, average 55.54% methane (CH_4) and 34.91% (CO_2) of carbon dioxide production per day was observed throughout biomethanation period of 80 days. The observed values of methane concentration in the produced biogas from codigestion of spent button mushroom substrate and cow dung have showed significantly similarity in the methane content range of biogas produced from cattle dung only.

10. The cumulative biogas production and cumulative biogas production at STP was found to be 148.18 m^3 and 130.91 m^3 respectively with substrate temperature varying in between 31.5 °C to 37.9 °C.
11. The observed range of specific biogas production yield in L/kg dm and L/kg VS with spent button mushroom substrate and cowdung substrate (25% SpBMS +75% CD) was observed in the range of 81.08–117.56 L/kg dm and 94.66–137.27 L/kg VS.
12. The average specific biogas production yield in L/kg dm and L/kg VS over 80 days period was recorded as 106.25 L/kg dm and 124.06 L/kg VS respectively. The average specific methane production yield in L/kg dm and L/kg VS over 80 days period was recorded as 54.058 L/kg dm and 63.12 L/kg VS.
13. The cumulative biogas, methane and carbon dioxide production at STP were found as 130.91 m^3, 66.60 m^3 and 48.55 m^3, respectively with substrate temperature varying in between 31.5 °C to 37.9 °C.
14. The total volatile solid mass removal efficiency (TVSMRE) over a period of 80 days of biomethanation time was found to be in the range of 5.28 to 15.78 %. The average total volatile solid mass removal efficiency (TVSMRE) of the substrate over 80 days of biomethanation was 12.81 %.

15. Average 15.65 % reduction in total solids and 17.59 % reduction in volatile solids were observed after 40 days of biomethanation whereas average 16.37 % reduction in the organic carbon content was observed after 40 days of biomethanation with average pH of inlet charge 6.68 and that of outlet slurry was 7.14.
16. The nutritional analysis of fresh and spent slurry was done in the laboratory. After 40 days of biomethanation, average N, P, & K were increased from 1.37%, 0.65% and 0.88% to 1.57%, 0.85% and 0.99% respectively. It showed an average increase in nitrogen 14.72%, in phosphate 30.5% and in potash content 13.76 % in the spent slurry compared to fresh slurry.
17. Net present worth (NPW) of the developed system after 15 years was found to be Rs. 4, 82,875/- , and internal rate of return (IRR) was found as 83.7 %. The benefit cost ratio was found to be 1.18 with a payback period of 1.19 years.

CHAPTER VII

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ABSTRACT

India is a country with variable agro climate and rich in fungal biodiversity. India is a potential major producer of temperate, tropical and subtropical mushroom species. Mushroom is a nutritious product and contains many vitamins and minerals. Mushroom is a highly perishable product therefore it needs immediate processing to increase its storage life. Therefore investigation was done on the design and development of solar-biogas integrated drying system including biomethanation study of spent mushroom substrate. Biomethanation study comprises of lab study of codigestion of spent mushroom substrate and cowdung in different proportions, identification of suitable combination of spent mushroom substrate and cowdung from results of lab study, development of biogas plant suitable for selected combination of spent mushroom substrate and cowdung and to study biogas production from selected combination in the modified biogas plant.

From biomethanation study it was found that combination of 25 % spent button mushroom substrate with 75% cow dung (T 6) was found better as compared to all other selected combinations. The total biogas production at STP from T6 was about 6.54 L in 40 days from 200 gm sample. Biogas plant of $2m^3$ was modified accordingly and the gas produced was measured continuously for 80 days. The average daily biogas production during 80 days of biomethanation period was observed as 1.852 m^3/day with substrate temperature varies in the range of 31.5 °C to 37.9 °C. The cumulative biogas production and cumulative biogas production at STP was found to be 148.185 m^3 and 130.908 m^3 respectively.

Solar energy and biogas produced from codigestion of spent button mushroom substrate and cowdung substrate were used for water heating. This hot water was circulated through radiator kept inside dryer. Ambient air was circulated at constant flow rate using air fan over radiator to absorb heat of the hot water flowing through radiator and to dissipate absorbed heat inside dryer for drying of mushroom at constant

temperature. This complete process was optimized in such a way that constant temperature of 50 °C was maintained throughout drying of mushroom.

The button mushroom was dried from moisture content of 91% (wb) to 8.257 % (wb) in 11 hours with average solar radiations availability of 560 W/m^2 and biogas consumption of 700 L. The oyster mushroom was dried from moisture content of 90% (wb) to 8.41 % (wb) in 10 hours with average solar radiations availability of 578.37 W/m^2 and biogas consumption of 600 L. The benefit-cost ratio of the developed system was found to be 1.184 with a payback period of 1.194 years (14 months and 10 days only). It can be inferred that the developed Solar-biogas hybrid drying system was technically as well as economically feasible.

अनुक्षेपन

भारत एक ऐसा देश है जो परिवर्तनशील कृषि जलवायु एवं फफूंद जैवविविधताओ से धनी है! भारत समशीतोष्ण, उष्णकटिबंधीय और उपोष्णकटिबंधीय मशरूम प्रजातियों का एक प्रमुख उत्पादक है! मशरूम एक पोस्टिक उत्पाद है जिसमे कई विटामिन एवं खनिज प्रदार्थ शामिल है! मशरूम जल्द ही सड़ने/ख़राब होने वाला उत्पाद है इसिलिये इसके सुरक्षित भंडारण हेतु कटाई उपरांत तुरंत प्रसंस्करण करने की आवशयकता होती है! इसिलिये मशरूम को सौर एवं बायोगैस एकीकृत तकनिकी द्वारा सुखाने एवं मशरूम अपशिष्ट द्वारा बायोगैस उत्पादन करने की प्रणाली का डिजाईन एवं विकास कर जांच हेतु अध्यन में लिया गया! बायोगैस अध्यन के अंतर्गत प्रयोगशाला में मशरूम अपशिष्ट एवं गोबर को अलग अलग अनुपात में मिला कर आये परिणामो से उपयुक्त संयोजन की पहचान की गयी! चयनित संयोजन का संशोधित बायोगैस सयंत्र द्वारा बायोगैस उत्पादन किया गया!

प्रयोगशाला आधारित अध्यन अनुसार 25% मशरूम अपशिष्ट एवं 75% गोबर वाले संयोजन (T6) से अन्य सयोजन की तुलना में सर्वाधिक बायोगैस का उत्पादन हुआ! सामान्य ताप एवं दाब की स्थिति में T6 सयोजन द्वारा 200 ग्राम नमूने से 40 दिनों में 6.54 लीटर बायोगैस उत्पन्न हुई! दो घन मीटर प्रतिदिन बायोगैस उत्पादन क्षमता वाले सयंत्र को संशोधित कर 80 दिनों तक बायोगैस उत्पादन का अवलोकन किया गया जिसमे औसत 1.852 घन मीटर प्रतिदिन बायोगैस का उत्पादन हुआ! संचयी बायोगैस का उत्पादन एवं मानक ताप एवं दाब पर संचयी बायोगैस का उत्पादन क्रमशः 148.18 लीटर एवं 130.90 लीटर पाया गया!

बटन मशरूम अपशिष्ट एवं गोबर के सहपाचन से उत्पादित बायोगैस एवं सोलर ऊर्जा का प्रयोग पानी गर्म करने में किया गया! ये गर्म पानी शुष्कक कक्ष के अन्दर रखे गए रेडियेटर से परिसंचालित किया गया! रेडियेटर के उपर से पंखे के माध्यम से समान प्रवाह की दर में व्यापक हवा परिचालित की गयी ताकि गर्म पानी से ऊष्मा सोख सखे! पूर्ण प्रक्रिया का

अनुकूलन इस प्रकार रहा की मशरूम सुखाते समय शुष्कक कक्ष का तापमान 50 डिग्री सेल्सियस रहे!

91% नमी वाले बटन मशरूम को 560 वाट प्रति घंटे की क्षमता वाली सौर किरण एवं 700 लीटर बायोगैस की खपत से 11 घंटो में 8.2% नमी तक सुखा दिया गया! 90% नमी वाले सीप मशरूम को 578.37 वाट प्रति घंटे की क्षमता वाली सौर किरण एवं 600 लीटर बायोगैस की खपत से 10 घंटो में 8.41% नमी तक सुखा दिया गया!

APPENDIX A

Design of Hybrid Dryer

Design of drying system

I. Total quantity of water in the product, M_{tw}

It was calculated by using following formula

$$M_w = \left[M \times \frac{M_i}{100} \right]$$

$$= 4 \times \frac{91}{100}$$

= 3.64 kg

II. Bone dry weight of the product, W_b

It was calculated by using following formula

$M_d = M - M_w$

= 4- 3.64

= 0.36 kg

III. Mass of the water to be removed during drying, M_w

It was calculated with the help of following formula.

$$M_w = \frac{M_i - M_f}{100 - M_f} \times M$$

$$= \frac{91 - 8}{100 - 8} \times 4$$

= 3.6086 kg

IV. Efficiency of Hybrid dryer

Total energy required for drying, Q_n

Total energy required for drying was estimated by using following formula.

$$Q_E = M \times C \times (T_d - T_a) + M_w \times \lambda$$

$$= 4 \times 3.99 \times (50 - 26) + 3.6086 \times 2257$$

= 8527.866 kJ

Total Energy required to heat water from solar and biogas for button mushroom:

Energy received from solar (Q_S)

Q_S = IA

= (560*10*3600*1)/1000

= 20160 kJ

Energy from Biogas for drying of button mushroom (Q_B)

Q_{B1}= m× λ

= 0.7 ×19719.19

= 13803.43 kJ

Total energy supplied for drying of button mushroom: $Q_S + Q_{B1}$

$Q_T = Q_S + Q_{B1}$= 33963.43

Efficiency of developed dryer for button mushroom drying:

= (Total energy required for drying/ total energy required to heat water from solar and biogas)

= 8527.866/33963.43

= 25.10%

Total Energy required to heat water from solar and biogas for Oyster mushroom:

Energy received from solar (Q_S)

Q_S = IA

= (578.37*9*3600)/1000

= 18739.18 kJ

Energy from Biogas for drying of Oyster mushroom (Q_B)

Q_{B2} = m× λ

= 0.6 ×19719.19

= 11831.51 kJ

Total energy supplied for drying of Oyster mushroom: $Q_S + Q_{B2}$

$Q_T = Q_S + Q_{B2}$= 30570.68 kJ

Efficiency of developed dryer for Oyster mushroom drying:

= (Total energy required for drying/ total energy required to heat water from solar and biogas)

= 8527.866/30570.68

= 27.89 %

V. Drying air requirement

Mass of the air required for drying, M_{ad}

$$M_a = \frac{M_w}{(H_e - H_d) \times t}$$

Here H_d & H_e are unknown firstly we have to calculate value of H_d

Therefore,

$$H_d = \frac{0.62198 \times P_{wd}}{(P_a - P_{wd})}$$

Before determining the value of H_d, we have to calculate value of P_{wd}

Value of P_{wd} at 25 °C is 3168 pa and at 30 °C it is 4242 pa (Geankoplis, 2003)

Therefore by linear interpolation P_{wd} at 26°C is 3382 pa.

Therefore,

$$H_d = \frac{0.62198 \times 3382}{(101325 - 3382)}$$

= 0.0214 kg/kg of dry air

Similarly,

$$H_e = \frac{0.62198 \times P_{we}}{(P_a - P_{we})}$$

Value of P_{we} at 40 °C is 7375 pa and at 50 °C it is 12333 pa (Geankoplis, 2003)

Therefore by linear interpolation P_{wd} at 46°C is 10349 pa.

Therefore,

$$H_e = \frac{0.62198 \times 10349}{(101325 - 10349)}$$

= 0.07064 kg/kg of dry air

Therefore,

$$M_a = \frac{3.604}{(0.07064-0.0214)\times 11}$$

= 6.653 kg/h

Volumetric flow rate

$V_a = M_a \times V_h$

In this equation V_h is unknown, we have to calculate value of V_h

Therefore,

$$V_h = \frac{287.09\times(273.15+T_d)}{(P-P_w)}$$

$$= \frac{287.09\times(273.15+26)}{(101325-3382)}$$

= 0.8768 m^3/kg

Therefore, $V_a = 6.653 \times 0.8768$

= 5.833 m^3/h

Area of air entering pipe= 0.00635 m^2

Air velocity (m/s)= 5.833/3600*0.00635= 0.26 m/s

VI. Total volume of product to be dried, V

Density of button mushroom is 780 kg/m^3 whereas density of oyster mushroom is 740 kg/m^3. For calculations we considered 740 kg/m^3 of product density; V= 4/740= 0.0054 m^3.

VII. Dimensions of Tray,

Thickness of drying is 5 mm; Area of drying= 0.0054/0.005= 1.08 m^2

Four trays were considered. Area of one tray= 1.08/4= 0.27 m^2

Therefore tray of 45 cm width and 60 cm length were selected.

VIII. Design of Chimney,

$$Q_a = \left[\frac{M_w \times \lambda}{C_a \times \rho_a (T_e - T_a)}\right]$$

$$Q_a = \left[\frac{4 \times 2257}{1.005 \times 1.184(46 - 26)}\right]$$

Q_a=379.35 m^3

Qa= 379.35/11×60×60= 0.00957 m^3/s

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

Considering chimney height of 52cm (without cap);

Di= 0.52 ×9.81× (1.184-1.109)

Di= 0.38259

Actual Draft D_a= 0.80 ×0.38259

Da= 0.3060

Velocity of exit air, $V = \sqrt{\frac{2D_a}{\rho_e}}$

$$V = \sqrt{\frac{2 \times 0.3060}{1.109}}$$

V= 0.7429 m/s

$$Area\ of\ Chimney = \frac{Q_a}{V}$$

$$Area\ of\ Chimney = \frac{0.00957}{0.7429}$$

Area of Chimney= 0.01288 m^2

Diameter of chimney, $D = \sqrt{\frac{4 \times 0.01288}{3.14}}$

Diameter of chimney (D) = 0.1281 m

= 12.81 cm

= 13 cm (Approx.)

APPENDIX B

Appendix B1: Data of No Load Test

Date: 23/12/2016

Time, hr	T1	T2	T3	T4	T5	Solar Radiations, W/m^2	Biogas Consumption, L
9	28	28	28	27	24	332	0
9.3	47	46	45	44	40	418	84
10	51	49	48	46	41	537	57
10.3	51	50	49	47	42	561	0
11	53	52	51	49	44	618	0
11.3	54	53	52	50	45	715	0
12	56	55	54	52	46	759	0
12.3	57	56	55	53	47	794	0
13	59	58	57	55	48	816	0
13.3	61	60	59	57	50	857	0
14	61	60	59	57	51	861	0
14.3	60	59	58	56	51	778	0
15	58	57	56	54	48	750	0
15.3	56	55	54	52	45	710	0
16	54	53	52	50	43	619	0
16.3	53	52	51	49	43	558	0
17	52	51	50	49	42	419	0
17.3	49	48	49	48	42	311	0
18	51	49	48	46	40	118	78
18.3	51	49	48	47	40	0	34
19	51	50	49	47	40	0	27
	53	**51.90**	**51.05**	**49.29**	**43.43**	**53**	**280**

T1: Temperature of bottom tray, T2: Temperature of 2nd tray from bottom, T3: Temperature of 3rd tray from bottom, T4: Temperature of top tray, T5: Temperature at the outlet of chimney. T1, T2, T3, T4, T5 are in ℃

Appendix B2: Data of Full Load Test

Product: Button Mushroom (*Agaricus Bisporus*) **Date: 27/12/2016**

Time, h	T1	T2	T3	T4	T5	Solar Radiations, W/m^2	Biogas Consumption, L
9	26	26	25	25	24	256	0
9.3	46	46	45	44	40	368	71
10	52	51	51	50	44	495	68
10.3	52	51	51	50	44	511	26
11	53	52	51	50	45	561	0
11.3	53	52	51	50	45	654	0
12	53	52	52	51	45	710	0
12.3	53	53	52	51	45	726	0
13	54	53	52	51	46	759	0
13.3	54	54	53	52	46	798	0
14	55	54	53	52	46	798	0
14.3	54	53	52	51	46	776	0
15	53	52	51	50	44	730	0
15.3	52	51	50	49	44	666	0
16	51	50	49	48	43	589	0
16.3	51	51	50	49	44	498	41
17	52	51	50	49	44	364	51
17.3	52	51	50	49	44	257	62
18	52	51	50	49	43	124	64
18.3	51	50	49	48	43	0	71
19	51	50	49	48	43	0	75
19.30	50	49	48	47	42	0	80
20	50	49	48	47	42	0	91
	50.87	**50.09**	**49.22**	**48.26**	**43.13**	**560**	**700**

Appendix B3: Data of Full Load Test

Product: Oyster Mushroom (*Pleurotus ostreatus*) **Date: 30/12/2016**

Time, h	T1	T2	T3	T4	T5	Solar Radiations, W/m^2	Biogas Consumption, L
9	25	24	23	23	21	264	0
9.3	45	44	43	43	38	381	76
10	51	50	49	49	43	496	74
10.3	53	52	51	51	43	534	42
11	53	52	51	50	44	584	0
11.3	53	52	50	50	44	676	0
12	54	53	52	52	46	735	0
12.3	54	53	52	51	45	769	0
13	54	53	52	52	45	789	0
13.3	54	54	53	52	45	829	0
14	54	54	53	52	45	826	0
14.3	54	53	52	52	44	793	0
15	53	52	52	51	43	763	0
15.3	52	51	51	50	43	686	0
16	51	51	50	49	42	597	0
16.3	52	51	51	50	43	513	61
17	53	52	51	50	43	376	57
17.3	52	51	51	50	43	257	68
18	52	51	50	49	42	121	67
18.3	51	50	49	49	42	0	74
19	51	50	49	49	41	0	81
	51.00	**50.14**	**49.29**	**48.76**	**42.14**	**578.37**	**600**

APPENDIX C

Appendix C1: Data Sheet-1

Drying data of Button Mushroom (Tray 1)

Drying Temperature: 50 °C **IMC of button mushroom= 91 % (wb)**

Tray 1 (Bottom tray of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	91.00	1011.11	
15	10.05	82.09	458.33	0.368519
30	6.98	74.21	287.78	0.113704
45	5.45	66.97	202.78	0.056667
60	4.52	60.18	151.11	0.034444
90	3.45	47.83	91.67	0.019815
120	2.85	36.84	58.33	0.011111
180	2.40	25.00	33.33	0.004167
240	2.25	20.00	25.00	0.001389
300	2.16	16.67	20.00	0.000833
360	2.11	14.69	17.22	0.000463
420	2.06	12.62	14.44	0.000463
480	2.02	10.89	12.22	0.000370
540	1.99	9.55	10.56	0.000278
600	1.97	8.63	9.44	0.000185
660	1.96	7.93	8.61	0.000139

Appendix C2: Data Sheet-2

Drying data of Button Mushroom (Tray 2)

Drying Temperature: 50 °C **IMC of button mushroom= 91 % (wb)**

Tray 2 (2nd Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	91.00	1011.11	
15	10.06	82.11	458.89	0.368148
30	6.99	74.25	288.33	0.113704
45	5.47	67.09	203.89	0.056296
60	4.54	60.35	152.22	0.034444
90	3.46	47.98	92.22	0.020000
120	2.86	37.06	58.89	0.011111
180	2.41	25.31	33.89	0.004167
240	2.26	20.35	25.56	0.001389
300	2.18	17.43	21.11	0.000741
360	2.13	15.49	18.33	0.000463
420	2.09	13.67	15.83	0.000417
480	2.04	11.81	13.39	0.000407
540	2.01	10.45	11.67	0.000287
600	1.98	9.14	10.06	0.000269
660	1.96	8.07	8.78	0.000213

Appendix C3: Data Sheet-3

Drying data of Button Mushroom (Tray 3)

Drying Temperature: 50 °C **IMC of button mushroom= 91 % (wb)**

Tray 3 (3rd Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	91.00	1011.11	
15	10.08	82.14	460.00	0.367407
30	7.01	74.32	289.44	0.113704
45	5.49	67.21	205.00	0.056296
60	4.56	60.53	153.33	0.034444
90	3.47	48.13	92.78	0.020185
120	2.87	37.28	59.44	0.011111
180	2.43	25.93	35.00	0.004074
240	2.27	20.70	26.11	0.001481
300	2.19	17.81	21.67	0.000741
360	2.13	15.49	18.33	0.000556
420	2.09	13.92	16.17	0.000361
480	2.05	12.37	14.11	0.000343
540	2.02	10.89	12.22	0.000315
600	1.99	9.55	10.56	0.000278
660	1.97	8.40	9.17	0.000231

Appendix C4: Data Sheet-4

Drying data of Button Mushroom (Tray 4)

Drying Temperature: 50 °C **IMC of button mushroom= 91 % (wb)**

Tray 4 (4th Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	91.00	1011.11	
15	10.11	82.20	461.67	0.366296
30	7.03	74.40	290.56	0.114074
45	5.51	67.33	206.11	0.056296
60	4.58	60.70	154.44	0.034444
90	3.49	48.42	93.89	0.020185
120	2.89	37.72	60.56	0.011111
180	2.45	26.53	36.11	0.004074
240	2.29	21.40	27.22	0.001481
300	2.20	18.18	22.22	0.000833
360	2.14	15.89	18.89	0.000556
420	2.10	14.29	16.67	0.000370
480	2.06	12.71	14.56	0.000352
540	2.03	11.11	12.50	0.000343
600	2.00	9.77	10.83	0.000278
660	1.97	8.63	9.44	0.000231

Appendix C5: Data Sheet-1

Drying data of Oyster Mushroom (Tray 1)

Drying Temperature: 50 °C **IMC of oyster mushroom= 90 % (wb)**

Tray 1 (Bottom tray of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	90.00	900.00	
15	10.15	80.30	407.50	0.328333
30	7.03	71.55	251.50	0.104000
45	5.74	65.16	187.00	0.043000
60	4.69	57.36	134.50	0.035000
90	3.65	45.21	82.50	0.017333
120	3.05	34.43	52.50	0.010000
180	2.64	24.24	32.00	0.003417
240	2.48	19.35	24.00	0.001333
300	2.37	15.61	18.50	0.000917
360	2.32	13.79	16.00	0.000417
420	2.27	11.89	13.50	0.000417
480	2.23	10.31	11.50	0.000333
540	2.20	9.09	10.00	0.000250
600	2.17	7.83	8.50	0.000250

Appendix C6: Data Sheet-2

Drying data of Oyster Mushroom (Tray 2)

Drying Temperature: 50 °C **IMC of oyster mushroom= 90 % (wb)**

Tray 2 (2nd Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	90.00	900.00	
15	10.17	80.33	408.50	0.327667
30	7.04	71.59	252.00	0.104333
45	5.75	65.22	187.50	0.043000
60	4.70	57.45	135.00	0.035000
90	3.67	45.50	83.50	0.017167
120	3.07	34.85	53.50	0.010000
180	2.65	24.53	32.50	0.003500
240	2.49	19.68	24.50	0.001333
300	2.38	15.97	19.00	0.000917
360	2.33	14.16	16.50	0.000417
420	2.28	12.28	14.00	0.000417
480	2.24	10.71	12.00	0.000333
540	2.20	9.09	10.00	0.000333
600	2.18	8.05	8.75	0.000208

Appendix C7: Data Sheet-3

Drying data of Oyster Mushroom (Tray 3)

Drying Temperature: 50 °C **IMC of oyster mushroom= 90 % (wb)**

Tray 3 (3rd Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	90.00	900.00	
15	10.18	80.35	409.00	0.327333
30	7.05	71.63	252.50	0.104333
45	5.77	65.34	188.50	0.042667
60	4.71	57.54	135.50	0.035333
90	3.68	45.65	84.00	0.017167
120	3.08	35.06	54.00	0.010000
180	2.66	24.81	33.00	0.003500
240	2.51	20.32	25.50	0.001250
300	2.39	16.32	19.50	0.001000
360	2.34	14.53	17.00	0.000417
420	2.29	12.66	14.50	0.000417
480	2.25	11.11	12.50	0.000333
540	2.22	9.91	11.00	0.000250
600	2.19	8.68	9.50	0.000250

Appendix C8: Data Sheet-4

Drying data of Oyster Mushroom (Tray 4)

Drying Temperature: 50 °C **IMC of oyster mushroom= 90 % (wb)**

Tray 4 (4th Tray from bottom of dryer)				
Time, min	**Mass**	**MC (wb)**	**MC (db)**	**DR**
0	20.00	90.00	900.00	
15	10.20	80.39	410.00	0.326667
30	7.07	71.71	253.50	0.104333
45	5.78	65.40	189.00	0.043000
60	4.73	57.72	136.50	0.035000
90	3.69	45.80	84.50	0.017333
120	3.09	35.28	54.50	0.010000
180	2.67	25.09	33.50	0.003500
240	2.52	20.63	26.00	0.001250
300	2.40	16.67	20.00	0.001000
360	2.35	14.89	17.50	0.000417
420	2.30	13.04	15.00	0.000417
480	2.26	11.50	13.00	0.000333
540	2.23	10.31	11.50	0.000250
600	2.20	9.09	10.00	0.000250

Appendix C9

Data of ln (MR) with drying time (t) at different trays of button mushroom drying

Time, t in min	ln (MR)			
	T1	T2	T3	T4
0	0.0000	0.0000	0.0000	0.0000
15	-0.1131	-0.1130	-0.1132	-0.1128
30	-0.2250	-0.2248	-0.2251	-0.2245
45	-0.3403	-0.3387	-0.3389	-0.3378
60	-0.4620	-0.4593	-0.4593	-0.4572
90	-0.7303	-0.7277	-0.7300	-0.7249
120	-1.0500	-1.0445	-1.0474	-1.0365
180	-1.5713	-1.5575	-1.5436	-1.5177
240	-1.9122	-1.8899	-1.8937	-1.8512
300	-2.2279	-2.1544	-2.1584	-2.1362
360	-2.4764	-2.3786	-2.4358	-2.4044
420	-2.8270	-2.6484	-2.6812	-2.6462
480	-3.2591	-3.0282	-3.0009	-2.9606
540	-3.8032	-3.4402	-3.4446	-3.4274
600	-4.4850	-4.1164	-4.1552	-4.1177
660	-5.8564	-5.6612	-6.3335	-6.0259

Appendix C10

Data of ln (MR) with drying time (t) at different trays of oyster mushroom drying

Time, t in min	ln (MR)			
	T1	T2	T3	T4
0	0.0000	0.0000	0.0000	0.0000
15	-0.1253	-0.1252	-0.1259	-0.1261
30	-0.2535	-0.2538	-0.2553	-0.2555
45	-0.3589	-0.3591	-0.3603	-0.3615
60	-0.5046	-0.5047	-0.5079	-0.5076
90	-0.7847	-0.7802	-0.7853	-0.7875
120	-1.1227	-1.1128	-1.1205	-1.1233
180	-1.6006	-1.5949	-1.6077	-1.6111
240	-1.9488	-1.9387	-1.9295	-1.9331
300	-2.3329	-2.3158	-2.3419	-2.3458
360	-2.5911	-2.5674	-2.6008	-2.6050
420	-2.9587	-2.9221	-2.9696	-2.9741
480	-3.4204	-3.3596	-3.4334	-3.4385
540	-4.0255	-4.2007	-4.0432	-4.0493
600	-5.9526	-6.0906	-6.0315	-6.0516

APPENDIX D

Score cards for sensory evaluation

Quality grade description	Score
Liked extremely	9
Liked very much	8
Liked moderately	7
Liked slightly	6
Neither Liked nor- disliked	5
Disliked slightly	4
Disliked moderately	3
Disliked very much	2
Disliked extremely	1

Appendix E

Specifications of Hunter lab colorimeter

S. No.	Particulars	Details
1.	Manufacturer's Name	Hunter Associates Laboratory, Inc.
2.	Product Name	Colourflex
3.	Model	CFLX-DIEF, CLFX-45
4.	Illumination and viewing	
	(i) Source	Dual beam Xenon flash lamp
	(ii) Source UV	Nominal match to D65
	(iii) Integrating Sphere	63.5 mm diameter, high efficiency, white coating
5.	Port diameters/view diameters	
	(i) 45/0 model	31.8 mm/25.4 mm
	(ii) Diffuse/80	14.9 mm/8.0 mm

Appendix F

Specifications of water activity meter

S. No.	Particulars	Details
1.	Manufacturer's Name	NOVASINA
2.	Measuring principle	Resistive- electrolyte
3.	Measuring range	0.03……1.00 a_w
4.	Accuracy range	+/- 0.010 a_w 0.10….0.95 a_w (10.95% rh)
5.	Main supply	5 VDC +/- 6% max. power requirement:4W Lithium ion battery 1700 mAh with protection control and "auto load"

6.	Display	Reflective, high contrast LCD- display, dimension: 35×69 mm
7.	Operating	3 multi function key including On/Off
8.	Dimensions approx.	225×140×85 mm
9.	Measuring chamber	Volume 21.1 ml standardized sample dishes Spring-loaded measurement head (diameter 40×12)

Appendix G

Specifications of Solar Water Heater

S. No.	Particulars	Details
1	Tank Capacity:	100 LPD
2	Type of Solar water heater:	Evacuated tube type solar water heater
3	Make:	Electrotherm Solar Ltd., Ahmedabad (Gujrat)
4	Type of collector:	✓ Evacuated tube type solar collector with high efficiency evacuated glass tubes with absorptivity > 92% & emissivity < 0.065. ✓ 3 Layer absorber target coating – (i)Cu for Infrared Reflection Layer, (ii)SS-AlN for Bonding agent cum absorption layer, (iii)AlN– Absorption cum antireflection layer.
5	Number of tubes:	10 Nos
6	Tube Size :	58 mm OD ×1800 mm Length
7	Tank MOC:	SS 304L
8	Collector Area:	1.5 m^2
9	Suitable for No of persons:	3-4
10	Installation space required:	2.5m ×1.2m
11	Tank Insulation:	PUF (38 kg/m^3 and 50 mm thick)
12	Inner and Outer Sealing:	High temperature silicon rubber

Appendix H

Materials utilized for the development of 2 m^3 biogas plant

Sr. No	Materials Required for modified 2 m^3 KVIC plant.	
A.	**Material required for construction**	
	1) Bricks (No's)	2460
	2) Sand (m^3)	1.97
	3) Stone Chips 1/2" or 3/4" (m^3)	0.60
	4) Cement (bags)	13
	5) A.C pipe 100mm internal diameter (R.M.)	3.8
B.	**Material required for central guide frame**	
	1) 35×35×5 mm angle iron (R.M)	10.9
	2) M.S. Pipe 40/68/80 mm	32 mm
	3) Square plate 250 ×250×6 mm (nos)	2
	4) 14 mm diameter and 32 mm long bolts with nuts (nos.)	16
C.	**Materials required for gas holder**	
	1) 35×35×5 mm angle iron (R.M)	16.8
	2) M. S. pipe 50/80/100 mm internal diameter	1.15
	3) 250 mm diameter and 6mm thick flange plate (nos.)	2
	4) Flats 40 × 6 mm thick (R.M.)	4.2
	5) Gas outlet pipe flange 25 mm diameter	1
	6) G.I bend 25 mm diameter (nos.)	1
	7) Heavy duty gas valve 25 mm diameter (nos.)	1
	8) M.S. sheet (2.5 m× 1.25 m) (nos.) (12 guage) (2.5 mm)	2.25
	9) G.I pipe, 2.7 m, 5cm diameter, 14 guage thickness	4 numbers

APPENDIX I

Experimental results of biogas production from the codigestion of cow dung and spent button mushroom substrate in modified plant:

Experimental study of biogas production
Feedstock: Cow dung (75%) + Spent Mushroom Substrate (25%)
Quantity: Mixture of Cow dung 37.50 kg and Spent Mushroom Substrate (SMS) 12.50

Appendix I1: Biogas production per day from codigestion of SMS and Cow dung.

Days	Biogas Production m^3/ day	Biogas Production at STP, m^3/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	Specific Methane Production, L/kg dm	Specific Methane Production, L/kg VS
1	0	0.0000	0.00	0.00	0.00	0.00
2	0	0.0000	0.00	0.00	0.00	0.00
3	0	0.0000	0.00	0.00	0.00	0.00
4	0	0.0000	0.00	0.00	0.00	0.00
5	0	0.0000	0.00	0.00	0.00	0.00
6	2.02	1.8022	117.02	136.64	19.78	23.09
7	1.4	1.2486	81.08	94.67	19.38	22.63
8	1.44	1.2855	83.48	97.47	20.20	23.59
9	1.5	1.3400	87.01	101.60	24.54	28.65
10	1.56	1.3872	90.08	105.18	31.08	36.29
11	1.6	1.4205	92.24	107.70	30.07	35.11
12	1.64	1.4560	94.55	110.39	34.41	40.18
13	1.7	1.5068	97.85	114.25	33.66	39.30
14	1.8	1.5934	103.47	120.81	38.70	45.18
15	1.88	1.6658	108.17	126.30	36.89	43.07
16	1.92	1.7046	110.69	129.24	39.40	46.01
17	1.96	1.7395	112.96	131.89	40.33	47.08
18	2.01	1.7868	116.03	135.48	42.00	49.04
19	2.016	1.7892	116.18	135.66	42.64	49.79
20	2.028	1.7975	116.72	136.29	43.30	50.56
21	2.04	1.8076	117.38	137.05	44.37	51.81
22	2.01	1.7827	115.76	135.17	51.40	60.01
23	2.03	1.8058	117.26	136.91	54.17	63.25
24	2.02	1.7893	116.19	135.66	56.35	65.80
25	2.02	1.7870	116.04	135.49	57.21	66.80
26	2.046	1.8111	117.61	137.32	58.92	68.80
27	2.036	1.8011	116.96	136.56	59.88	69.92
28	2.014	1.7805	115.62	135.00	63.01	73.57
29	2.026	1.7876	116.08	135.54	63.61	74.28
30	2.04	1.8012	116.96	136.56	65.73	76.75
31	2.042	1.8018	117.00	136.61	65.17	76.09
32	2.054	1.8124	117.69	137.41	65.20	76.13
33	2.042	1.8029	117.07	136.70	66.97	78.19
34	2.034	1.7988	116.80	136.38	67.05	78.28

35	2.03	1.7941	116.50	136.03	66.17	77.26
36	2.02	1.7824	115.74	135.14	63.54	74.19
37	2.024	1.7859	115.97	135.40	64.71	75.56
38	2.028	1.7877	116.08	135.54	64.66	75.50
39	2.034	1.8005	116.92	136.52	65.94	76.99
40	2.01	1.7764	115.35	134.69	65.06	75.96
41	2.014	1.7771	115.39	134.74	64.74	75.59
42	2.02	1.7778	115.44	134.79	66.03	77.10
43	2.034	1.7912	116.31	135.81	66.65	77.82
44	2.028	1.7825	115.75	135.15	66.90	78.12
45	1.96	1.7294	112.30	131.12	63.34	73.95
46	2.004	1.7728	115.12	134.41	64.58	75.41
47	2.001	1.7673	114.76	134.00	64.15	74.90
48	2.036	1.7976	116.73	136.30	65.02	75.92
49	2.048	1.8159	117.91	137.68	66.50	77.65
50	2.02	1.7852	115.92	135.36	65.73	76.75
51	2.034	1.8005	116.92	136.52	66.53	77.68
52	2.048	1.8106	117.57	137.28	67.37	78.66
53	2.054	1.8153	117.88	137.63	67.31	78.59
54	2.042	1.8041	117.15	136.79	64.31	75.10
55	2.054	1.8141	117.80	137.55	66.44	77.58
56	2.056	1.8141	117.80	137.55	66.20	77.30
57	2.034	1.7941	116.50	136.03	65.36	76.31
58	2.02	1.7806	115.63	135.01	65.56	76.55
59	2.014	1.7748	115.24	134.56	64.88	75.76
60	2.024	1.7819	115.70	135.10	66.07	77.14
61	2.042	1.7960	116.62	136.17	66.71	77.89
62	2.048	1.8012	116.96	136.57	65.97	77.02
63	2.036	1.7901	116.24	135.73	65.21	76.14
64	2.02	1.7766	115.36	134.70	64.95	75.84
65	2.024	1.7888	116.15	135.62	64.93	75.81
66	2.03	1.7912	116.31	135.81	65.25	76.19
67	2.034	1.7959	116.61	136.16	65.07	75.98
68	2.028	1.7900	116.23	135.72	64.63	75.46
69	2.01	1.7712	115.02	134.29	62.80	73.32
70	2.016	1.7691	114.88	134.13	61.80	72.16
71	2.02	1.7755	115.29	134.62	60.99	71.21
72	2.024	1.7778	115.44	134.79	62.11	72.52
73	2.03	1.7854	115.94	135.37	62.72	73.23
74	2.02	1.7738	115.18	134.49	62.08	72.49
75	2.014	1.7708	114.98	134.26	65.31	76.26
76	2.024	1.7830	115.78	135.19	63.56	74.22
77	2.048	1.8024	117.04	136.66	64.14	74.89
78	2.042	1.7965	116.66	136.21	65.91	76.96
79	2.036	1.7895	116.20	135.68	66.58	77.75
80	2.02	1.7766	115.36	134.70	64.83	75.70
Average	**1.852**	**1.636**	**106.26**	**124.07**	**54.06**	**63.12**

Appendix I2: Cumulative biogas, methane, and carbon dioxide production.

Days	Biogas Production at STP, m^3/day	Cumulative Biogas Production, m^3	Cumulative Biogas Production at STP, m^3	Methane (CH_4), %	Carbon dioxide (CO_2), %	Cumulative Methane Yield at STP, m^3	Cumulative Carbon dioxide Yield at STP, m^3
1	0.0000	0	0.0000	0	0	0.000	0.000
2	0.0000	0	0.0000	0	0	0.000	0.000
3	0.0000	0	0.0000	0	0	0.000	0.000
4	0.0000	0	0.0000	0	0	0.000	0.000
5	0.0000	0	0.0000	0	0	0.000	0.000
6	1.8022	2.02	1.8022	16.9	53.4	0.305	0.962
7	1.2486	3.42	3.0508	23.9	46.3	0.603	1.540
8	1.2855	4.86	4.3363	24.2	46.1	0.914	2.133
9	1.3400	6.36	5.6763	28.2	47	1.292	2.763
10	1.3872	7.92	7.0635	34.5	43.5	1.771	3.366
11	1.4205	9.52	8.4840	32.6	42.6	2.234	3.971
12	1.4560	11.16	9.9400	36.4	40.4	2.764	4.560
13	1.5068	12.86	11.4468	34.4	40	3.282	5.162
14	1.5934	14.66	13.0402	37.4	39.1	3.878	5.785
15	1.6658	16.54	14.7060	34.1	38.8	4.446	6.432
16	1.7046	18.46	16.4106	35.6	41.1	5.053	7.132
17	1.7395	20.42	18.1502	35.7	41.8	5.674	7.859
18	1.7868	22.43	19.9370	36.2	39.2	6.321	8.560
19	1.7892	24.446	21.7262	36.7	41.2	6.977	9.297
20	1.7975	26.474	23.5238	37.1	41.2	7.644	10.038
21	1.8076	28.514	25.3313	37.8	40.1	8.327	10.763
22	1.7827	30.524	27.1141	44.4	38.6	9.119	11.451
23	1.8058	32.554	28.9199	46.2	38.6	9.953	12.148
24	1.7893	34.574	30.7092	48.5	37.6	10.821	12.820
25	1.7870	36.594	32.4961	49.3	39.4	11.702	13.525
26	1.8111	38.64	34.3073	50.1	37.6	12.609	14.206
27	1.8011	40.676	36.1084	51.2	37.5	13.532	14.881
28	1.7805	42.69	37.8889	54.5	36.8	14.502	15.536
29	1.7876	44.716	39.6766	54.8	35.2	15.482	16.165
30	1.8012	46.756	41.4777	56.2	36	16.494	16.814
31	1.8018	48.798	43.2795	55.7	37.1	17.497	17.482
32	1.8124	50.852	45.0918	55.4	36.1	18.501	18.137
33	1.8029	52.894	46.8948	57.2	36	19.533	18.786
34	1.7988	54.928	48.6936	57.4	35.8	20.565	19.430
35	1.7941	56.958	50.4876	56.8	34.6	21.584	20.050
36	1.7824	58.978	52.2700	54.9	35.2	22.563	20.678
37	1.7859	61.002	54.0559	55.8	35.8	23.559	21.317
38	1.7877	63.03	55.8435	55.7	35.4	24.555	21.950
39	1.8005	65.064	57.6441	56.4	36.1	25.571	22.600
40	1.7764	67.074	59.4205	56.4	34.6	26.572	23.215
41	1.7771	69.088	61.1975	56.1	34.2	27.569	23.822
42	1.7778	71.108	62.9753	57.2	33.5	28.586	24.418
43	1.7912	73.142	64.7665	57.3	35.1	29.613	25.047
44	1.7825	75.17	66.5490	57.8	36.1	30.643	25.690
45	1.7294	77.13	68.2784	56.4	34.1	31.618	26.280
46	1.7728	79.134	70.0512	56.1	34.1	32.613	26.884

47	1.7673	81.135	71.8185	55.9	35.2	33.601	27.506
48	1.7976	83.171	73.6162	55.7	35.6	34.602	28.146
49	1.8159	85.219	75.4320	56.4	36.1	35.626	28.802
50	1.7852	87.239	77.2173	56.7	34.2	36.638	29.412
51	1.8005	89.273	79.0178	56.9	34.6	37.663	30.035
52	1.8106	91.321	80.8284	57.3	33.4	38.700	30.640
53	1.8153	93.375	82.6437	57.1	35.6	39.737	31.286
54	1.8041	95.417	84.4478	54.9	37.1	40.727	31.956
55	1.8141	97.471	86.2619	56.4	34.8	41.751	32.587
56	1.8141	99.527	88.0760	56.2	35.4	42.770	33.229
57	1.7941	101.561	89.8701	56.1	34.8	43.777	33.854
58	1.7806	103.581	91.6507	56.7	34.2	44.786	34.463
59	1.7748	105.595	93.4255	56.3	35.1	45.785	35.085
60	1.7819	107.619	95.2074	57.1	34.8	46.803	35.706
61	1.7960	109.661	97.0033	57.2	35.4	47.830	36.341
62	1.8012	111.709	98.8046	56.4	35.4	48.846	36.979
63	1.7901	113.745	100.5947	56.1	35.8	49.850	37.620
64	1.7766	115.765	102.3713	56.3	35.8	50.850	38.256
65	1.7888	117.789	104.1600	55.9	36.1	51.850	38.902
66	1.7912	119.819	105.9512	56.1	34.8	52.855	39.525
67	1.7959	121.853	107.7471	55.8	35.2	53.857	40.157
68	1.7900	123.881	109.5371	55.6	35	54.853	40.784
69	1.7712	125.891	111.3083	54.6	36.1	55.820	41.423
70	1.7691	127.907	113.0774	53.8	36.2	56.771	42.063
71	1.7755	129.927	114.8529	52.9	37.1	57.711	42.722
72	1.7778	131.951	116.6307	53.8	35.6	58.667	43.355
73	1.7854	133.981	118.4161	54.1	35.4	59.633	43.987
74	1.7738	136.001	120.1899	53.9	34.3	60.589	44.595
75	1.7708	138.015	121.9606	56.8	37.1	61.595	45.252
76	1.7830	140.039	123.7436	54.9	36.5	62.574	45.903
77	1.8024	142.087	125.5460	54.8	36.5	63.561	46.561
78	1.7965	144.129	127.3426	56.5	37.8	64.577	47.240
79	1.7895	146.165	129.1321	57.3	36.2	65.602	47.888
80	1.7766	148.185	130.9087	56.2	37.2	66.600	48.549

Appendix I3: Total Volatile Solids Mass Removal Efficiency (TVMRE)

Days	Biogas Production at STP, m^3/day	Temperature of substrate inside digester, ^{o} C	Methane (CH_4), %	Carbon dioxide (CO_2), %	Dry Biogas Factor (DBF)	TVSMRE, %
1	0.0000	31.5	0	0	0.000	0.000
2	0.0000	32	0	0	0.000	0.000
3	0.0000	32.5	0	0	0.000	0.000
4	0.0000	32.5	0	0	0.000	0.000
5	0.0000	32.5	0	0	0.000	0.000
6	1.8022	33	16.9	53.4	0.892	6.033
7	1.2486	33.1	23.9	46.3	0.892	5.271
8	1.2855	32.8	24.2	46.1	0.893	5.482
9	1.3400	32.6	28.2	47	0.893	6.506
10	1.3872	34	34.5	43.5	0.889	7.863
11	1.4205	34.5	32.6	42.6	0.888	7.633

12	1.4560	34.5	36.4	40.4	0.888	8.554
13	1.5068	35	34.4	40	0.886	8.400
14	1.5934	35.4	37.4	39.1	0.885	9.523
15	1.6658	35.1	34.1	38.8	0.886	9.178
16	1.7046	34.5	35.6	41.1	0.888	9.841
17	1.7395	34.6	35.7	41.8	0.888	10.085
18	1.7868	34.1	36.2	39.2	0.889	10.422
19	1.7892	34.6	36.7	41.2	0.888	10.609
20	1.7975	35	37.1	41.2	0.886	10.746
21	1.8076	35.1	37.8	40.1	0.886	10.948
22	1.7827	34.8	44.4	38.6	0.887	12.431
23	1.8058	33.9	46.2	38.6	0.890	13.091
24	1.7893	35.2	48.5	37.6	0.886	13.469
25	1.7870	35.6	49.3	39.4	0.885	13.692
26	1.8111	35.4	50.1	37.6	0.885	14.035
27	1.8011	35.6	51.2	37.5	0.885	14.226
28	1.7805	35.8	54.5	36.8	0.884	14.863
29	1.7876	36.4	54.8	35.2	0.882	14.920
30	1.8012	36.2	56.2	36	0.883	15.424
31	1.8018	36.4	55.7	37.1	0.882	15.326
32	1.8124	36.4	55.4	36.1	0.882	15.308
33	1.8029	36.2	57.2	36	0.883	15.694
34	1.7988	35.7	57.4	35.8	0.884	15.727
35	1.7941	35.9	56.8	34.6	0.884	15.487
36	1.7824	36.4	54.9	35.2	0.882	14.901
37	1.7859	36.4	55.8	35.8	0.882	15.176
38	1.7877	36.7	55.7	35.4	0.881	15.139
39	1.8005	35.4	56.4	36.1	0.885	15.512
40	1.7764	35.9	56.4	34.6	0.884	15.234
41	1.7771	36.4	56.1	34.2	0.882	15.127
42	1.7778	37.2	57.2	33.5	0.880	15.348
43	1.7912	37	57.3	35.1	0.881	15.549
44	1.7825	37.6	57.8	36.1	0.879	15.599
45	1.7294	36.4	56.4	34.1	0.882	14.792
46	1.7728	35.6	56.1	34.1	0.885	15.127
47	1.7673	36.1	55.9	35.2	0.883	15.039
48	1.7976	36.2	55.7	35.6	0.883	15.254
49	1.8159	34.9	56.4	36.1	0.887	15.670
50	1.7852	35.9	56.7	34.2	0.884	15.373
51	1.8005	35.4	56.9	34.6	0.885	15.593
52	1.8106	35.8	57.3	33.4	0.884	15.724
53	1.8153	35.9	57.1	35.6	0.884	15.778
54	1.8041	36	54.9	37.1	0.883	15.162
55	1.8141	36.1	56.4	34.8	0.883	15.553
56	1.8141	36.4	56.2	35.4	0.882	15.506
57	1.7941	36.5	56.1	34.8	0.882	15.286
58	1.7806	36.7	56.7	34.2	0.881	15.293
59	1.7748	36.8	56.3	35.1	0.881	15.166
60	1.7819	37.1	57.1	34.8	0.880	15.403
61	1.7960	37.4	57.2	35.4	0.880	15.554
62	1.8012	37.4	56.4	35.4	0.880	15.397
63	1.7901	37.5	56.1	35.8	0.879	15.234
64	1.7766	37.4	56.3	35.8	0.880	15.174

65	1.7888	35.9	55.9	36.1	0.884	15.260
66	1.7912	36.4	56.1	34.8	0.882	15.266
67	1.7959	36.2	55.8	35.2	0.883	15.252
68	1.7900	36.3	55.6	35	0.883	15.140
69	1.7712	36.8	54.6	36.1	0.881	14.742
70	1.7691	38.1	53.8	36.2	0.878	14.467
71	1.7755	37.6	52.9	37.1	0.879	14.345
72	1.7778	37.8	53.8	35.6	0.878	14.534
73	1.7854	37.4	54.1	35.4	0.880	14.684
74	1.7738	37.9	53.9	34.3	0.878	14.481
75	1.7708	37.5	56.8	37.1	0.879	15.283
76	1.7830	36.9	54.9	36.5	0.881	14.922
77	1.8024	37.2	54.8	36.5	0.880	15.045
78	1.7965	37.3	56.5	37.8	0.880	15.461
79	1.7895	37.6	57.3	36.2	0.879	15.538
80	1.7766	37.4	56.2	37.2	0.880	15.192
Average	**1.6364**	**35.74**	**47.22**	**34.91**	**0.828**	**12.813**

APPENDIX J: Laboratory Results of Biomethanation Study

Lab Results of Biomethanation study (Treatment 1-3)

Day	(T1)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T2)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T3)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS
1	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
2	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
3	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
4	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
5	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
6	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.0	0.00	0.00
7	23	20.93	0.33	0.38	20	18.20	0.20	0.23	15	13.7	0.12	0.13
8	40	36.40	0.58	0.67	60	54.60	0.61	0.68	27	24.6	0.21	0.23
9	90	81.90	1.30	1.50	80	72.80	0.81	0.91	40	36.4	0.31	0.34
10	120	109.20	1.73	2.00	100	91.00	1.02	1.14	90	81.9	0.71	0.78
11	160	145.60	2.31	2.67	140	127.40	1.43	1.59	120	109.2	0.94	1.03
12	210	191.10	3.03	3.50	190	172.90	1.93	2.16	140	127.4	1.10	1.21
13	230	209.30	3.32	3.84	196	178.36	2.00	2.23	148	134.7	1.16	1.27
14	240	218.40	3.46	4.00	204	185.64	2.08	2.32	154	140.1	1.21	1.33
15	270	245.70	3.89	4.50	215	195.65	2.19	2.44	158	143.8	1.24	1.36
16	274	249.34	3.95	4.57	221	201.11	2.25	2.51	162	147.4	1.27	1.40
17	281	255.71	4.05	4.69	228	207.48	2.32	2.59	164	149.2	1.29	1.41
18	284	258.44	4.10	4.74	229	208.39	2.33	2.60	167	152.0	1.31	1.44
19	288	262.08	4.15	4.80	231	210.21	2.35	2.62	168	152.9	1.32	1.45
20	290	263.90	4.18	4.84	235	213.85	2.39	2.67	169	153.8	1.33	1.46
21	280	254.80	4.04	4.67	241	219.31	2.45	2.74	164	149.2	1.29	1.41
22	271	246.61	3.91	4.52	238	216.58	2.42	2.70	156	142.0	1.23	1.34
23	268	243.88	3.86	4.47	239	217.49	2.43	2.72	148	134.7	1.16	1.27
24	260	236.60	3.75	4.34	238	216.58	2.42	2.70	144	131.0	1.13	1.24
25	255	232.05	3.68	4.25	235	213.85	2.39	2.67	134	121.9	1.05	1.15
26	260	236.60	3.75	4.34	231	210.21	2.35	2.62	132	120.1	1.04	1.14
27	255	232.05	3.68	4.25	226	205.66	2.30	2.57	134	121.9	1.05	1.15
28	260	236.60	3.75	4.34	221	201.11	2.25	2.51	128	116.5	1.01	1.10
29	240	218.40	3.46	4.00	214	194.74	2.18	2.43	118	107.4	0.93	1.02
30	230	209.30	3.32	3.84	204	185.64	2.08	2.32	117	106.5	0.92	1.01

31	220	200.20	3.17	3.67	184	167.44	1.87	2.09	115	104.7	0.90	0.99
32	200	182.00	2.88	3.34	176	160.16	1.79	2.00	98	89.2	0.77	0.84
33	200	182.00	2.88	3.34	151	137.41	1.54	1.72	90	81.9	0.71	0.78
34	190	172.90	2.74	3.17	135	122.85	1.37	1.53	72	65.5	0.57	0.62
35	170	154.70	2.45	2.84	110	100.10	1.12	1.25	54	49.1	0.42	0.47
36	140	127.40	2.02	2.34	100	91.00	1.02	1.14	46	41.9	0.36	0.40
37	120	109.20	1.73	2.00	90	81.90	0.92	1.02	43	39.1	0.34	0.37
38	75	68.25	1.08	1.25	51	46.41	0.52	0.58	37	33.7	0.29	0.32
39	55	50.05	0.79	0.92	26	23.66	0.26	0.30	21	19.1	0.17	0.18
40	30	27.30	0.43	0.50	14	12.74	0.14	0.16	5	4.6	0.04	0.04
	6.78	**6.17**	**97.76**	**113.09**	**5.67**	**5.16**	**57.75**	**64.45**	**3.678**	**3.347**	**28.93**	**31.68**

Lab Results of Biomethanation study (Treatment 4-6)

Day	(T4)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T5)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T6)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS
1	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
7	5.00	4.55	0.03	0.03	23	20.93	0.57	0.72	23	20.93	0.34	0.40
8	5.00	4.55	0.03	0.03	46	41.86	1.14	1.44	49	44.59	0.72	0.85
9	12.50	11.38	0.08	0.09	124	112.84	3.07	3.89	124	112.84	1.83	2.14
10	22.50	20.48	0.14	0.16	201	182.91	4.97	6.31	195	177.45	2.88	3.36
11	30.00	27.30	0.19	0.21	229	208.39	5.66	7.19	219	199.29	3.24	3.78
12	40.00	36.40	0.26	0.28	238	216.58	5.89	7.47	230	209.30	3.40	3.97
13	41.00	37.31	0.26	0.28	260	236.60	6.43	8.16	240	218.40	3.55	4.14
14	42.50	38.68	0.27	0.29	283	257.53	7.00	8.88	270	245.70	3.99	4.66
15	43.00	39.13	0.28	0.30	290	263.90	7.17	9.10	280	254.80	4.14	4.83

16	44.50	40.50	0.29	0.31	295	268.45	7.29	9.26	284	258.44	4.20	4.90
17	46.00	41.86	0.29	0.32	284	258.44	7.02	8.91	275	250.25	4.06	4.74
18	47.50	43.23	0.30	0.33	305	277.55	7.54	9.57	286	260.26	4.23	4.93
19	47.00	42.77	0.30	0.33	302	274.82	7.47	9.48	293	266.63	4.33	5.05
20	45.00	40.95	0.29	0.31	306	278.46	7.57	9.60	290	263.90	4.28	5.00
21	45.00	40.95	0.29	0.31	302	274.82	7.47	9.48	280	254.80	4.14	4.83
22	44.00	40.04	0.28	0.31	302	274.82	7.47	9.48	275	250.25	4.06	4.74
23	43.50	39.59	0.28	0.30	288	262.08	7.12	9.04	274	249.34	4.05	4.73
24	43.00	39.13	0.28	0.30	285	259.35	7.05	8.94	270	245.70	3.99	4.66
25	42.50	38.68	0.27	0.29	285	259.35	7.05	8.94	270	245.70	3.99	4.66
26	42.00	38.22	0.27	0.29	280	254.80	6.92	8.79	268	243.88	3.96	4.62
27	41.00	37.31	0.26	0.28	275	250.25	6.80	8.63	265	241.15	3.91	4.57
28	37.50	34.13	0.24	0.26	265	241.15	6.55	8.32	257	233.87	3.80	4.43
29	37.50	34.13	0.24	0.26	254	231.14	6.28	7.97	240	218.40	3.55	4.14
30	35.00	31.85	0.22	0.24	240	218.40	5.93	7.53	230	209.30	3.40	3.97
31	35.00	31.85	0.22	0.24	225	204.75	5.56	7.06	210	191.10	3.10	3.62
32	35.00	31.85	0.22	0.24	216	196.56	5.34	6.78	206	187.46	3.04	3.55
33	32.50	29.58	0.21	0.23	189	171.99	4.67	5.93	180	163.80	2.66	3.10
34	32.50	29.58	0.21	0.23	182	165.62	4.50	5.71	176	160.16	2.60	3.04
35	30.00	27.30	0.19	0.21	178	161.98	4.40	5.59	172	156.52	2.54	2.97
36	25.00	22.75	0.16	0.17	169	153.79	4.18	5.30	155	141.05	2.29	2.67
37	21.50	19.57	0.14	0.15	146	132.86	3.61	4.58	135	122.85	1.99	2.33
38	18.50	16.84	0.12	0.13	137	124.67	3.39	4.30	110	100.10	1.63	1.90
39	10.50	9.56	0.07	0.07	123	111.93	3.04	3.86	85	77.35	1.26	1.47
40	2.50	2.28	0.02	0.02	109	99.19	2.70	3.42	67	60.97	0.99	1.16
	1.13	**1.02**	**7.21**	**7.81**	**7.63**	**6.95**	**188.83**	**239.63**	**7.183**	**6.54**	**106.11**	**123.90**

Lab Results of Biomethanation study (Treatment 7-9)

Day	(T7)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T8)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS	(T9)	Daily biogas production at STP, ml/day	Specific Biogas Production L/kg dm	Specific Biogas Production L/kg VS
1	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
2	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
3	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
4	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
5	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
6	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
7	20	18.20	0.21	0.24	20	18.20	0.16	0.18	10	9.10	0.07	0.07
8	40	36.40	0.42	0.48	30	27.30	0.25	0.36	10	9.10	0.07	0.07
9	70	63.70	0.74	0.83	80	72.80	0.65	0.64	25	22.75	0.17	0.18
10	120	109.20	1.26	1.43	120	109.20	0.98	1.09	45	40.95	0.30	0.33
11	140	127.40	1.47	1.67	140	127.40	1.15	1.27	60	54.60	0.40	0.44
12	160	145.60	1.69	1.90	155	141.05	1.27	1.45	80	72.80	0.54	0.59
13	190	172.90	2.00	2.26	160	145.60	1.31	1.72	82	74.62	0.55	0.60
14	200	182.00	2.11	2.38	170	154.70	1.39	1.82	85	77.35	0.57	0.62
15	220	200.20	2.32	2.62	172	156.52	1.41	2.00	86	78.26	0.58	0.63
16	242	220.22	2.55	2.88	178	161.98	1.46	2.20	89	80.99	0.60	0.65
17	248	225.68	2.61	2.95	184	167.44	1.51	2.25	92	83.72	0.62	0.67
18	250	227.50	2.63	2.97	189	171.99	1.55	2.27	95	86.45	0.64	0.70
19	258	234.78	2.72	3.07	188	171.08	1.54	2.34	94	85.54	0.63	0.69
20	264	240.24	2.78	3.14	180	163.80	1.47	2.40	90	81.90	0.60	0.66
21	268	243.88	2.82	3.19	180	163.80	1.47	2.43	90	81.90	0.60	0.66
22	270	245.70	2.84	3.21	176	160.16	1.44	2.45	88	80.08	0.59	0.65
23	270	245.70	2.84	3.21	174	158.34	1.42	2.45	87	79.17	0.58	0.64
24	260	236.60	2.74	3.09	172	156.52	1.41	2.36	86	78.26	0.58	0.63
25	255	232.05	2.69	3.03	170	154.70	1.39	2.31	85	77.35	0.57	0.62
26	260	236.60	2.74	3.09	168	152.88	1.37	2.36	84	76.44	0.56	0.62
27	255	232.05	2.69	3.03	164	149.24	1.34	2.31	82	74.62	0.55	0.60
28	254	231.14	2.68	3.02	150	136.50	1.23	2.31	75	68.25	0.50	0.55
29	234	212.94	2.46	2.78	150	136.50	1.23	2.12	75	68.25	0.50	0.55

30	220	200.20	2.32	2.62	140	127.40	1.15	2.00	70	63.70	0.47	0.51
31	202	183.82	2.13	2.40	140	127.40	1.15	1.83	70	63.70	0.47	0.51
32	200	182.00	2.11	2.38	140	127.40	1.15	1.82	70	63.70	0.47	0.51
33	170	154.70	1.79	2.02	130	118.30	1.06	1.54	65	59.15	0.43	0.48
34	168	152.88	1.77	2.00	130	118.30	1.06	1.52	65	59.15	0.43	0.48
35	162	147.42	1.71	1.93	120	109.20	0.98	1.47	60	54.60	0.40	0.44
36	152	138.32	1.60	1.81	100	91.00	0.82	1.38	50	45.50	0.33	0.37
37	110	100.10	1.16	1.31	86	78.26	0.70	1.00	43	39.13	0.29	0.32
38	90	81.90	0.95	1.07	74	67.34	0.61	0.82	37	33.67	0.25	0.27
39	32	29.12	0.34	0.38	41	37.31	0.34	0.29	21	19.11	0.14	0.15
40	20	18.20	0.21	0.24	10	9.10	0.08	0.18	5	4.55	0.03	0.04
	6.27	**5.71**	**66.08**	**74.62**	**4.58**	**4.17**	**37.49**	**56.94**	**2.25**	**2.05**	**15.06**	**16.52**

Appendix K

Uncertainty Analysis of Lab scale results of Biogas Production

Treatment T1, 25% SpOMS +75% Cow dung					**Treatment T2, 50% SpOMS +50% Cow dung**					**Treatment T3, 75% SpOMS +25% Cow dung**				
B1R1	B1R2	Average of B1R1 and B1R2	Uncertainty	Average ± Uncertainty	B2R1	B2R2	Average	Uncertainty	Average± Uncertainty	B3R1	B3R2	Average	Uncertainty	Average±Uncertainty
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	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	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	0	0	0	0	0	0
24	22	23	1	23±1	22	18	20	2	20±2	15	15	15	0	15±0
42	38	40	2	40±2	63	57	60	3	60±3	28	26	27	1	27±1
91	89	90	1	90±1	84	76	80	4	80±4	41	39	40	1	40±1
123	117	120	3	120±3	102	98	100	2	100±2	89	91	90	1	90±1
162	158	160	2	160±2	141	139	140	1	140±1	122	118	120	2	120±2
214	206	210	4	210±4	189	191	190	1	190±1	142	138	140	2	140±2
229	231	230	1	230±1	197	195	196	1	196±1	150	146	148	2	148±2
243	237	240	3	240±3	201	207	204	3	204±3	153	155	154	1	154±1
272	268	270	2	270±2	219	211	215	4	215±4	160	156	158	2	158±2
277	271	274	3	274±3	224	218	221	3	221±3	164	160	162	2	162±2
282	280	281	1	281±1	228	228	228	0	228±0	167	161	164	3	164±3
285	283	284	1	284±1	231	227	229	2	229±2	168	166	167	1	167±1

290	286	288	2	288±2	233	229	231	2	231±2	169	167	168	1	168±1
292	288	290	2	290±2	237	233	235	2	235±2	171	167	169	2	169±2
282	278	280	2	280±2	241	241	241	0	241±0	166	162	164	2	164±2
273	269	271	2	271±2	239	237	238	1	238±1	158	154	156	2	156±2
268	268	268	0	268±0	238	240	239	1	239±1	149	147	148	1	148±1
261	259	260	1	260±1	239	237	238	1	238±1	146	142	144	2	144±2
254	256	255	1	255±1	237	233	235	2	235±2	137	131	134	3	134±3
261	259	260	1	260±1	233	229	231	2	231±2	135	129	132	3	132±3
254	256	255	1	255±1	229	223	226	3	226±3	136	132	134	2	134±2
262	258	260	2	260±2	224	218	221	3	221±3	130	126	128	2	128±2
242	238	240	2	240±2	216	212	214	2	214±2	121	115	118	3	118±3
231	229	230	1	230±1	207	201	204	3	204±3	120	114	117	3	117±3
221	219	220	1	220±1	185	183	184	1	184±1	118	112	115	3	115±3
202	198	200	2	200±2	176	176	176	0	176±0	100	96	98	2	98±2
203	197	200	3	200±3	150	152	151	1	151±1	91	89	90	1	90±1
194	186	190	4	190±4	136	134	135	1	135±1	74	70	72	2	72±2
171	169	170	1	170±1	112	108	110	2	110±2	56	52	54	2	54±2
143	137	140	3	140±3	98	102	100	2	100±2	46	46	46	0	46±0
121	119	120	1	120±1	91	89	90	1	90±1	44	42	43	1	43±1
76	74	75	1	75±1	52	50	51	1	51±1	38	36	37	1	37±1
57	53	55	2	55±2	27	25	26	1	26±1	22	20	21	1	21±1
31	29	30	1	30±1	13	15	14	1	14±1	5	5	5	0	5±0

Uncertainty Analysis of Treatment 4, 6 and 7

Treatment T4, 100% SpOMS					Treatment T6, 25% SpBMS +75% Cow dung					Treatment T7,50% SpBMS +50% Cow dung				
B4R1	B4R2	Average	Uncertainty	Average ±Uncertainty	O1R1	O1R2	Average of Pand Q	Uncertainty	Average± Uncertainty	O2R1	O2R2	Average	Uncertainty	Average±Uncertainty
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
0	0	0.00	0.00	0.00	0	0	0	0	0	0	0.00	0.00	0.00	0.00
5	5	5.00	0.00	5±0	24	22	23	1	23±1	21	19.00	20.00	1.00	20±1
5	5	5.00	0.00	5±	51	47	49	2	49±2	42	38.00	40.00	2.00	40±2
13	12	12.50	0.50	12.5±0.5	125	123	124	1	124±1	71	69.00	70.00	1.00	70±1
24	21	22.50	1.50	22.5±1.5	197	193	195	2	195±2	121	119.00	120.00	1.00	120±1
31	29	30.00	1.00	30±1	220	218	219	1	219±1	142	138.00	140.00	2.00	140±2
42	38	40.00	2.00	40±2	231	229	230	1	230±1	163	157.00	160.00	3.00	160±3
43	39	41.00	2.00	41±2	242	238	240	2	240±2	189	191.00	190.00	1.00	190±1
43	42	42.50	0.50	42.5±0.5	273	267	270	3	270±3	202	198.00	200.00	2.00	200±2
45	41	43.00	2.00	43±2	281	279	280	1	280±1	223	217.00	220.00	3.00	220±3
46	43	44.50	1.50	44.50±1.50	283	285	284	1	284±1	244	240.00	242.00	2.00	242±2
47	45	46.00	1.00	46±1	276	274	275	1	275±1	251	245.00	248.00	3.00	248±3
48	47	47.50	0.50	47.5±0.5	287	285	286	1	286±1	252	248.00	250.00	2.00	250±2
49	45	47.00	2.00	47±2	294	292	293	1	293±1	261	255.00	258.00	3.00	258±3
46	44	45.00	1.00	45±1	292	288	290	2	290±2	267	261.00	264.00	3.00	264±3

46	44	45.00	1.00	45±1	281	279	280	1	280±1	268	268.00	268.00	0.00	268±0
45	43	44.00	1.00	44±1	276	274	275	1	275±1	271	269.00	270.00	1.00	270±1
44	43	43.50	0.50	43.5±0.5	274	274	274	0	274±0	275	265.00	270.00	5.00	270±5
43	43	43.00	0.00	43±0	271	269	270	1	270±1	264	256.00	260.00	4.00	260±4
43	42	42.50	0.50	42.5±0.5	270	270	270	0	270±0	254	256.00	255.00	1.00	255±1
42	42	42.00	0.00	42±0	269	267	268	1	268±1	263	257.00	260.00	3.00	260±3
42	40	41.00	1.00	41±1	266	264	265	1	265±1	257	253.00	255.00	2.00	255±2
38	37	37.50	0.50	37.5±0.5	257	257	257	0	257±0	255	253.00	254.00	1.00	254±1
37	38	37.50	0.50	37.5±0.5	242	238	240	2	240±2	236	232.00	234.00	2.00	234±2
36	34	35.00	1.00	35±1	231	229	230	1	230±1	221	219.00	220.00	1.00	220±1
35	35	35.00	0.00	35±0	213	207	210	3	210±3	204	200.00	202.00	2.00	202±2
34	36	35.00	1.00	35±1	207	205	206	1	206±1	201	199.00	200.00	1.00	200±1
33	32	32.50	0.50	32.5±0.5	183	177	180	3	180±3	172	168.00	170.00	2.00	170±2
33	32	32.50	0.50	32.5±0.5	178	174	176	2	176±2	169	167.00	168.00	1.00	168±1
30	30	30.00	0.00	30±0	173	171	172	1	172±1	164	160.00	162.00	2.00	162±2
24	26	25.00	1.00	25±1	157	153	155	2	155±2	154	150.00	152.00	2.00	152±2
22	21	21.50	0.50	21.5±0.5	136	134	135	1	135±1	111	109.00	110.00	1.00	110±1
19	18	18.50	0.50	18.5±0.5	112	108	110	2	110±2	94	86.00	90.00	4.00	90±4
11	10	10.50	0.50	10.5±0.5	87	83	85	2	85±2	35	29.00	32.00	3.00	32±3
3	2	2.50	0.50	2.5±0.5	69	65	67	2	67±2	21	19.00	20.00	1.00	20±1

Uncertainty Analysis of Treatment 8 and 9

Treatment T8, 75% SpBMS +25% Cow dung					Treatment T9, 100% SpBMS				
O3R1	O3R2	Average	Uncertainty	Average±Uncertainty	O4R1	O4R2	Average	Uncertainty	Average±Uncertainty
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	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	0	0	0	0
21	19	20	1	20±1	10	9	9.5	0.5	9.5±0.5
32	28	30	2	30±2	11	9	10	1	10±1
79	81	80	1	80±1	26	24	25	1	25±1
123	117	120	3	120±3	47	43	45	2	45±2
143	137	140	3	140±3	63	57	60	3	60±3
154	156	155	1	155±1	82	78	80	2	80±2
164	156	160	4	160±4	82	82	82	0	82±0
172	168	170	2	170±2	86	82	84	2	84±2
174	170	172	2	172±2	89	81	85	4	85±4
179	177	178	1	178±1	90	87	88.5	1.5	88.5±1.5
185	183	184	1	184±1	93	90	91.5	1.5	91.5±1.5
189	189	189	0	189±0	94	96	95	1	95±1
187	189	188	1	188±1	94	95	94.5	0.5	94.5±0.5
179	181	180	1	180±1	91	90	90.5	0.5	90.5±0.5
180	180	180	0	180±0	90	90	90	0	90±0
175	177	176	1	176±1	89	88	88.5	0.5	88.8±0.5
174	174	174	0	174±0	87	87	87	0	87±0
172	172	172	0	172±0	86	86	86	0	86±0

171	169	170	1	170±1	85	84	84.5	0.5	84.5±0.5
167	169	168	1	168±1	83	86	84.5	1.5	84.5±1.5
165	163	164	1	164±1	82	81	81.5	0.5	81.5±0.5
153	147	150	3	150±3	76	71	73.5	2.5	73.5±2.5
152	148	150	2	150±2	75	73	74	1	74±1
142	138	140	2	140±2	72	66	69	3	69±3
141	139	140	1	140±1	71	68	69.5	1.5	69.5±1.5
140	140	140	0	140±0	70	70	70	0	70±0
132	128	130	2	130±2	66	62	64	2	64±2
131	129	130	1	130±1	65	64	64.5	0.5	64.5±0.5
121	119	120	1	120±1	62	57	59.5	2.5	59.5±2.5
100	100	100	0	100±0	52	48	50	2	50±2
87	85	86	1	86±1	44	41	42.5	1.5	42.5±1.5
75	73	74	1	74±1	38	35	36.5	1.5	36.5±1.5
40	42	41	1	41±1	22	20	21	1	21±1
11	9	10	1	10±1	6	3	4.5	1.5	4.5±1.5

Appendix L

Uncertainty analysis of biogas production measurement in field

Days	Biogas Production m^3/day	Uncertainty in biogas measurement 1± 0.005 m^3	Absolute Uncertainty	Percentage Uncertainty
1	0.000	0.000	0.000	0
2	0.000	0.000	0.000	0
3	0.000	0.000	0.000	0
4	0.000	0.000	0.000	0
5	0.000	0.000	0.000	0
6	2.020	0.010	2.02± 0.010	0.5
7	1.400	0.007	1.4±0.007	0.5
8	1.440	0.007	1.44±0.007	0.5
9	1.500	0.008	1.5 ±0.008	0.5
10	1.560	0.008	1.56±0.008	0.5
11	1.600	0.008	1.6±0.008	0.5
12	1.640	0.008	1.64±0.008	0.5
13	1.700	0.009	1.7±0.009	0.5
14	1.800	0.009	1.8±0.009	0.5
15	1.880	0.009	1.88±0.009	0.5
16	1.920	0.010	1.92±0.01	0.5
17	1.960	0.010	1.96±0.01	0.5
18	2.010	0.010	2.01±0.01	0.5
19	2.016	0.010	2.016±0.01	0.5
20	2.028	0.010	2 .028±0.01	0.5
21	2.040	0.010	2.04±0.01	0.5
22	2.010	0.010	2.01±0.01	0.5
23	2.030	0.010	2.03±0.01	0.5
24	2.020	0.010	2.02±0.01	0.5
25	2.020	0.010	2.02±0.01	0.5
26	2.046	0.010	2.046±0.01	0.5
27	2.036	0.010	2.036±0.01	0.5
28	2.014	0.010	2.014±0.01	0.5
29	2.026	0.010	2.026±0.01	0.5
30	2.040	0.010	2.04±0.01	0.5
31	2.042	0.010	2.042±0.01	0.5
32	2.054	0.010	2.054±0.01	0.5
33	2.042	0.010	2.042±0.01	0.5
34	2.034	0.010	2.034±0.01	0.5
35	2.030	0.010	2.03±0.01	0.5
36	2.020	0.010	2.02±0.01	0.5
37	2.024	0.010	2.024±0.01	0.5
38	2.028	0.010	2.028±0.01	0.5
39	2.034	0.010	2.034±0.01	0.5
40	2.010	0.010	2.010±0.01	0.5
41	2.014	0.010	2.014±0.01	0.5

42	2.020	0.010	2.02±0.01	0.5
43	2.034	0.010	2.034±0.01	0.5
44	2.028	0.010	2.028±0.01	0.5
45	1.960	0.010	1.96±0.01	0.5
46	2.004	0.010	2.004±0.01	0.5
47	2.001	0.010	2.001±0.01	0.5
48	2.036	0.010	2.036±0.01	0.5
49	2.048	0.010	2.048±0.01	0.5
50	2.020	0.010	2.02±0.01	0.5
51	2.034	0.010	2.034±0.01	0.5
52	2.048	0.010	2.048±0.01	0.5
53	2.054	0.010	2.054±0.01	0.5
54	2.042	0.010	2.042±0.01	0.5
55	2.054	0.010	2.054±0.01	0.5
56	2.056	0.010	2.056±0.01	0.5
57	2.034	0.010	2.034±0.01	0.5
58	2.020	0.010	2.020±0.01	0.5
59	2.014	0.010	2.014±0.01	0.5
60	2.024	0.010	2.024±0.01	0.5
61	2.042	0.010	2.042±0.01	0.5
62	2.048	0.010	2.048±0.01	0.5
63	2.036	0.010	2.036±0.01	0.5
64	2.020	0.010	2.02±0.01	0.5
65	2.024	0.010	2.024±0.01	0.5
66	2.030	0.010	2.030±0.01	0.5
67	2.034	0.010	2.034±0.01	0.5
68	2.028	0.010	2.028±0.01	0.5
69	2.010	0.010	2.010±0.01	0.5
70	2.016	0.010	2.016±0.01	0.5
71	2.020	0.010	2.020±0.01	0.5
72	2.024	0.010	2.024±0.01	0.5
73	2.030	0.010	2.030±0.01	0.5
74	2.020	0.010	2.020±0.01	0.5
75	2.014	0.010	2.014±0.01	0.5
76	2.024	0.010	2.024±0.01	0.5
77	2.048	0.010	2.048±0.01	0.5
78	2.042	0.010	2.042±0.01	0.5
79	2.036	0.010	2.036±0.01	0.5
80	2.020	0.010	2.020±0.01	0.5
	1.852	0.009	1.852±0.01	0.5

Appendix M
Uncertainty Analysis of Drying Experiment

Tray 1: Drying of Button Mushroom

Time	Mass in Tray 1, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.01	91.00	0.005	91±0.005
15	10.05	10.05±0.001	0.01	82.20	0.008	82.20±0.008
30	6.98	6.98±0.001	0.01	74.40	0.011	74.40±0.011
45	5.45	5.45±0.001	0.02	67.33	0.012	67.33±0.012
60	4.52	4.52±0.001	0.02	60.70	0.013	60.70±0.013
90	3.45	3.45±0.001	0.03	48.42	0.014	48.42±0.014
120	2.85	2.85±0.001	0.04	37.72	0.013	37.72±0.013
180	2.40	2.40±0.001	0.04	26.53	0.011	26.53±0.011
240	2.25	2.25±0.001	0.04	21.40	0.010	21.40±0.010
300	2.16	2.16±0.001	0.05	18.18	0.008	18.18±0.008
360	2.11	2.11±0.001	0.05	15.89	0.008	15.89±0.008
420	2.06	2.06±0.001	0.05	14.29	0.007	14.29±0.007
480	2.02	2.02±0.001	0.05	12.71	0.006	12.71±0.006
540	1.99	1.99±0.001	0.05	11.11	0.006	11.11±0.006
600	1.97	1.97±0.001	0.05	9.77	0.005	9.77±0.005
660	1.96	1.96±0.001	0.05	7.93	0.004	7.93±0.004

Tray 2: Drying of Button Mushroom

Time	Mass in Tray 2, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.005	91.00	0.005	91±0.005
15	10.06	10.65±0.001	0.010	82.11	0.008	82.11±0.008
30	6.99	6.99±0.001	0.014	74.25	0.011	74.25±0.011
45	5.47	5.47±0.001	0.018	67.09	0.012	67.09±0.012
60	4.54	4.54±0.001	0.022	60.35	0.013	60.35±0.013
90	3.46	3.46±0.001	0.029	47.98	0.014	47.98±0.014
120	2.86	2.86±0.001	0.035	37.06	0.013	37.06±0.013
180	2.41	2.41±0.001	0.041	25.31	0.011	25.31±0.011
240	2.26	2.26±0.001	0.044	20.35	0.009	20.35±0.009
300	2.18	2.18±0.001	0.046	17.43	0.008	17.43±0.008
360	2.13	2.13±0.001	0.047	15.49	0.007	15.49±0.007
420	2.09	2.09±0.001	0.048	13.67	0.007	13.67±0.007
480	2.04	2.04±0.001	0.049	11.81	0.006	11.81±0.006
540	2.01	2.01±0.001	0.050	10.45	0.005	10.45±0.005
600	1.98	1.98±0.001	0.050	9.14	0.005	9.14±0.005
660	1.96	1.96±0.001	0.051	8.07	0.004	8.07±0.004

Tray 3: Drying of Button Mushroom

Time	Mass in Tray 3, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.005	91.00	0.005	91±0.005
15	10.08	10.08±0.001	0.010	82.14	0.008	82.14±0.008
30	7.01	7.01±0.001	0.014	74.32	0.011	74.32±0.011
45	5.49	5.49±0.001	0.018	67.21	0.012	67.21±0.012
60	4.56	4.56±0.001	0.022	60.53	0.013	60.53±0.013
90	3.47	3.47±0.001	0.029	48.43	0.014	48.43±0.014
120	2.87	2.87±0.001	0.035	37.28	0.013	37.28±0.013
180	2.43	2.43±0.001	0.041	25.93	0.011	25.93±0.011
240	2.27	2.27±0.001	0.044	20.70	0.009	20.70±0.009
300	2.19	2.19±0.001	0.046	17.81	0.008	17.81±0.008
360	2.13	2.13±0.001	0.047	15.49	0.007	15.49±0.007
420	2.09	2.09±0.001	0.048	13.92	0.007	13.92±0.007
480	2.05	2.05±0.001	0.049	12.37	0.006	12.37±0.0006
540	2.02	2.02±0.001	0.050	10.89	0.005	10.89±0.005
600	1.99	1.99±0.001	0.050	9.55	0.005	9.55±0.005
660	1.97	1.97±0.001	0.051	8.40	0.004	8.40±0.004

Tray 4: Drying of Button Mushroom

Time	Mass in Tray 4, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.005	91	0.005	91±0.005
15	10.11	10.11±0.001	0.010	82.2	0.008	82.2±0.008
30	7.03	7.03±0.001	0.014	74.4	0.011	74.4±0.011
45	5.51	5.51±0.001	0.018	67.33	0.012	67.33±0.012
60	4.58	4.58±0.001	0.022	60.7	0.013	60.7±0.013
90	3.49	3.49±0.001	0.029	48.42	0.014	48.42±0.014
120	2.89	2.89±0.001	0.035	37.72	0.013	37.72±0.013
180	2.45	2.45±0.001	0.041	26.53	0.011	26.53±0.011
240	2.29	2.29±0.001	0.044	21.4	0.009	21.4±0.009
300	2.20	2.20±0.001	0.045	18.18	0.008	18.18±0.008
360	2.14	2.14±0.001	0.047	15.89	0.007	15.89±0.007
420	2.10	2.10±0.001	0.048	14.29	0.007	14.29±0.007
480	2.06	2.06±0.001	0.048	12.71	0.006	12.71±0.006
540	2.03	2.03±0.001	0.049	11.11	0.005	11.11±0.005
600	2.00	2±0.001	0.050	9.77	0.005	9.77±0.005
660	1.97	1.97±0.001	0.051	8.63	0.004	8.63±0.004

Tray 1: Drying of Oyster Mushroom

Time	Mass in Tray 1, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.01	90	0.005	90±0.005
15	10.15	10.05±0.001	0.01	80.3	0.008	80.3±0.008
30	7.03	7.03±0.001	0.01	71.55	0.010	71.55±0.010
45	5.74	5.74±0.001	0.02	65.16	0.011	65.16±0.011
60	4.69	4.69±0.001	0.02	57.36	0.012	57.36±0.012
90	3.65	3.65±0.001	0.03	45.21	0.012	45.21±0.012
120	3.05	3.05±0.001	0.03	34.43	0.011	34.43±0.011
180	2.64	2.64±0.001	0.04	24.24	0.009	24.24±0.009
240	2.48	2.48±0.001	0.04	19.35	0.008	19.35±0.008
300	2.37	2.37±0.001	0.04	15.61	0.007	15.61±0.007
360	2.32	2.32±0.001	0.04	13.79	0.006	13.79±0.006
420	2.27	2.27±0.001	0.04	11.89	0.005	11.89±0.005
480	2.23	2.23±0.001	0.04	10.31	0.005	10.31±0.005
540	2.20	2.20±0.001	0.05	9.09	0.004	9.09±0.004
600	2.17	2.17±0.001	0.05	7.83	0.004	7.83±0.004

Tray 2: Drying of Oyster Mushroom

Time	Mass in Tray 2, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB),%	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.01	90	0.005	90±0.005
15	10.17	10.17±0.001	0.01	80.33	0.008	80.33±0.008
30	7.04	7.04±0.001	0.01	71.59	0.010	71.59±0.010
45	5.75	5.75±0.001	0.02	65.22	0.011	65.22±0.011
60	4.70	4.70±0.001	0.02	57.45	0.012	57.45±0.012
90	3.67	3.67±0.001	0.03	45.5	0.012	45.5±0.012
120	3.07	3.07±0.001	0.03	34.85	0.011	34.85±0.011
180	2.65	2.65±0.001	0.04	24.53	0.009	24.53±0.009
240	2.49	2.49±0.001	0.04	19.68	0.008	19.68±0.008
300	2.38	2.38±0.001	0.04	15.97	0.007	15.97±0.007
360	2.33	2.33±0.001	0.04	14.16	0.006	14.16±0.006
420	2.28	2.28±0.001	0.04	12.28	0.005	12.28±0.005
480	2.24	2.24±0.001	0.04	10.71	0.005	10.71±0.005
540	2.20	2.20±0.001	0.05	9.09	0.004	9.09±0.004
600	2.18	2.18±0.001	0.05	8.05	0.004	8.05±0.004

Tray 3: Drying of Oyster Mushroom

Time	Mass in Tray 3, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.01	90	0.005	90±0.005
15	10.18	10.18±0.001	0.01	80.35	0.008	80.35±0.008
30	7.05	7.05±0.001	0.01	71.63	0.010	71.63±0.010
45	5.77	5.77±0.001	0.02	65.34	0.011	65.34±0.011
60	4.71	4.71±0.001	0.02	57.54	0.012	57.54±0.012
90	3.68	3.68±0.001	0.03	45.65	0.012	45.65±0.012
120	3.08	3.08±0.001	0.03	35.06	0.011	35.06±0.011
180	2.66	2.66±0.001	0.04	24.81	0.009	24.81±0.009
240	2.51	2.51±0.001	0.04	20.32	0.008	20.32±0.008
300	2.39	2.39±0.001	0.04	16.32	0.007	16.32±0.007
360	2.34	2.34±0.001	0.04	14.53	0.006	14.53±0.006
420	2.29	2.29±0.001	0.04	12.66	0.006	12.66±0.006
480	2.25	2.25±0.001	0.04	11.11	0.005	11.11±0.005
540	2.22	2.22±0.001	0.05	9.91	0.004	9.91±0.004
600	2.19	2.19±0.001	0.05	8.68	0.004	8.68±0.004

Tray 4: Drying of Oyster Mushroom

Time	Mass in Tray 4, g	Absolute Uncertainty, g	Percentage Uncertainty,	MC (WB), %	Uncertainty In MC,%	MC(WB)±Uncertainty, %
0	20.00	20±0.001	0.01	90	0.005	90±0.005
15	10.20	10.20±0.001	0.01	80.39	0.008	80.39±0.008
30	7.07	7.07±0.001	0.01	71.71	0.010	71.71±0.010
45	5.78	5.78±0.001	0.02	65.4	0.011	65.4±0.011
60	4.73	4.73±0.001	0.02	57.72	0.012	57.72±0.012
90	3.69	3.69±0.001	0.03	45.8	0.012	45.8±0.012
120	3.09	3.09±0.001	0.03	35.28	0.011	35.28±0.011
180	2.67	2.67±0.001	0.04	25.09	0.009	25.09±0.009
240	2.52	2.52±0.001	0.04	20.63	0.008	20.63±0.008
300	2.40	2.40±0.001	0.04	16.67	0.007	16.67±0.007
360	2.35	2.35±0.001	0.04	14.89	0.006	14.89±0.006
420	2.30	2.30±0.001	0.04	13.04	0.006	13.04±0.006
480	2.26	2.26±0.001	0.04	11.5	0.005	11.5±0.005
540	2.23	2.23±0.001	0.04	10.31	0.005	10.31±0.005
600	2.20	2.20±0.001	0.05	9.09	0.004	9.09±0.004