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Experimental Study on Natural and Force Convection Hybrid Active Greenhouse Solar Drying of Mushroom

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ABSTRACT

This manuscript deals with drying of food to avoid losses between accumulation and consumption of edible material (food), as higher moisture content is one of the reasons for its spoilage during the storage period at time of accumulation (harvesting) .High moisture content in crops leads to fungus infection, attacked by insects, pests and the increased respiration of agriculture produce, which further all threat to food productivity and food security. In order to ensure this concern Solar drying of Mushroom is conducted to investigate the performance of the hybrid active greenhouse for drying mushroom and also study the drying behavior of mushroom (Pleurotus Florida) in terms of its convective heat transfer coefficient and moisture removing rate (% db). The green house consists of a transparent UV stabilized plastic covered and wire & tube type heat exchanger and drying chamber unit. Various experiments are conducted during the course of winter season, in months November and December 2017 and also January 2018 at Madhav Institute of Technology and Science, Gwalior campus (26°.2183N and 78°.1828E), India. Experimental set up is situated on the open floor to have a good exposure to the solar radiation. Experimental data are used to calculate the Nusselt number constants using linear regression method. The products (mushroom) to be dried are placed on a single layer wire mesh in the drying chamber to receive energy from hot water obtained from the evacuated tube solar collector (ETSC) and the incident solar radiation on products. During the experimental procedure minimum and maximum solar radiations are 243 W/m² and 925 W/m² respectively. The generated voltages for the 40 W solar modules are 4.5. V to 14.8 V and temperatures in the drying chamber varied from 37.0°C to 72.5° C. Moisture content of mushrooms are decreasing from about 89.41% to 5.94% in 5 hours. In the same time the moisture content of mushrooms reduced from 89.41% to15% in the traditional sun drying method also called OSD. In addition, the Mushroom being dried in the hybrid active greenhouse solar drier are fully protected from rain, insects and dust, and the dried mushrooms are great quality dried products terms of flavor, color and texture. As the fans are powered by a solar module, the drier could be used in rural areas where there is no supply of electricity from grid.

Keywords: Indirect solar dryer; mushroom drying; natural convection drying; convective heat transfer coefficient; moisture removing rate.

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1. INDRODUCTION

To lead an energetic and vigorous life, man desires adequate food and a balanced nutritious diet. Minerals, vitamins and fibres are abundant in vegetables and fruits. Fruits and vegetables also provide antioxidants that avoid many chronic diseases. Fruits and vegetables are maximum seasonal. Seasonal surplus and low shelf life destroy these food crops (Bala, Morshedand Rahman2009). About 20 to 30% of the total production is lost due to failure at various post-harvest stages. Food failure causes the operation of microbes such as yeast, bacteria, mold and enzymes (Medgu, 2010). Food conservation can reduce deterioration due to seasonal surplus and achieve higher market prices through demand (Nahar, 2009). Drying food is one of the conservation process used to prolong the shelf life of the crop and provide it during the year (GETA, 2011). Natural sun drying is the traditional technique used in most of tropical and subtropical countries (Hussein and Bala, 2007). But, the quality of the food crop dried is found to be poor due to contamination by dust, birds, rodents and insects (Akpinar 2010;Wakjira 2010). Uncontrolled drying, uncertainty in weather conditions such as rain, large area and long duration required for drying, and high labor cost are also motives that limit the use of natural sun drying (Ezekoye and Enebe2006).To overcome the disadvantages of natural sun drying also called open sun drying, various efforts have been done to develop mechanical driers in the recent years. Most of these mechanicaldriers need electricity or fossil fuel for operation andthe energy reserves are depleting at a rapid rate. These driers also cause pollution. Solar energy is richly available and is also unlimited. Mechanical driers which use sun as the source of energy can solve the problem of pollution (Mohanraj and Chandrasekar2009). Solar driers are nearly attractive, as they are pollutant-free and eco-friendly.

Various types of solar driers are available to dryagricultural products (Chanchal, 2012;Ayyappanand Mayilsamy2010),(Mohanrajet al., 2009), (Fudholi et al., 2010), (Fudholi, A., Sopian, Ruslan, Alghoul, and Sulaiman, 2010), (Ayyappan et al., 2012)solar driers need solar collectors to absorb solar isolation. Flat Plate Collector (FPC) consists of an absorber plate enclosed with a glass top to trap solar radiation.

Mushrooms are edible fungi of commercial importance and their cultivation and consumption have increased significantly due to their nutritional value, weakness and taste. It is rich in vitamin D2, B2, C and MG, P, CA, nutritional fiber and amino acids. Another important component of mushrooms is the polysaccharide compound beta-gluten, which improves cellular immunity function. But mushrooms are quite bad and the shelf life of fresh mushrooms is only 24 hours and 7-10 days in ambient conditions even with its high moisture content and rich nutrients that are easily and quickly stored in the fridge due to bad. Then, various physical and morphological changes occur after harvest, which make these mushrooms unacceptable for consumption. Therefore, mushrooms are usually dried to extend shelf life. Therefore, these should be consumed or processed immediately after the harvest. Drying is an important process by which mushrooms are being preserved. Mushrooms are very sensitive to temperature, it is very important to choose the right drying method.

Many secondary metabolites of fungi are of great commercial importance. Fungi naturally produce antibiotics to kill or inhibit bacterial growth, limiting their competitiveness in the natural environment. Important antibiotics, such as penicillin and cephalosporin, can be separated from the fungus. Among the drugs valued apart from the fungus include the immunosuppressive drug cyclosporine (which reduces the risk of rejection after organ transplantation), the precursor to steroid hormones, and the argotal alkaloid used to prevent bleeding. Psilocybin is a compound found in fungi such as Psilocybesemilanceata and Gymnopilusjunius, which have been used by different cultures for thousands of years for their hallucinogenic properties.

2. PREVIOUS STUDY ON SOLAR DRYER

Literature survey reveals that most of the solar driers are assistedwith FPC (Parikh,Agrawal2011),(Saravanakumarand Mayilsamy,2010),(Yadav and Bajpai,2011). Evacuated Tube Solar Collector (ETSC) could be a good alternative to FPC to trap solar isolation. ETSC is consisting of two glass tubes – an innertube and an outer tube. The inner tube is coated using selective coating and the space between the two tubes isevacuated. As the space between the two tubes is evacuated, there is no heat loss due to convection, andconduction. This improves the efficiency of the collector (Lamnatou, Papanicolaou, Belessiotis, and Kyriakis, 2012) and hence the performance of the drier could be relatively better than the FPC assisted solar drier. Only very few attempts have been made and reported in designing solar driers with ETC so far (Mahesh,Sooriamoorthiand Kumaraguru,2012), (Umayal, Neelamegamand Subramanian, 2013),(Koua, Gbaha, Koffi, Fassinou, and Toure,2011).Several studies have been reported on drying behavior of various agricultural products such as rice(Ezekoye et al.,2006), cassava (Alakaliand Satimehin,2005), ginger (Basunia and Abe,2001), pork strips [Wiriyaumpaiwong and Jamradloedluk,2012)], prickly pear cladode [Lahsasni,Kouhila, Mahrouz, Mohamed, and Agorram,2004),tomato (Gürlek,Özbaltaand Güngö2009), onion (EL-Mesery and Mwithiga,2012) and grapes [Zomorodian and Dadashzadeh,2009),(Fadhel et al.(2005),(Pangavhane, Sawhney, and Sarsavadia,1999),(Rajesh wariand Ramalingam,2012). Also from the literature, it isnoted that no study has been carried out on drying kinetics of grapes in solar driers with ETC.

Table 1: Outcomes of previous Researcher

S. No.	Researcher	Year	Crop	Significant Contribution/ Outcomes
1.	Umayal Sundari et al.	2014	Grapes	Experimental Studied on drying kinetics of Muscat grapes in a solar drier with Evacuated Tube Collector.
2.	Rajeshwari et al.	2012	Grapes	Presented low cost material used to construct effective box type solar dryer.
3.	EL-Mesery et al.	2012	Onion	Conducted experiment on the drying of onion slices in two types of hot-air convective dryers.
4.	Wiriyaumpaiwong et al.	2012	Pork strips	Experimental Investigation and mathematical modeling of Pork Strips
6.	Gurlek et al.	2009	Tomato	Studied on solar tunnel drying characteristics and mathematical modelling of tomato.
7.	Zomorodian et al.	2009	Grapes	Experimental study on Indirect and mixed mode solar drying mathematical models for Sultana grape.
8.	Ezekoye et al.	2006	Rice	Development and performance evaluation of modified integrated passive solar grain dryer.
9.	Alakali et al.	2005	Cassava	Presented drying kinetics of cassava.
10.	Fadheleet al.	2005	Grapes	Study of the solar drying of grapes by three different processes.
11.	Lahsasni et al.	2004	Prickly pear cladode	Experimental study of characteristic drying curve and mathematical modeling of thin layer solar drying of prickly pear cladode (opuntiaficusindica).
12.	Basunia et al.	2001	Ginger	Conducted study on thin layer solar drying characteristics of rough rice under natural convection.

3. MATERIAL AND METHOD

3.1 Experimental Set–up

The most essential parts of the designed solar drier are evacuated tube solar collector, drying chamber, pump and heat exchanger. The schematic view and photograph of the innovative solar drier are presented in Fig.1, 2(a), and 2(b) respectively. Experimental set-up fabricated in the climatic conditions of Gwalior (26°.2183N and 78°.1828E), India.

The size of the drying chamber is chosen such that the design parameter (ratio of surface area to volume) is greater than 3.The greenhouse (hut type) drying chamber is made of having floor area of 2.50 m × 2.60 m, 1.80 m central height and 1.05 m side walls height from ground and 30° roof slope and is thermally insulated with UV film covering to minimize the heat losses. The innovative idea in the design of the solar drier is that it is assisted with evacuated tube solar collectors. Ten evacuated tube solar collectors are used in this drier.

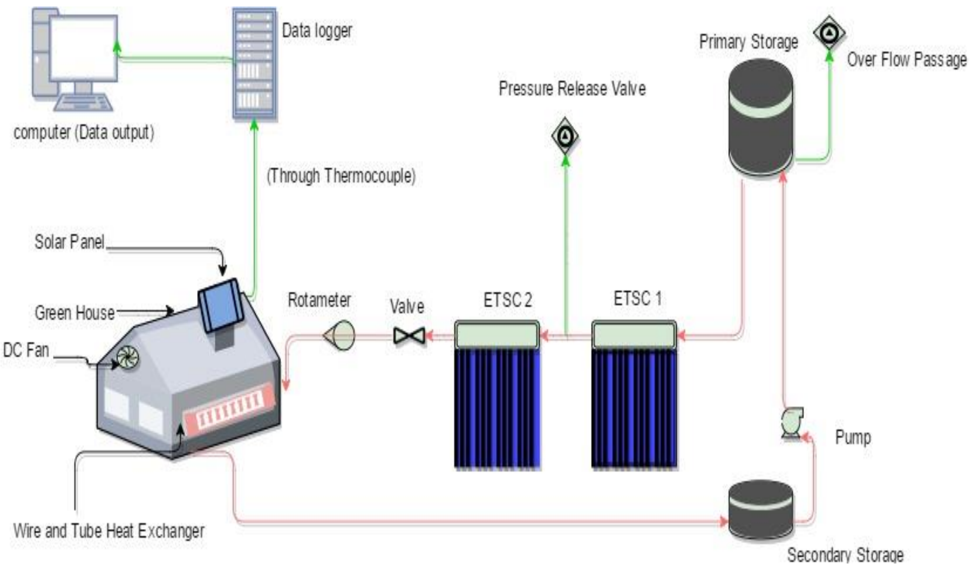


Figure.1 Schematic view of experimental setup.

Figure.2. (a) Pictorial views of experimental setup, Mushroom drying in greenhouse under natural convection mode.

Grounded on the latitude of Gwalior district (26°.2183N) the collector is placed at an angle of (25°45") facing south in order to trap optimum solar isolation the whole day. As the space between the inner and outer tube is evacuated, heat loss is minimized to a greater extent.

Ethylene Propylene Diene Monomer (EPDM) rubber hose is used to connect the greenhouse drying chamber to ETSC. Heat exchanger (2m × 0.66m) is used to warm the greenhouse drying chamber by flowing hot water from ETSC through the copper tube due its high conductivity with the help of pump. The flow of hot water can be adjusted and controlled with the help of the regulator attached in the pump. On the top of the greenhouse drying chamber, an air vent is provide at the roof level with an effective opening of ($0.36m^2$) for the moist air to escape from the chamber. It also increases the flow of air inside the chamber under the convective principle of hot air rising up (Umayal et al.2013)

Figure.2. (b) Pictorial view of Experimental setup, Mushroom drying in greenhouse under forced convection mode.

3.2Measuring Instruments and Devices

A digital hygrometer (model HT-315) is located just above the product surface to monitor the relative humidity and product surrounding temperature. The temperature of air as well as greenhouse drying chamber is measured by thermocouples (PT-100 with accuracy ± 0.1˚C) at different locations of drying chamber as shown in **Fig. 1.** The velocity of fresh air is measured by digital anemometer (model AM-4201, least count 0.1 m/s). A digital solar power meter also called Pyranometer (model WACO-206, least readability ± 10 W/m2) is used to collect the solar isolation data of drying days.

3.3 Sample Preparation

Fresh mushroom is purchased from local market of Gwalior, India and washed thoroughly to remove the surface dust. The clean mushroom hand peeled by knife and shaped circular disc with a diameter of 0.5 cm and length of 3 cm. The samples are collected in a rectangular-shaped wire mesh tray placed on the weighing balance.

3.4 Experimental Procedure

Experimental observations are recorded between 10:00 am to 04:00 pm in the month of Nov and Dec 2017 at Madhav Institute of Technology and Science, Gwalior. Two different sizes of rectangular-shaped wire mesh trays are used to accommodate different masses of mushroom samples. These trays are kept on the digital electronic balance machine to determine the moisture content removal for every drying period. Temperature is measured by using calibrated thermocouples at different locations, namely dryer inlet temperature, product surface temperature, hot water inlet and outlet temperature in heat exchanger. A digital anemometer (Model AM-4201) having a least count of 0.1 m/s is used to measure the air flow just above the product surface. Solar isolation data of drying days is recorded by digital solar power meter (model WACO-206). Experimental data are recorded at every 1 hour time interval. Before drying and after drying mushroom samples are shown in **Fig. 3**.

(a) (b)

Figure.3. Mushroom samples (a) before drying; (b) after drying.

4. THEORY

4.1 Thermal Modeling

Convective heat transfer coefficient h_c can becalculatedintermofNusseltNumber (N_u) as

$$h_c = \left(\frac{K_v}{L_c}\right) \times N_u \qquad (1)$$

Where,

$$L_c = \frac{l \times b}{2}$$

Rate of heat absorbed,

$$q_e = 0.016 \times h_c[P(T_P) - \gamma_e P(T_e)] \qquad (2)$$

From eq. (1) and (2)

$$q_e = 0.016 \times \left(\frac{K_v}{L_c}\right) \times [P(T_P) - \gamma_e P(T_e)] \times N_u \qquad (3)$$

The moisture evaporated (m_{ev}) can be determined by,

$$m_{ev} = \frac{q_e}{\lambda} \times A_t \times t$$

$$m_{ev} = \left[\frac{0.016 \times [P(T_P) - \gamma_e P(T_e)] \times K_v \times A_t \times t}{L_c \times \lambda}\right] \times N_u$$

(i) In natural convection the Nusselt number (Nu) is a function of Reynolds number (Gr) and Prandtl number (Pr) and can be expressed as [Tiwari et al.(2004)].

Nu = C (Gr × Pr) ^{n}

Nu = $\frac{m_{ev}}{R}$ = C (Gr × Pr) ^{n}

Taking logarithm on both sidescan be written as

ln [Nu] = ln C + n ln(Gr × Pr)

It is in the form of linear equation,

Y= mX + c

Where, Y = ln [Nu], m = n, X = ln [Gr × Pr] and c = lnC and C = e^c

(ii)In forced convection the Nusselt number (Nu) is a function of Reynolds number (Re) and Prandtl number (Pr) and can be expressed as,

Nu = C' (Re × Pr) $^{n'}$

Nu = $\frac{m_{ev}}{R}$ = C' (Re × Pr) $^{n'}$

Taking logarithm on both sides Eq (4.8) can be written as,

ln [Nu] = ln C' + n' ln (Re × Pr)

It is in the form of linear equation,

Y= mX + c

Where Y = ln [Nu], m = n', X = ln [Re × Pr] and c = lnC' and C' = e^c

Hence, the constant C, C' and exponent n, n' can be obtained from the given equations.

Thus,

$$n = \frac{N_0 \sum XY - \sum X \sum Y}{N_0 \sum X^2 - (\sum X)^2} \qquad (4)$$

$$C = \frac{\sum X^2 \sum Y - \sum X \sum XY}{N_0 \sum X^2 - (\sum X)^2} \qquad (5)$$

4.2 Thermal Properties of Air

The physical properties of humid air can be determined using the following expressions [Jain Tiwari2004):

$$C_V = 999.2 + 0.143T_i + 1.101 \times 10^{-4} T_i^2 - 6.7581 \times 10^{-8} T_i^3 \qquad (6)$$

$$K_V = 0.0244 + 0.7673 \times 10^{-4} T_i \qquad (7)$$

$$K_V = \frac{353.44}{T_i + 273.15}$$

$$\mu_V = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_i \qquad (8)$$

$$P(T) = \exp\left[25.317 - \frac{5144}{T_i + 273.15}\right] \qquad (9)$$

Where $P(T)$ is the vapour pressure at temperature T (N/m^2) and $T_i = (T_p + T_e)/2$

Knowing the convective mass transfer coefficient h_c the evaporative mass transfer coefficients h_e can also be evaluated from Eq. (10) as follows.

$$h_e = 16.273 \times 10^{-3} h_c \left(\frac{P(T_p) - \gamma P(T_e)}{T_p - T_e}\right) \qquad (10)$$

5. RESULT AND DISCUSSION

The hand-peeled disc shaped (diameter 0.5cm, length 3cm) different masses of mushroom samples were dried under natural convection mode as well as forced convection mode.Moisture removing rate (%, dry basis), and convective heat transfer coefficients for mushroom samples were evaluated as given in Table 1.

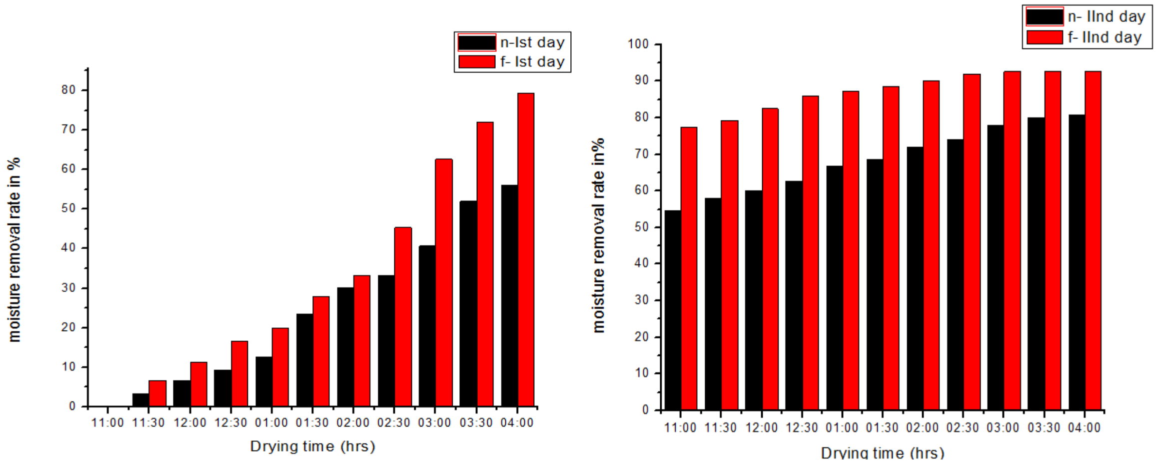
The data given in Table 1 were used to determine the moisture removing rate, drying rate, and convective heat transfer coefficients at drying time of half hour interval under natural convection indirect solar drying as well as forced convection mode for first, and second, day of drying of mushroom samples as shown in **Fig. 3**.

In mushroom drying, the moisture available with the mushroom is present in two forms, namely free moisture and bound moisture. Free moisture is present in the outside resins of the mushroom, which can be simply evaporated using suitable amount of heated air where the bound moisture is present in mushroom internal cells under capillary action, which takes time for its evaporation and leads to higher drying time.

In **Fig. 4** the moisture removing rate is observed to be dependent on the total moisture present in the product mass and hence, it has been observed that the moisture removing rate increases with increase in mushroom samples mass and decreases significantly with the progression of drying days (Gürlek et al.,2009).

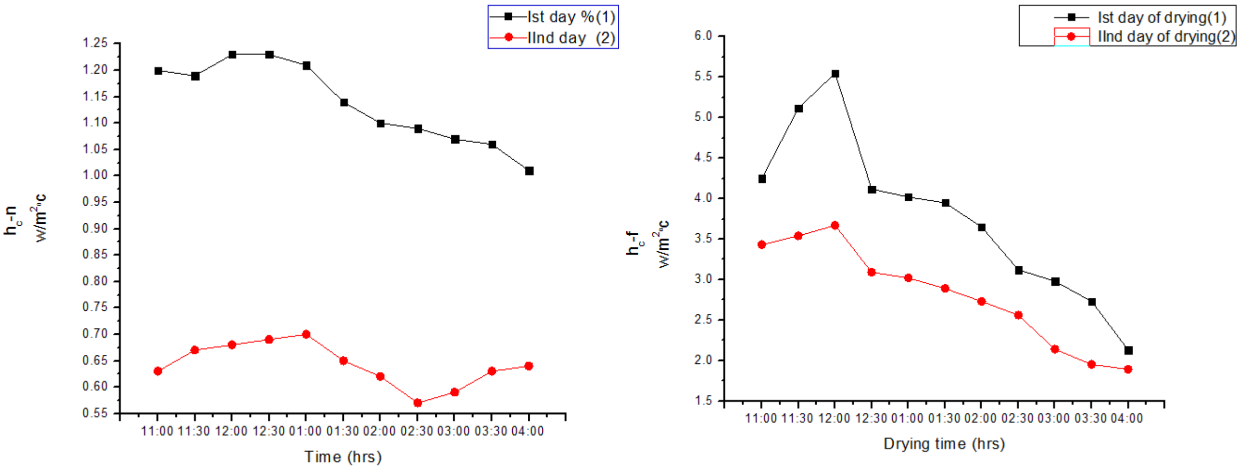
Table 2: Experimental data for mushroom drying during Nov 29-30 2017 under natural convection mode as well as under force convection mode.

Time	T_m	T_c	Weight	m_{ev}	I	γ	Gr	P_r	C	n	h_c	h_e
Mushroom sample on the first day of drying(29/11/2017)												
11:00	28.9	28.2	150		570	46.7	3.75×10^7	0.697	0.63	0.16	1.20	22.54
11:30	29.1	28.9	145	0.005	587	40.6	6.19×10^7	0.697			1.19	18.64
12:00	30.9	29.5	140	0.005	603	39.4	8.76×10^7	0.697			1.23	15.01
12:30	32.2	31.2	136	0.004	609	37.8	8.32×10^7	0.695			1.23	14.81
01:00	32.6	32.1	131	0.005	612	37.0	8.11×10^7	0.695			1.21	16.62
01:30	34.5	33.6	115	0.016	620	37.5	5.25×10^7	0.695			1.14	16.82
02:00	33.2	32.8	105	0.010	590	39.4	4.93×10^7	0.694			1.10	11.30
02:30	36.5	35.2	100	0.0054	565	38.8	3.94×10^7	0.694			1.09	9.16
03:00	36.2	35.1	89	0.011	502	38.2	3.72×10^7	0.693			1.07	8.91
03:30	31.2	30.6	72	0.011	487	38.5	2.94×10^7	0.693			1.06	7.93
04:00	30.2	29.5	65	0.0070	430	39.4	2.81×10^7	0.693			1.01	7.39
Mushroom sample on the second day of drying(30/11/2017)												
11:00	27.9	28.1	68		445	42.3	4.71×10^7	0.695	0.53	0.14	0.63	12.67
11:30	28.1	29.3	63	0.005	495	39.2	6.05×10^7	0.695			0.67	7.65
12:00	29.2	29.1	60	0.003	520	37.2	7.15×10^7	0.695			0.68	8.07
12:30	29.9	30.1	56	0.004	580	37.9	8.25×10^7	0.694			0.69	8.40
01:00	31.2	32.2	51	0.005	601	37.5	8.79×10^7	0.694			0.70	8.98
01:30	31.9	33.1	47	0.004	619	39.3	5.38×10^7	0.694			0.65	6.97
02:00	33.9	34.2	42	0.005	635	36.3	4.49×10^7	0.694			0.62	5.23
02:30	32.1	33.9	39	0.003	681	34.2	4.74×10^7	0.694			0.57	8.16
03:00	31.2	33.7	33	0.006	575	34.3	3.95×10^7	0.695			0.59	5.01
03:30	31.1	32.2	30	0.003	556	38.1	3.36×10^7	0.695			0.63	7.94
04:00	30.1	31.3	29	0.001	535	39.1	3.21×10^7	0.695			0.64	8.16
Mushroom sample on the first day of drying(29/11/2017)												
11:00	27.9	32.2	150		570	42.6	7.16×10^7	0.696	0.23	0.31	3.43	36.98
11:30	32.9	37.2	142	0.008	587	39.2	8.18×10^7	0.696			3.54	27.36
12:00	35.2	41.2	133	0.009	603	37.1	7.87×10^7	0.696			3.67	32.56
12:30	41.3	44.2	125	0.011	609	35.5	5.4×10^7	0.695			3.09	25.62
01:00	42.9	47.2	120	0.005	612	34.9	4.89×10^7	0.695			3.02	24.85
01:30	44.2	51.2	108	0.012	620	34.8	3.85×10^7	0.695			2.89	21.54
02:00	46.9	54.5	100	0.008	590	37.2	3.26×10^7	0.695			2.73	18.54
02:30	45.2	61.1	82	0.018	565	36.2	3.12×10^7	0.695			2.56	17.42
03:00	44.3	71.2	56	0.016	502	36.5	2.95×10^7	0.695			2.14	16.58
03:30	43.2	65.2	41	0.015	487	36.4	2.45×10^7	0.695			1.95	15.25
04:00	43.1	59.2	31	0.010	430	37.2	1.95×10^7	0.696			1.89	14.42
Mushroom sample on the second day of drying(30/11/2017)												
11:00	28.9	32.6	34		570	40.1	4.78×10^7	0.695	0.19	0.27	4.25	65.30
11:30	32.5	36.9	31	0.003	587	37.5	5.75×10^7	0.695			5.12	49.85
12:00	34.6	41.2	27	0.004	603	35.2	8.12×10^7	0.695			5.55	62.13
12:30	36.5	43.5	21	0.006	609	35.1	9.25×10^7	0.694			4.12	39.14
01:00	40.2	46.2	19	0.002	612	34.9	8.12×10^7	0.694			4.02	30.12
01:30	42.5	51.2	17	0.002	620	36.2	5.65×10^7	0.694			3.95	25.55
02:00	43.2	57.6	15	0.002	590	32.6	4.65×10^7	0.695			3.65	24.21
02:30	46.8	67.5	12	0.003	565	30.2	3.25×10^7	0.695			3.12	21.20
03:00	44.5	70.2	11	0.001	502	31.9	3.15×10^7	0.695			2.98	19.45
03:30	45.2	72.2	11	0.000	487	34.2	2.95×10^7	0.696			2.73	18.12
04:00	44.6	57.2	11	0.000	430	33.2	2.13×10^7	0.696			2.13	16.32



(a) (b)

Figure. 4.variations in moisture removing rate in %db with respect to drying time under natural and forced convection mode respectively (a)Ist day of experiment (b) IInd day of experiment.



(a) (b)

Figure.5. **Variations in convective heat transfer coefficient with respect to drying time (a) under natural convection mode (b) under forced convection mode**.

However, the moisture removing rate is also dependent on the ease of heat transfer. More the coefficient of convective heat transfer more will be the moisture removing rate and vice versa as illustrated in **Fig. 5**. Forced convection drying system has been reported to be best suitable for faster drying as the value of coefficient of convective heat transfer associated with them is more than the natural convection drying (EL-Mesery et al, 2012).

From **Fig. 5**, it has been observed that the values of convective heat transfer coefficient (h_c) decreases with the progression of drying days (i.e. from first day of drying to the next day drying). This decrease in convective heat transfer coefficient value is due to continuous reduction in moisture removal rate from the first day to the next day of drying (Zomorodian, and Dadashzadeh,2009). The values of convective heat transfer coefficient have been observed to be dependent on the mass of fresh mushroom samples and decreases with increase in mass of the mushroom samples.

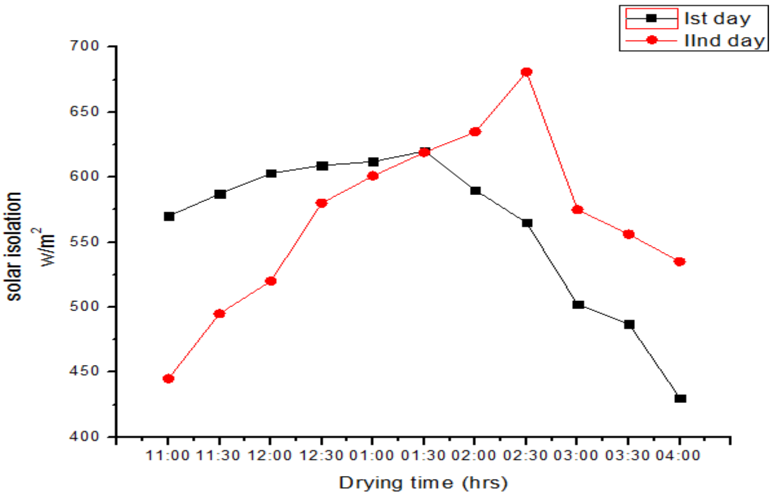


Figure.6. **Variations in solar isolation with respect to drying time.**

6.CONCLUSION AND RECOMMENDATIONS

On the basis of the result reported **Fig. 4-6** and table 1, the following conclusion can be drawn:

- ❖ The complete drying of mushroom under forced convection is faster than under natural convection as predictable.
- ❖ The convective mass transfer coefficient in forced convection mode is higher than in the natural convection mode.
- ❖ For a given mass of mushroom (150gm), the size of a greenhouse will be same as shown in **Fig. 2(a).**
- ❖ Initially the convective mass transfer coefficient is higher and decreases as drying proceeds in both the cases as expected **(Fig.5).** Similar results were also observed in the case of evaporative mass transfer coefficient.

ACKNOWLEDGEMENTS

We would like to convey our appreciation to Madhav Institute of Technology and Science, Gwalior, for providing laboratory facilities and technical assistance to carry out this research work successfully.

OMENCLATURES			
A_t	Area of mushroom tray (m^2)	Re	Reynolds number $=\frac{\rho V_v d}{\mu_v}$
C	Experimental constant	t	Time (sec)
C_v	Specific heat of humid air (J/kg°C)	T_m	Temperature of mushroom (°C)
g	Acceleration due to gravity (m/s^2)	T_c	Above mushroom surface temperature(°C)
h_c	Convective heat transfer coefficient $W/m^2{}^\circ C$)	L_c	Characteristic length (m)
h_e	Evaporative mass transfer coefficients $(W/m^2{}^\circ C)$	Gr	Grashof number $=\frac{g\beta L_c^3\rho_V^2\Delta T}{\mu_V^2}$
Q_e	Rate of heat utilized to evaporated moisture (J/m^{2}s)	*Greeks*	
K_V	Thermal conductivity of humid air	β	Coefficient of volumetric $(W/m^\circ C)$
m_{ev}	Moisture evaporated (Kg)	γ	Relative humidity (%)
n	Experimental constant	σ	Surface tension of liquid vapor interface (N/m)
Nu	Nusselt number $=\frac{h_c L_c}{K_v}$	λ	Latent of heat of Vaporization (J/kg)

Pr	Prandtl number of humid air = $\frac{\mu_v c_v}{K_v}$	μ_V	Dynamic viscosity (kg/m sec)
P (T)	Partial vapor pressure at temperature T (N/m^2)	ρ_V	Density (kg/m^3)

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