Solar drying of mushroom using solar tunnel dryer

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Abstract

Solar drying of Mushroom was conducted to investigate the performance of the solar tunnel dryer for drying mushrooms. The dryer consists of a transparent UV stabilized plastic covered flat plate collector and drying tunnel unit. The drier is arranged to supply hot air directly into the drying tunnel using three dc fans powered by a 40 watt solar module. The products to be dried are placed in a single layer on a wire mesh in the drying tunnel to receive energy from both hot air supplied from the collector and from the incident solar radiation on products. During the experimental period the minimum and maximum solar radiation were 273 W/m² and 885 W/m² respectively. The generated voltages for the 40 W solar modules were 4.5. V to 14.8 V. Temperatures in the drying chamber varied from 37.0° C to 66.5° C. Mushrooms were dried from about 89.41% to 6.14% moisture content (w.b) in about 8 hours. In the same drying period, the moisture content of mushrooms reduced from 89.41% to15% in the traditional sun drying method. In addition, the Mushroom being dried in the solar tunnel drier were completely protected from rain, insects and dust, and the dried mushrooms were high 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.

1. Introduction

Mushrooms are edible fungi of commercial importance and their cultivation and consumption have increased substantially due to their nutritional value, delicacy and flavor. It is rich in vitamins C, D_2, B_2, and Mg, P, Ca, dietary fibers and amino acids. Another important ingredient of mushroom is the polysaccharide compound beta-glucan, which enhances cellular immune function. But mushrooms are extremely perishable and the shelf life of fresh mushrooms is only about 24 hrs at ambient conditions and 7-10 days even with refrigerated storage because of its high moisture content and rich nutrients that spoil easily and quickly. Again, various physiological and morphological changes occur after harvest, which make these mushrooms unacceptable for consumption. Therefore, mushrooms are usually dried to extend the shelf-life. Hence, these should be consumed or processed promptly after harvest. Drying is one of the important process by which mushrooms are being preserved. As mushrooms are very sensitive to temperature, choosing the right drying method is very much important.

The growers of mushrooms dry mushrooms under sun, which yields unhygienic and poor quality dried products. Due to long drying time and over-heating of surface during sun drying, the problems of darkening of color, loss in flavor and decrease in re-hydration ability occur. Mechanical driers can be used, but it requires fossil fuel and electrical energy. Since drying is an energy conservation process, it is not economic to use mechanical dryers. All the areas in Bangladesh receive abundant of solar radiation and it is environmentally sound. Solar dryers have the potential for adoption and application in Bangladesh.

Solar drying can be considered as an elaboration of sun drying and it is an efficient system of utilizing solar energy (Mulhbauer, 1986 and Bala, 1997). Many studies have been reported on natural convection solar drying of agricultural products (Exell and Kornsakoo,1978; Exell and Kornsakoo,1980; Zaman and Bala, 1989; Oosthuizen, 1995 and Sharma *et al.,* 1995).

Considerable studies on simulation of natural convection solar drying of agricultural products and optimization have also been reported (Bala and Woods, 1994 & 1995; Simate, 2003 and Forson *et al*., 2007). The success achieved by natural convection solar dryers has been limited due to low buoyancy induced air flow. These prompted researchers to develop forced convection solar dryers. Many research and performance studies have been reported on forced convection solar dryers (Esper and Mulhbauer, 1993; Esper and Mulhbauer, 1994; Oosthuizen, 1996; Ratti and Majumdar, 1997; Bala and Mondal, 2001; Bala *et al.*, 2003; Karim and Hawlader, 2005 and Hossain and Bala, 2007). Studies on simulation and optimization of forced convection solar tunnel dryers have also been reported (Hossain, 2003; Hossain *et al.*, 2005 a&b). Numerous tests in the different regions of the tropics and subtropics have shown that fruits, vegetables, cereals, grain, legumes, oil seeds, spices, fish and even meat can be dried properly in the plastic covered solar tunnel dryer (Esper and Mulhbauer, 1993; Esper and Mulhbauer, 1994; Bala and Mondal, 2001; Bala *et al.*, 2003 and Hossain and Bala, 2007).

Several studies have been reported on drying of mushrooms (Giri and Parasad, 2007; Kotwaliwale *et al*., 2007; Shukla and Singh, 2007; Torringa *et al.*, 2001 and Wallde *et al.*, 2006). Although many studies have been reported on solar drying of fruits and vegetables (Karim and Hawlader, 2005; Ratti and Majumdar, 1997; Bala *et al.*, 2003; Esper and Mulhbauer, 1996 & Schirmer *et al.*, 1996), limited studies have been reported on solar drying of mushrooms (Mastekbayeva *et al*., 1999 and Middili *et al.*, 2001).

Although very limited studies have been reported on solar drying of mushrooms, no study has been reported on solar drying of mushroom using solar tunnel dryer. This paper presents experimental studies of solar drying of mushrooms using solar tunnel dryer.

2. Description of the Solar Tunnel Dryer

The drier essentially consists of a flat plate air heating collector, a tunnel drying unit and three small fans to provide the required air flow over the products to be dried. These are connected in series as shown in Fig.1 and Fig. 2 shows the pictorial view of the dryer. Both the collector and the drying units are covered with uv stabilized plastic sheets. Black paint is used as an absorber in the collector. The products to be dried are placed in a single layer on a wire mesh in the tunnel drier. Glass wool is used as insulation materials to reduce the heat loss from the bottom of the drier. The whole system is placed horizontally on a raised platform. The air at required flow rate is provided by three dc fans operated by one photovoltaic module. As the air is passed over the products rather than through the products in the drier, the power requirement to drive the fans is low. To prevent the entry of water inside drier unit during rain, the cover foil is fixed like a sloping roof.

Solar radiation passes through the transparent cover of the collector and heats the absorber. Ambient air is forced through the collector. Heat is transferred from absorber to air in the collector and heated air from collector while passing over the products absorbs moisture from the products. Solar radiation also passes through the transparent cover of the drier and heats the products in the drier. This enhances the drying rate and the temperature in the drier rises in the ranges of 37.0°C to 66.5 °C. Due to extremely low resistance when forcing the air over the products to be dried only 20-30 W of electric power is required to operate the fans.

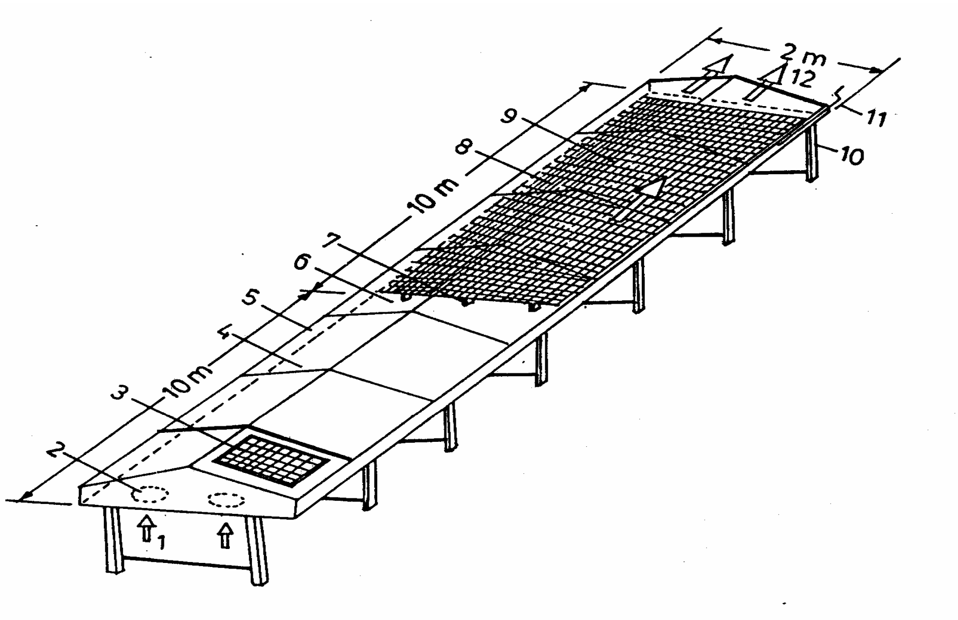

Fig.1. Solar tunnel drier:
1. air inlet, 2. fan, 3. solar module, 4. solar collector, 5. side metal frame, 6. outlet of the collector, 7. wooden support, 8. plastic net, 9. roof structure for supporting the plastic cover, 10. base structure for supporting the tunnel drier, 11. rolling bar, 12. outlet of the drier tunnel.

Fig. 2. Pictorial view of the solar tunnel dryer

3. Materials and Methods

A solar tunnel drier was installed at the yard of the workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh, Bangladesh. The drier was placed on raised platform. Mushrooms used for solar drying were collected from the local markets of Mymensingh and Savar. Three tests on solar drying of Mushrooms were carried out at Bangladesh Agricultural University, Mymensingh in the month of May in 2007 and in the month of March and May in 2008.

3.1 Experimental procedure

Important parameters affecting the performance of the drier were measured. The k-type thermocouple was used to measure the drying air temperature along the flow direction of the air inside the drier and a solar meter was used to measure the global radiation. The relative humidity and temperature of the ambient air were measured with a digital thermometer and relative humidity meter. The velocity of drying air was measured with an air velocity meter at the outlet of the drier. Weight loss of the product during drying period was also measured with an electronic balance. The sun dried control samples were weighed as well. All these data were recorded at one hour interval.

The samples of mushrooms were placed on the wire mesh of the drier in a single layer. Drying was started at about 9 to 10 am. Drying of mushrooms was stopped at about 4 to 5 pm. Then samples were collected and kept in a sealed container. To compare the performance of the tunnel drier with that of the natural sun drying, control samples of mushrooms were placed on trays in single layer beside the drier. Both experimental and control samples were dried simultaneously under the same weather condition. At the beginning of each experimental run, the initial moisture content of mushrooms was measured by oven drying method at a temperature of 105 °C for 24 hours.

3.2 Collector and drying Efficiency

Collector efficiency is defined as the ratio of energy output of the collector to energy input to the collector. Solar energy input on the collector is computed as

$$IA_{collectorc} = 10^{-6} \times A_{collector} \int_0^t Sr(t)\, dt \qquad (1)$$

Where $IA_{collector}$ = Solar energy input on the collector, MJ

$Sr(t)$ = Solar radiation at time t, W/m^2

$A_{\text{collector}}$ = Collector area, m^2

t = time, s

and that of the solar module is computed as

$$IA_{module} = 10^{-6} \times A_{module} \int_0^t Sr(t)\, dt \qquad (2)$$

Where IA_{module} = Solar energy input on the solar module, MJ

A_{module} = Module area, m^2

The output of the collector in terms of energy is

$$Output_{collector} = 10^{-3} \int_0^t \dot{m}(t)\ C_{pa} (T_c - T_i)\, dt \qquad (3)$$

Where $Output_{collector}$ = Collector output, MJ

$\dot{m}(t)$ = Airflow rate at time t, kg/s

C_{pa} = kJ/kg°C

T_c = Temperature at the collector outlet, °C

T_i = Temperature at the collector inlet, °C

Thus, collector efficiency is

$$Collector\ efficiency = \frac{Output_{collector}}{IA_{collector} + IA_{module}} \qquad (4)$$

The drying efficiency is defined as the ratio of energy output of the drying section to energy input to the drying section. Solar radiation input on the drying section is

$$IA_{dryer} = 10^{-6} \times A_{dryer} \int_0^t Sr(t)\, dt \qquad (5)$$

Where IA_{dryer} = Solar energy input on the dryer, MJ

$Sr(t)$ = Solar radiation at time t, W/m^2

A_{dryer} = Dryer area, m^2

t = time, s

The output of the dryer in terms of energy is

$$Output_{dryer} = 10^{-3} \times mr \times L_g \qquad (6)$$

Where $Output_{dryer}$ = Dryer output, MJ

mr = Moisture removed, kg

L_g = Latent heat of vaporization of moisture, kJ/kg

Thus, the efficiency of the dryer is

$$\eta_{drying} = \frac{Output_{dryer}}{IA_{dryer} + Output_{collector}} \qquad (7)$$

The overall drying efficiency is defined as the ratio of energy output of the dryer to the total energy input. Thus, overall efficiency of the system is

$$\eta_{overall} = \frac{Output_{dryer}}{IA_{collector} + IA_{module} + IA_{dryer}} \qquad (8)$$

3.3 Economics of solar tunnel drier

For extension of solar tunnel drier for production of quality dried product it must be economically viable. To assess economic viability the payback period of the solar tunnel drier for drying of mushrooms is determined and it is usually measured in years. The formula used here is given by:

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Net\ Undiscounted\ Benifits} \qquad (9)$$

4. Results and Discussions

4.1 Solar drying of mushroom

The solar tunnel drier installed at Bangladesh Agricultural University was used to test the suitability of the solar tunnel dryer for drying of mushrooms under Bangladesh conditions. The length of both collector and tunnel drier was 20 m and the width was 2 m with a drying area of 20 m². The power requirement of the fans operated by photovoltaic drive system was 40 W. Three experimental runs were conducted for solar drying of mushroom. Experimental data on solar radiation, ambient air temperature and relative humidity, air velocity inside the drier and temperatures at six different positions of the drier along the length were recorded.

Fig.3 shows the variations of the ambient temperature and relative humidity with the time of day during solar drying of a typical experimental run. The relative humidity decreases with the increase of ambient air temperature.

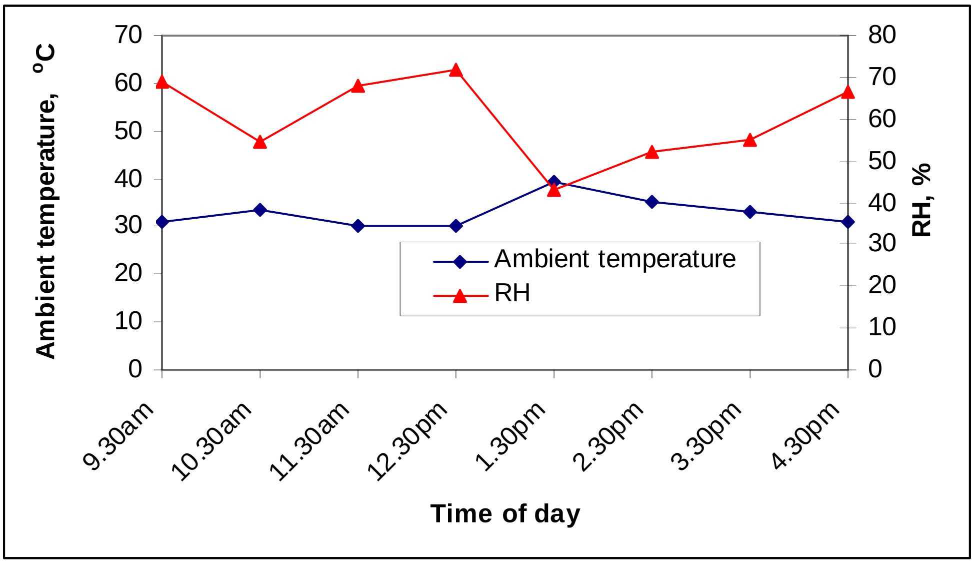

Fig.3. Variations of ambient temperature and relative humidity with the time of the day for a typical experimental run.

The solar radiation varied from 273 W/m² to 885 W/m² while the generated voltage varied from 4.5 V to 14.8 V. The variations of solar radiation and generated voltage with the time of day of a typical experimental run are shown in Fig. 4. The generated voltage increases with the increase in solar radiation.

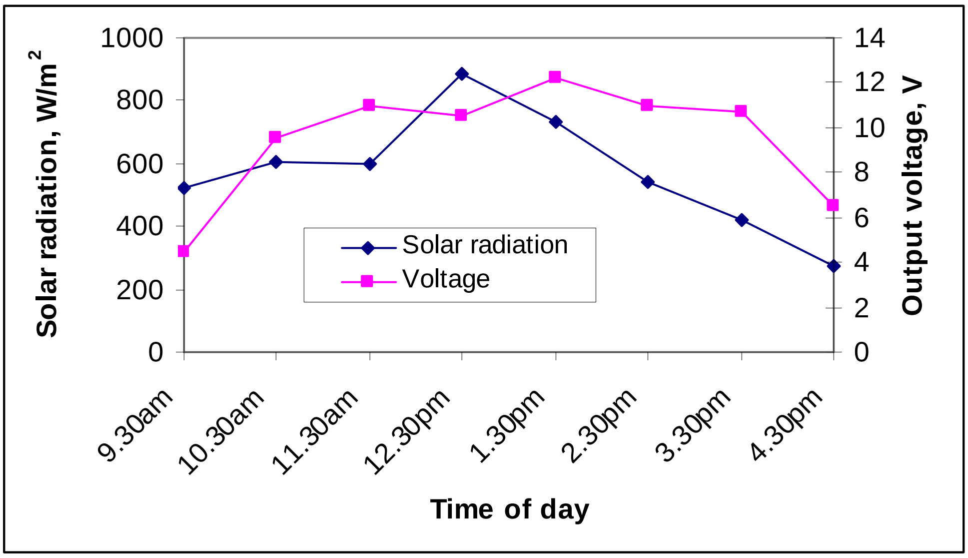

Fig.*4. Variations of solar radiation and generated voltage with the time of the day for a typical experimental run.*

Drying air temperature varied from 37.0 °C to 66.5 °C at the collector outlet of the drier during drying period depending on weather conditions and time of the day. The variations of solar radiation and temperature with time of day in a technical run is shown in Fig.5. The temperature at the collector output changes within a narrow band and this implies that the maximum permissible temperature for product being dried at a specific location can be maintained within a narrow band of temperature changes by proper design of the solar tunnel dryer.

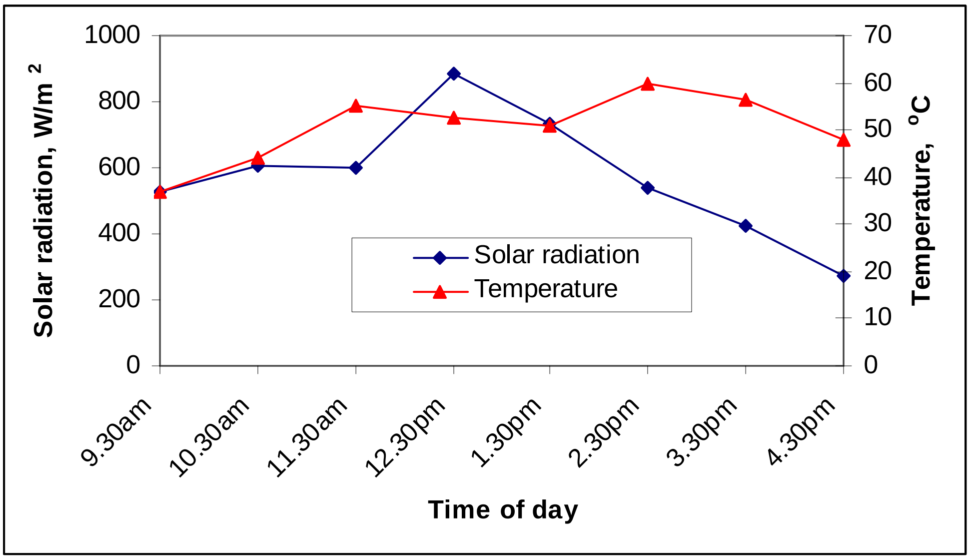

Fig.5. Variations of solar radiation and temperature at the collector outlet with the time of the day for a typical experimental run.

Fig. 6 shows the variations of the temperature at the collector outlet and the air velocity with the time of day of a typical experimental run. The variation of the air flow rate helped to regulate the drying temperature. During the high insolation period more energy was received by the collector which was intended to increase the drying air temperature but it was compensated by the increase of the air flow rate. During low solar insolation period less energy was received by the collector and the air flow rate was low. This resulted in minimum variation of the drying air temperature throughout the drying period. Air velocity was very low during all the experimental runs.

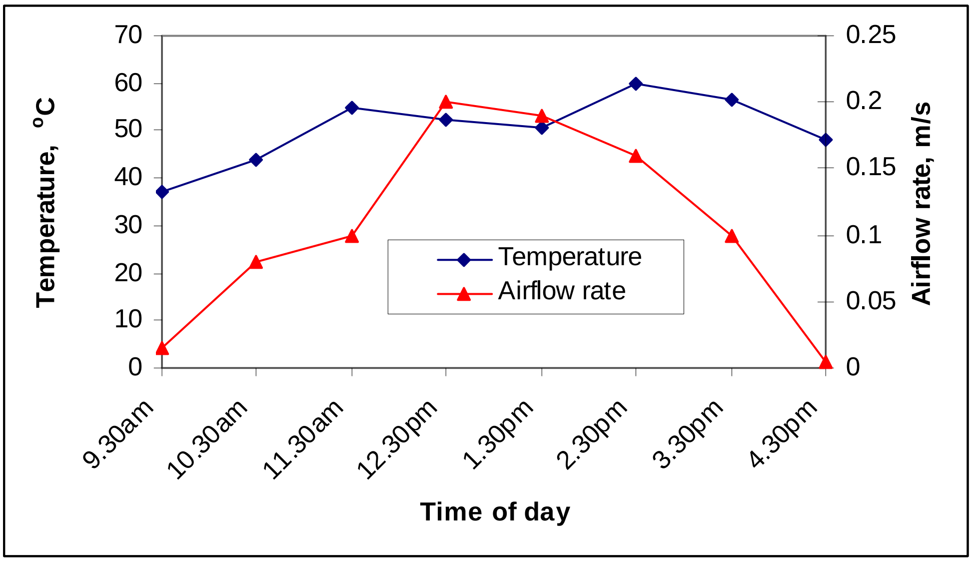

Fig.6. Variations of temperature at the collector outlet and air flow rate with the time of the day for a typical experimental run

Fig. 7 shows the comparison of the variations of the moisture content with the time during solar drying of mushrooms with those of sun drying for a typical experimental run. The moisture content of mushroom reached from 89.41% to 6.14% (wb) in 8 hours of drying in the solar tunnel drier while it took 8 hours of drying to bring down the moisture content in a similar sample to 15.0% in traditional sun drying method. There is a considerable reduction in drying time of mushroom in solar tunnel drier as compared to sun drying of mushroom. The solar dried products are protected from dirt, pest and are of good quality. The dried mushroom is a quality dried product.

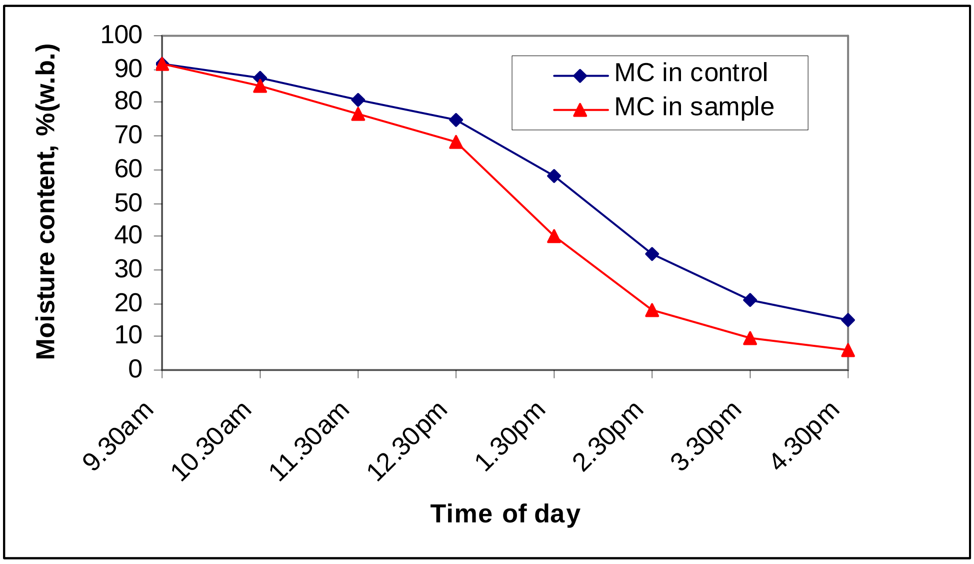

Fig.7 Comparison of the variations of the moisture content with the time during solar drying of mushrooms with those of sun drying for a typical experimental run

4.2 Collector efficiency, drying efficiency and overall efficiency

Table-1 shows collector efficiency, drying efficiency and overall efficiency for a loading of 160 kg of mushrooms. The overall efficiency is within the range of 30.43% – 38.47% while the overall efficiency for natural convection solar dryer is within the range of 12% – 18%. This high overall efficiency for the solar tunnel dryer is due to the fact that the solar tunnel dryer is a forced convection solar drier and the drying unit receives energy from both collector and incident radiation.

Table1 Collector efficiency, drying efficiency and overall efficiency

Experimental run	Collector			Drier			Overall efficiency (%)
	Energy input (MJ)	Energy output (MJ)	efficiency (%)	Energy input (MJ)	Energy output (MJ)	efficiency (%)	
1	396	140.2	35.34	536.2	307.36	57.32	38.77
2	504.4	161.71	32.12	666.11	306.14	45.95	30.43
Average	450.2	150.96	33.73	601.16	306.75	51.64	34.6

4.3 Payback period

Table-2 shows the computation of payback period of the solar tunnel drier for drying mushrooms and it is 0.70 year. But the initial cost is very high. The producers of dried products in the rural areas of Bangladesh should be provided with micro-credit and extension of the micro-credit approach of Grameen Bank may be considered.

Table 2 Computation of payback period of the solar tunnel drier for drying of mushroom

Item	No.	Rate (Tk/No.)	Price (Tk)
Cost of drier	1	70,000	70,000
Salvage value	1	5,000	5,000
Expected life	-	-	15 years
Depreciation	1	4,333	4,333
Labor cost	12 × 180 days	200/man/day	4,32,000

Cost of raw mushroom	100 kg × 180 days	150 Tk/kg	27,00,000
Maintenance cost	1	3000	3,000
Total cost			31,39,333
Total income	15 kg × 180 days	1200 Tk/kg Dried mushroom	32,40,000
Net income			1,00,667

$$Payback\ Period = \frac{70,000}{1,000,667} = 0.7\ year$$

5. Conclusions

Tests of the solar tunnel drier demonstrate the potentiality of the solar tunnel drier for drying of mushrooms in Bangladesh. It is worth adoption since the product has a market and the quality of the product is reflected in its price.

There is a considerable reduction in drying time of mushrooms in solar tunnel drier as compared to sun drying of mushrooms. The solar dried products are protected from dirt, pest and the dried mushrooms are a quality dried product.

This drier is simple in construction and it can be constructed using locally available materials by the local craft man.

The solar tunnel drier can be operated by a photovoltaic module independent of electric grid.

The photovoltaic has the advantage that the temperature of drying air is automatically controlled by the solar radiation.

The photovoltaic driven solar tunnel drier must be optimized for efficient operation.

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