Solar Drying of Fish (Bombay Duck) Using Solar Tunnel Dryer

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ABSTRACT

Field level experiments on solar drying of fish using solar tunnel dryer were conducted at Cox's Bazar, Bangladesh. The dryer consists of a transparent plastic covered flat plate collector and a drying tunnel connected in serie to supply hot air directly into the drying tunnel using four dc fans, operated by two solar modules. This dryer has a loading capacity of 120 to 150 kg of fish. The drying air temperature at the collector outlet varied between 38.2 °C to 50.2 °C in the month of December, 1999 and 29.5 °C to 55.0 °C in the month of December, 2000. The temperature inside the collector increased along the length of the collector while the drying air temperature decreased along the dryer length during the early stage of drying and then remains almost constant. In a typical experimental run Bombay duck was dried to a moisture content of 15% from 89.8% in 9 hours of drying in solar tunnel dryer as compared to 20 hours of drying in the traditional method of comparable samples to a final moisture content of 15%. Drying of Bombay duck in the solar tunnel dryer can be described by a single exponential equation. Drying behaviour depends on species and the resistance to drying in Bombay duck is much lower as compared to that of salt treated Silver jew fish. In all the cases, the use of solar tunnel dryer leads to considerable reduction of drying time in comparison to sun drying. The quality of the product dried in the solar tunnel dryer is better than sun dried products. The dryer is simple in design and can be constructed using locally available materials by a local craftsman. The solar tunnel dryer can be operated by two photovoltaic modules independent of electrical grid. The photovoltaic system has the advantage that the temperature of the drying air is automatically controlled by the solar radiation. In this work, altogether, a total of four experiments are conducted.

1. INTRODUCTION

Fish is an important component of the daily diet and the dried fish is an important source of protein in Bangladesh. Traditionally, drying of fish is mainly carried out by direct sun drying. The drying procedure is not hygienic and the fish is vulnerable to insect attack. To avoid this infestation and for safe storage, dried fish producers often apply insecticides including DDT in fish. This fish is highly contaminated and creates broad range of environmental and health hazards.

Fresh fish contains up to 80% of water and it is a highly perishable material. When moisture content is reduced to 25% (w.b.), contaminating agents can not survive and autolytic activity is greatly reduced. However, to prevent mould growth during storage, moisture content must be reduced to 15%. Tropical species of fish can generally withstand temperatures of 45 to 50°C, before proteins are denatured or cooking starts.

Solar drying can be considered as an elaboration of sun drying [1,2]. Doe *et al*. [3] developed a polythene tent solar dryer for drying fish. The tent dryer is effective in controlling fly larvae infestation in fish with a slightly higher drying rate [4,5]. A Comparative study of tent dryer, cabinet dryer and a dryer with a separate collector unit and drying unit shows the tent dryer to be the most suitable design [6]. Sachithananthan *et al*. [7] conducted four experimental trials in Yemen comparing the performance of solar drying and sun drying of fish. Solar drying was found to be a realistic option. Mukherjee *et al.* [8] designed and tested a greenhouse type solar dryer and reported that it was possible to dry fresh fish of mixed variety and size to the desired moisture content within 2 to 3 days.

Doe and Heruwatti [9] developed and applied a computer model to the traditional sun drying as well as to mechanical drying of fish. The computer simulation if set up over a range of climatic conditions, can be used with some confidence to predict the effects of change in the various variables involved.

Natural convection dryer is low cost that can be locally constructed. It does not require any power from electrical grid or fossil fuels. But, the natural convection solar dryers suffer from the limitations due to extremely low buoyancy induced airflow inside the dryers [10,11]. The high weather dependent risk and drying limitations due to extremely low buoyancy induced air flow inside the natural convection solar dryer were the main reasons for the development of solar tunnel dryer in which a fan is providing the air flow required to remove the evaporated moisture. The electric power requirement of the fan is very low and can be operated by one photovoltaic module (12 V, 40 W) independent to electric grid. Numerous tests in regions of different climatic conditions have shown that fruits, vegetables, cereals, grain, legumes, oil seeds, spices, fish and meat can be dried properly in the tunnel dryer [12-29]. The objective of this work was to investigate the performance of the solar tunnel dryer for drying fish (bombay duck) under ambient conditions in Bangladesh.

2. MATERIALS AND METHODS

2.1 Solar Tunnel Dryer

The solar tunnel dryer consists of a flat plate air heating collector, a tunnel drying unit and a small fan to provide the required air flow over the product to be dried. These are connected in series as shown in Figure1. Both the collector and the drying unit are covered with plastic. Black paint is used as an absorber in the collector. The products to be dried are placed in a thin layer on a bamboo split net in the tunnel dryer. Glass wool is used as insulation material to reduce the heat loss from the dryer. The whole system is placed horizontally on a raised platform. The air at required flow rate is provided by four dc fans operated by two photovoltaic modules. As the air is passed over the product rather than through the product in the dryer, the power requirement to drive a fan is low. To prevent the entry of water inside dryer unit during rain, the cover is fixed like a sloping roof. Solar radiation passes through the transparent cover of the collector and heats 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 dryer and heats the products. This enhances the drying rate and the temperature in the dryer rises in the ranges of 29.5°C to 55.0°C.

2.2 Experimental Procedure

The solar tunnel dryer was installed at the Marine Fisheries Research Institute, Cox's Bazar, Bangladesh. The dryer was placed on raised platform and it was not shaded by trees or building during 8.0 am. to 4.0 pm. Four sets of full scale experimental runs on solar drying of Bombay duck were carried out in the month of December, 1999 and 2000.

Important parameters affecting the performance of the dryer were measured. The k-type thermocouple was used to measure the drying air temperature along the flow direction of the air inside the dryer and a pyranometer (photovoltaic solar cell type) was used to measure the global radiation at the inlet of the dryer. The relative humidity and temperature of the ambient air were measured with a digital thermometer and relative humidity meter (Lutron HT-3003). The velocity of drying air was measured with an anemometer (Taylor 3132) at the outlet of the dryer. Weight loss of the product during drying period was measured with an electronic balance. The sun dried control samples were weighed as well. All these data were recorded at one hour interval. The moisture contents of the fish were measured at the starting and end of each run of experiments by air oven method using about 5 g of finely minced fish at 105°C for 24 hours.

Experimental solar drying runs were conducted on Bombay duck. For each of the experimental runs the dryer was loaded to the full capacity of 120.0 kg of Bombay duck. The drying was started usually at 9.0 am and discontinued at 4.0 pm. for each day. During night the fish was left in dryer and was protected from the cat using wire net at the outlet of the dryer. To compare the performance of the tunnel dryer with that of the sun drying, control samples of fish were placed on trays in a single layer on a raised platform beside the dryer. Both experimental and control samples were dried simultaneously under the same weather conditions.

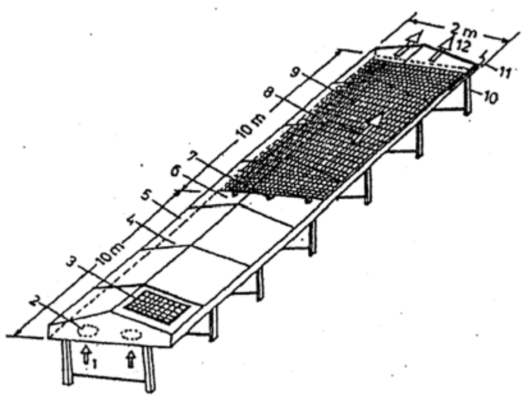

Fig. 1. A typical solar tunnel dryer.

3. RESULTS AND DISCUSSION

3.1 Experimental Results

Variations of solar radiation and output voltage for a typical experimental run during drying of Bombay duck are shown in figure 2. During drying of Bombay duck solar radiation varied from 150 W/m^2 to 550 W/m^2 while the output voltage varied from 6.0 V to 15.0 V.

Figure 3 shows the variations of the ambient air temperature and relative humidity of a typical experimental run during solar drying of Bombay duck. The ambient relative humidity decreases with the increase in ambient temperature. The second day of the experiment was bright in the morning and cloudy in the afternoon which resulted in the sharp fall and rise in the relative humidity.

The patterns of temperature changes of the drying air at the collector outlet and airflow rate of a typical experimental run are shown in figure 4. The variation of the airflow rate helped to regulate the drying temperature. During 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. While during low solar insolation period less energy was received by the collector and airflow rate was low. Hence, the decrease in temperature due to low solar insolation was compensated by the increase in temperature due to low airflow rate. This resulted in minimum variation of the drying air temperature throughout the drying period and saved the product from partial cooking due to excess temperature.

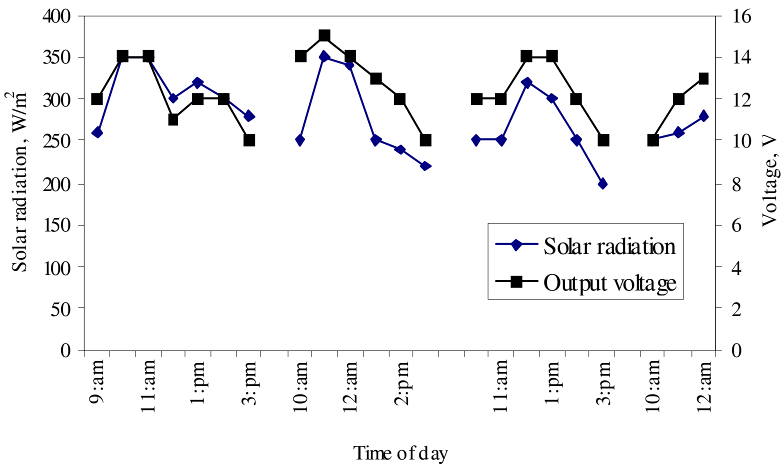

Fig. 2. Variations of solar radiation and output voltage with time of day during drying of Bombay duck.

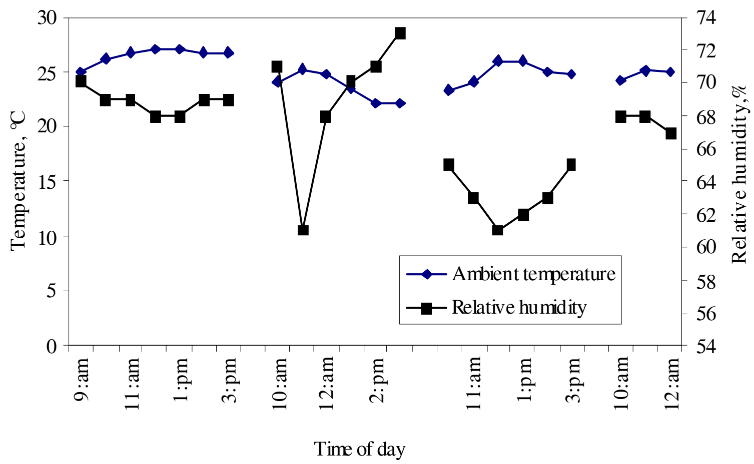

Fig. 3. Variations of ambient temperature and relative humidity with time of day during drying of Bombay duck.

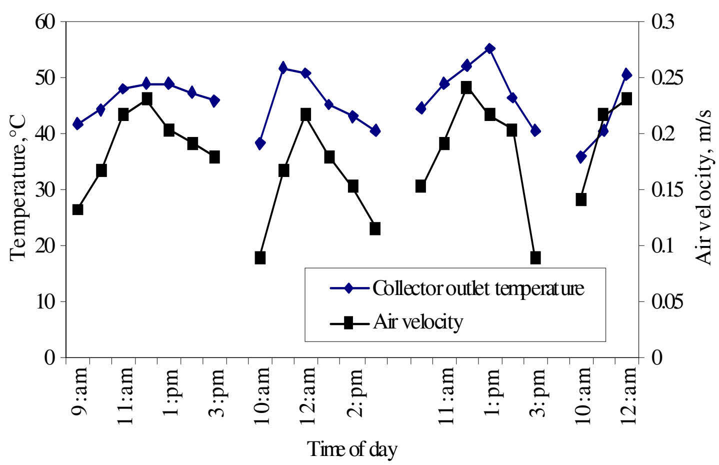

Fig. 4. Variations of collector outlet temperature and air flow rate with time of day during drying of Bombay duck.

Figure 5 shows the variations of airflow rate with the changes in solar radiation and it is described by the following equation:

$$Air\,flow = 0.0012 \times solar\ \ radiation\ + 0.1131 \qquad r^2 = 0.55 \qquad (1)$$

where air flow is in m/s and solar radiation is in W/m^2. The coefficient of determination r^2 = 0.55 is highly significant at 1% level and 55% of the variation of airflow is explained by solar radiation. The cross-sectional area of the airflow channel is 0.38 m^2.

Figure 5 shows that most of the time solar radiation is available in the intermediate ranges between 200 W/m^2 and 450 W/m^2 with wide fluctuation in air velocity. This fluctuation is probably due to inherent time delay and improper matching in the dc motor-fan combination.

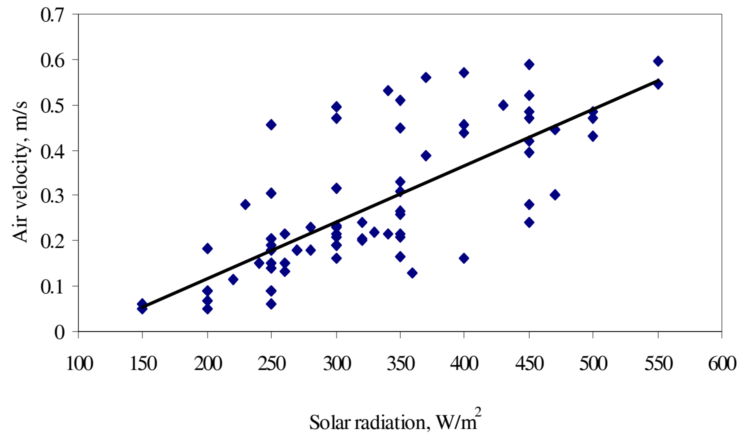

Fig. 5. Air flow rate as a function of solar radiation.

Figure 6 shows the variations of collector outlet temperatures with solar radiation. The equation relating collector outlet temperature (°C) and solar radiation (W/m^2) is given below:

$$Collector\ outlet\ temperature = 0.0282 \times solar\ radiation + 35.523 \qquad r^2 = 0.30 \qquad (2)$$

The coefficient of determination r^2 = 0.30 is highly significant at 1% level. Here, the intercept is significant but the slope is insignificant and hence, the collector outlet temperature changes within a close range.

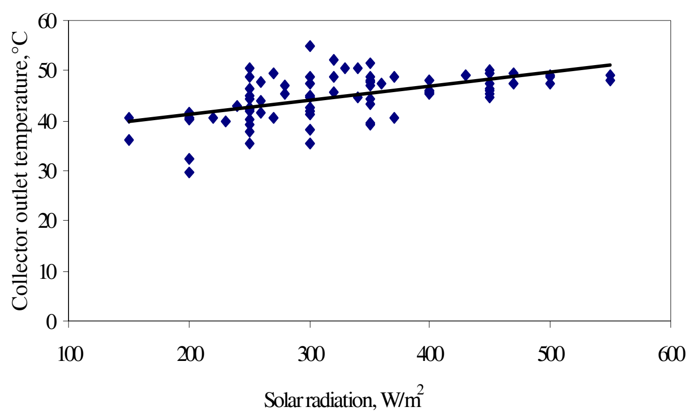

Fig. 6. Air temperature at the outlet of the collector as a function of solar Radiation.

Figure 7 shows the variation of the air temperature along the length of both collector and dryer for different solar radiations for a typical experimental run. The temperature inside the collector increases along the length of the collector from the inlet of the collector while the drying air temperature decreases along the dryer length during the early stage of drying and then remains almost constant throughout the dryer length. As a result the fish was uniformly dried along the length of the dryer.

The collector outlet temperature should not exceed the maximum permissible temperature of the product to be dried. The maximum permissible drying air temperature at the collector outlet for maximum available solar radiation is set by changing the number of fans or by shifting the position of the collector outlet by moving the drying trays either towards the inlet or outlet of the drying system.

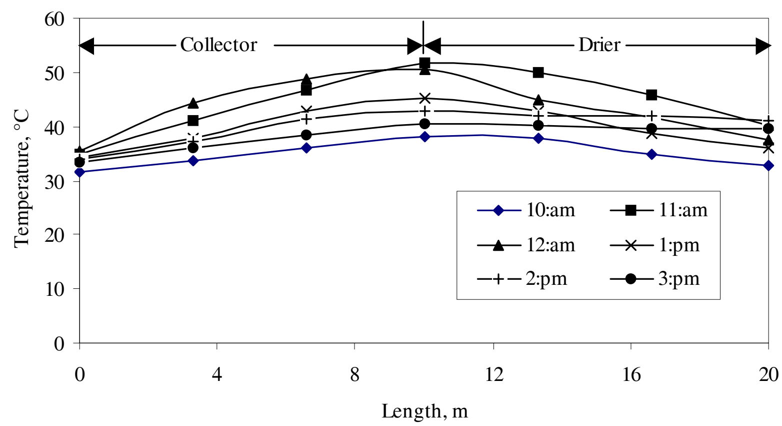

Fig. 7. Variations of temperature with the length of the solar tunnel dryer during drying of Bombay duck fish.

Statistical analysis of solar drying data of Bombay duck of 4 experimental runs shows that although there is a highly significant difference in the experimental runs at 0% level, the difference between the drying in the solar tunnel dryer and dying in the sun is also highly significant at 0% level (table 1). This implies that drying in the solar tunnel dryer considerably reduces the drying time.

Comparison of the moisture contents of Bombay duck in the solar tunnel dryer with those obtained by the traditional method of a typical experimental run during drying of fish is shown in figure 8. The moisture content of Bombay duck reached to 15% (w.b.) from 89.8% (w.b.) in 9 hours of drying in the solar tunnel dryer while it took 20 hours of drying to bring down the moisture content of similar sample to 15% (w.b.) in traditional method. This is due to the fact that Bombay duck in the dryer that received energy both from the collector and from incident solar radiation, while the control samples received energy only from incident radiation and lost significant amount of energy to the environment.

Table 1. Analysis of Variance of the Solar Drying Data of 4 Experimental Runs

K value	Source	df	SS	MS	F value	Prob.
2	Treatment A	3	323.382	107.794	32.1194	0.0000
4	Block B	1	165.690	165.690	49.3703	0.0000
6	AB	3	42.513	14.171	4.2225	0.0223
-7	Error	16	53.697	3.356		
	Total	23	585.282			

Note. Block (Solar drying in the tunnel dryer and sun drying) and Treatment (Experimental runs).

A single exponential equation was fitted to all the experimental data of Bombay duck and the fitted equation is

$$Moisture\ content = 98.702\, e^{-0.1464\, time} \qquad r^2 = 0.96 \qquad (3)$$

where the moisture content is in percent (w.b.) and time is in hour. The coefficient of determination $r^2 = 0.96$ is highly significant at 1% level.

Figure 9 shows the comparison between experimental and predicted data of a typical experimental run of solar drying of Bombay duck. The agreement between the experimental and predicted values is excellent.

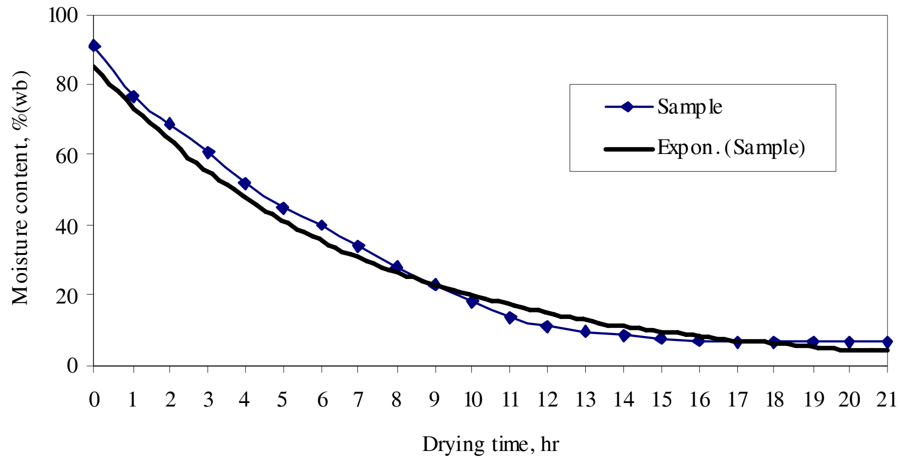

Fig. 9. Comparison between experimental and predicted values during drying of Bombay duck.

Comparisons of the drying behaviour of Bombay duck with that of Silver jew fish under almost similar conditions of drying are shown in figure 10. It is evident from the figure 10 that Bombay duck had much higher initial moisture content and also Bombay duck did dry at much higher rate to a much lower moisture content. This mainly due to the fact that the muscle tissue of Bombay duck is damaged under normal drying conditions while that of silver jew fish remains intact. As a result the resistance to the drying in case of Bombay duck is significantly reduced and it is much lower than that of Silver jew fish and Bombay duck dry much faster rate than that of Silver jew fish. Thus, drying behaviour of fish is highly dependent on the species of fish.

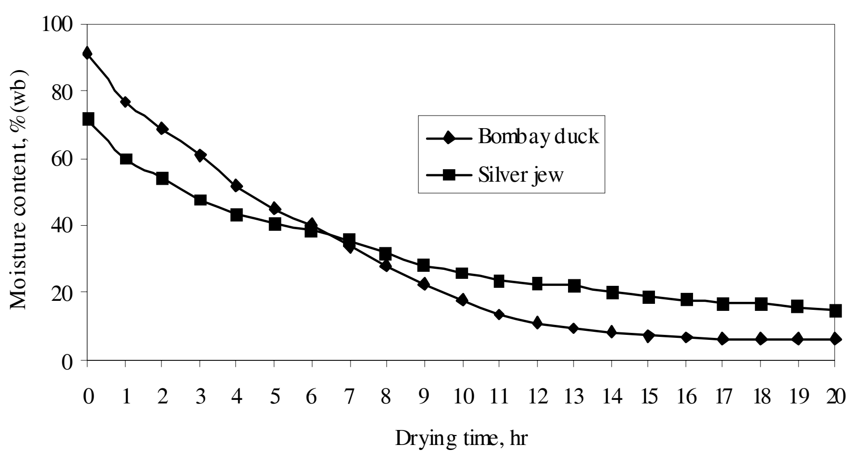

Fig. 10. Comparisons of the drying behaviour of Bombay duck with that of Silver jew fish.

Proximate analysis was carried out for dried fish (table 2) and the solar dried fish contained higher amount of protein and lipid. Chemical compositions of the dried fish represent that the fish dried in the solar tunnel dryer was a good quality product for human consumption. Furthermore, E-coli and samonella were not found in the solar dried fish. Similar results have been reported by Ahmed et al [4]. In all cases, the quality of fish dried in the tunnel dryer was of quality dried product as compared to sun dried fish and the price of fish dried in solar tunnel dryer was 2.5 times the price of sun dried fish. Also in the markets there exist two different grades of dried fish commanding different prices. Thus, this study demonstrated the potential of the solar tunnel dryer for drying of fish in Bangladesh.

Table 2. Proximate Composition of Dried Fish

Moisture %	Ash %	Protein %	Lipid %	Total count FEC/g	E-coli	Salmonella
8.94	8.94	61.52	21.82	2.1×10^3	Nil	Nil
8.94	7.94	61.46	21.82		Nil	Nil
28.95	13.10	47.88	10.12	7.1×10^3	Nil	Nil

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

$$IA_{collectorc} = 10^{-6} \times A_{collector} \int_0^t Sr(t)\, dt \tag{4}$$

where
$IA_{collector}$ = Solar energy input on the collector, MJ
$Sr(t)$ = Solar radiation at time t, W/m^2
$A_{collector}$ = Collector area, m^2
t = time, s

and that of the solar module is computed as

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

where
IA_{module} = Solar energy input on the solar module, MJ
$A_{cmodule}$ = Module area, m^2

The output of the collector in terms of energy is

$$Output_{collector} = 10^{-3} \int_0^t \dot{m}(t)\, C_{pa} (T_c - T_i)\, dt \tag{6}$$

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

$$Collector\ efficiency = \frac{Output_{collector}}{IA_{collector} + IA_{module}} \tag{7}$$

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

$$IA_{dryer} = 10^{-6} \times A_{dryer} \int_0^t Sr(t)\, dt \tag{8}$$

where IA_{dryer} = Solar energy input on the dryer, MJ
A_{dryer} = Dryer area, m^2

The output of the dryer in terms of energy is

$$Output_{dryer} = 10^{-3} \times mr \times L_g \tag{9}$$

$Output_{dryer}$ = Output of the dryer, MJ
mr = Moisture removed, kg
L_g = Latent heat of vaporization of moisture, kJ/kg

Thus, efficiency of the dryer is

$$\eta_{drying} = \frac{Output_{dryer}}{IA_{dryer} + Output_{collector}} \tag{10}$$

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

$$\eta_{overall} = \frac{Output_{dryer}}{IA_{collector} + IA_{module} + IA_{dryer}} \tag{11}$$

Table 3 shows collector efficiency, drying efficiency and over all efficiency for a loading of 120 kg. The over all efficiency is within the range of 33 to 49% while the over all efficiency for natural convection solar dryers is within the range of 12 to 18% [30]. This over all efficiency of the solar tunnel dryer is due to the fact that the solar tunnel dryer is a forced convection solar dryer and the drying unit receives energy from both collector and incident radiation.

Table 3. Collector Efficiency, Drying Efficiency and over all Efficiency

Experime-ntal run	Collector			Dryer			Overall efficiency (%)
	Energy input (MJ)	Energy output (MJ)	Efficiency (%)	Energy input (MJ)	Energy output (MJ)	Efficiency (%)	
1	335.34	100.22	29.88	435.56	269.27	61.82	40.15
2	403.38	181.48	44.98	548.86	267.95	45.81	33.21
3	381.67	124.09	32.51	505.76	269.52	53.29	35.31
4	274.43	61.92	22.56	336.35	269.27	80.00	49.06
Average	348.71	116.93	32.48	456.63	269.00	60.23	39.43

3.3 Economics of Solar Tunnel Dryer

For extension of solar tunnel for production of quality dried product it must be economically viable. To assess the economic viability the payback period of the solar tunnel dryer for drying Bombay duck is determined and it is usually measured in years. The formula used here is given in [31]:

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Net\ Undiscounted\ Benifits} \tag{12}$$

Table 4 shows that the payback period of the solar tunnel dryer for drying Bombay duck is almost 1 year. But the initial cost is very high. The dried product producers in the rural areas in Bangladesh should be provided with micro-credit and extension of the micro-credit approach of Grameen Bank should be adopted [32].

Table 4. Computation of Payback Period of the Solar Tunnel Dryer

Cost of dryer	Tk 70,000
Salvage value	Tk 5,000
Expected life	15 years
Depreciation	Tk. 4,333
Labour cost 70×6×30	Tk 12,600
Cost for sample preparation 50×2×24×6	Tk 14,400
Maintenance cost	Tk 1,000
Total operating cost	Tk 27,000
Cost of raw fish 24×120×10	Tk 28,800
Total cost	Tk 61,133
Total income 24×20×250	Tk 120,000
Net income	Tk 58,867

Note: 1 US Dollar = Tk. 61.00

$$Payback\ \ period = \frac{70{,}000}{58{,}867} = 1.19\, years$$

4. CONCLUSIONS

Four full scale field level drying experimental runs for Bombay duck were conducted. The temperature of the drying air at the collector outlet was varied from 29.5 ^{0}C to 55.0 ^{0}C during drying. This dryer can be used to dry up to 150 kg of fish.

In all the cases, solar tunnel dryer leads to considerable reduction of drying time as compared to sun drying. The fish dried in the solar tunnel dryer was completely protected from rain, insects and dust, and the dried fish was a high quality product.

The solar drying of Bombay duck can be described by a single exponential equation and it also depends on the species of the fish.

The solar tunnel dryer can be operated by a photovoltaic module independent of electrical grid. The photovoltaic system has the advantage that the temperature of the drying air is automatically controlled by the solar radiation. The photovoltaic driven solar tunnel dryer must be optimized for efficient operation.

This dryer is simple in design and it can constructed using locally available materials by the local craftsman.

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