Technical and financial evaluation of a solar dryer in Bhutan

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Abstract

Bhutan is a mountainous country sandwiched between India and the Tibet. Agriculture forms the backbone of Bhutan's economy. Chilli is the most important spice crop, for both sale and consumption. As the chilli harvest season coincides with the monsoon, it is not always possible to dry chilli. It has therefore become a common feature in Bhutan to see chilli flooding the local market for a relatively short period and then disappearing until the next season. This problem could be reduced if chilli could be dried when it is available abundantly. Solar drying may be a feasible option and therefore the technical and financial performance of a proven commercial-scale solar crop dryer has been evaluated for Bhutan. The performance of the complete dryer system has been predicted to dry chilli and beef strips using the solar simulation program, TRNSYS. From the technical evaluation, the average collector, pick-up and system efficiencies were found to be 30%, 23% and 14.5% respectively for chilli. The solar contribution to the load is approximately 24.4%. Similar performance figures were predicted for drying beef. However, the current dryer does not appear to be financially viable. The net present value is negative and the benefit cost ratio is less than unity.

1. INTRODUCTION

Bhutan is a rugged mountainous country that lies sandwiched between India on the South, East and West and the Tibetan part of China on the North. Bhutan is located between 26°45' North to 28°10' North latitude and 88°45' East to 92°10' East longitude. The altitude varies from 100m in the south to 7 500 m in the northern regions. Agriculture forms the backbone of the Bhutan's economy contributing 32.4% of estimated GDP in 2002 (CSO, 2003; EIU, 2004). Chilli is the most important spice crop, for both sale and consumption. In Bhutan, both green (fresh) and dried chilli is consumed as a vegetable rather than as a spice (Berke, 2002; Wissink, 2004). Chilli is also not only an important part of the family diet but also one of the main cash crops. It is reported that farmers in the main chilli growing regions earn US$555 to US$667 per annum from the sale of chilli (Wangchuk, 2004). The common species is *Capsicum annum* L which is large, fleshy and mild (Luitel, 2004). As the chilli harvest season coincides with the monsoon, it is not always possible to dry the chilli. Thus, it has become a common feature in Bhutan to see chilli flooding the local market for a relatively short period and then to disappear until the next season. Meat also forms an indispensable part of the Bhutanese cuisine. Although, fresh meat is consumed, Bhutanese prefer dried meat. In 2002, residents of Bhutan's capital, Thimphu, consumed 1438 tonnes of meat valued at US$3 million, of which 665 tonnes was beef (Dorji, 2004).

Chilli and beef are currently dried using simple sun and air drying methods. Chilli is normally dried on open ground with no shelter provided. It is common to see rooftops covered with chilli during the summer months. This practice results in poor final quality associated with huge financial losses to the poor farmers. The method of drying beef is similarly crude. It is common to see almost every household drying beef in the open air. The quality of dried beef is also very poor, resulting in losses. An improved way of drying may result in better quality and reduced losses. Considering the importance of chilli and meat in Bhutan and need to dry them when they are available abundantly, there is a need to study improved drying systems, which are reliable and affordable to the local farmers. However, the country has no proven deposits of crude oil and natural gas (PCS, 2002), so conventional drying systems would be too expensive for the Bhutanese farmers to use. An alternative approach, as suggested by the literature, may be to use solar drying. This technique has been used in both developed and developing countries with some success. Therefore, this study evaluates the technical and financial performance of a proven solar dryer design in Bhutan. The principle product to be dried is chilli and beef is dried as a supplemental product when chilli is not available. The paper begins with a description of the dryer, its operation and key parameters. The paper then describes the method of evaluation, which is by thermal and financial modelling. The results of the modelling are then presented and discussed, followed by overall conclusions drawn from the evaluation.

2. DESCRIPTION OF SOLAR DRYER

The solar dryer design chosen for this evaluation has previously been built and used commercially to successfully dry vegetables, including chillies, in Khao-kor, north-east Thailand (Figure 1). The complete solar drying system consists of four separate drying troughs. There is a 73-m^2 solar collector array, ductwork, fan and heat exchanger for each drying trough. A central boiler provides supplementary energy to the heat exchanger in each system. A more detailed description of the system has previously been reported by Rakwichian *et al*. (1998). Key design parameters for the solar dryer are given in Table 1.

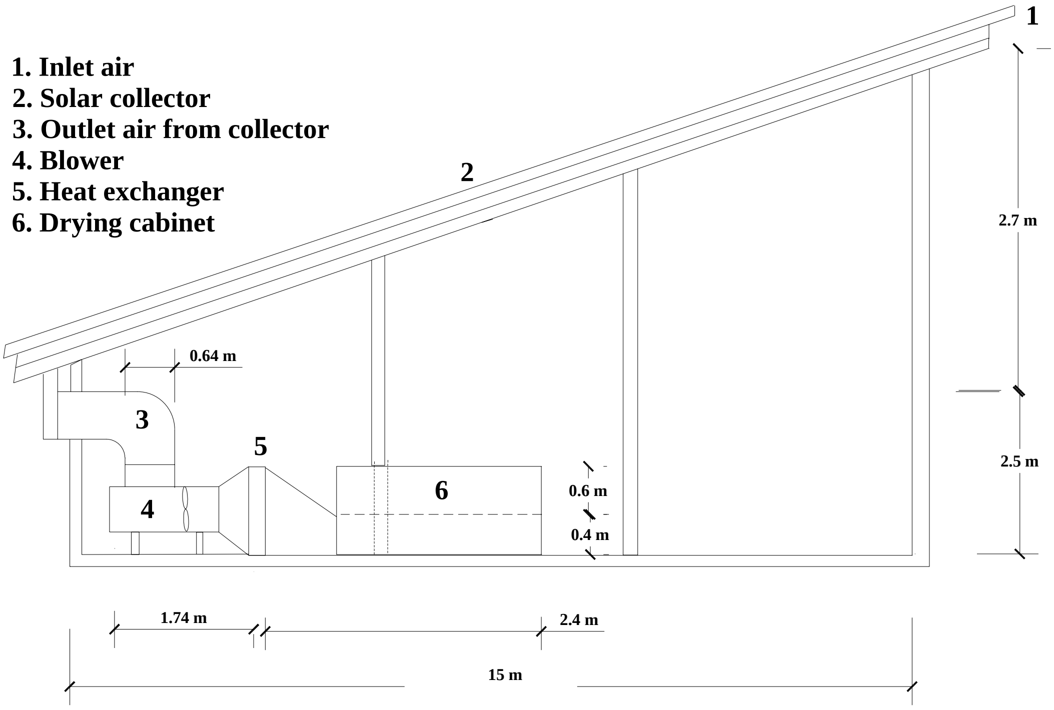

Figure 1 Schematic diagram of solar dryer

Although the solar dryer installed in northeast Thailand has been used successfully (Swasdisevi *et al*., 1999), the same performance level cannot be guaranteed in Bhutan. Operational variations particularly climate and the economic considerations both affect the technical and financial viability. Thus a comprehensive evaluation is necessary before replicating this solar dryer in Bhutan.

Table 1 Key parameters of the solar dryer

Parameters	Unit	Value
Capacity of dryer	kg	100-150
Collector area	m^2	73
Mass flow rate of air	kg/h	3120
Velocity of air	m/s	0.75
Drying air temperature	^{0}C	60
Drying bed area	m^2	2.75

3. MODELLING

Thermal and financial modelling has been used to evaluate the suitability of the solar dryer for Bhutan. The thermal performance of the dryer has been predicted using the solar simulation program, TRNSYS (2003) and the outputs from this thermal model were used as the inputs for a life-cycle cost analysis of the system.

3.1. Climatic Data

To study the performance of a solar dryer during different times of a year and at various locations requires climatic data for that location. Ali and Sakr (1981) claimed that at least ten years meteorological data is necessary to create a representative climatic data file. Unfortunately, Bhutan does not have a meteorological station and so measured data is not available. A search of the literature indicated that there has been no previous attempt to generate climatic data. Meteorological data for Bhutan was therefore generated using the Type 54 weather generator supplied in the TRNSYS software. The Type 54 requires monthly average insolation, ambient temperature, wind speed and humidity ratio as inputs Unfortunately, none of this climatic data is available for Bhutan and therefore these data have been sourced from NASA (NASA, 2004). The monthly solar radiation and dry bulb ambient air temperatures generated for Bhutan are shown in Figure 2, together with similar data for Khao-kor in Thailand. The marked differences illustrate the earlier observation that climatic differences will impact on the technical and financial viability of the dryer.

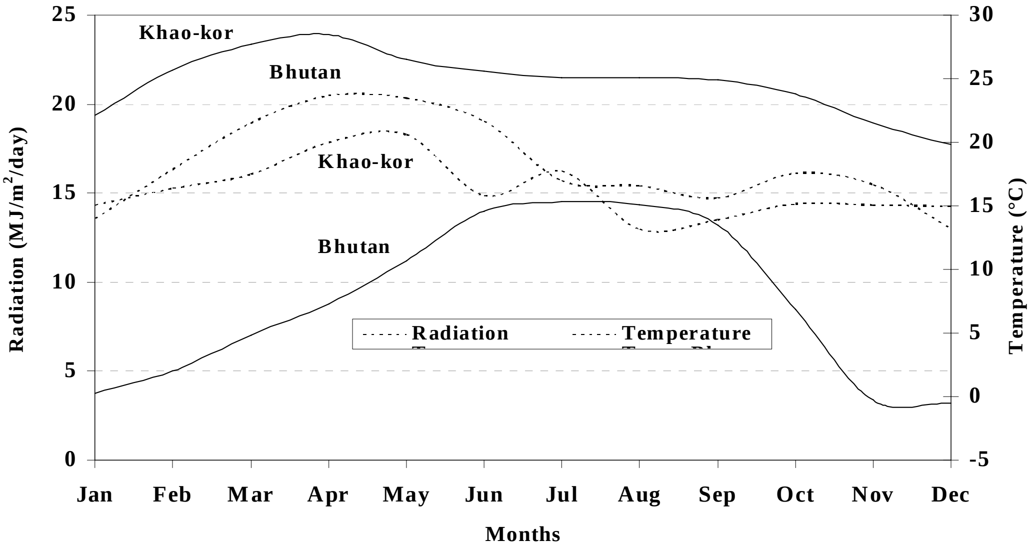

Figure 2 Monthly solar radiation and ambient temperature data generated for Bhutan and Khao-kor, Thailand.

3.2. Crop Models

Predictions of crop drying times are required for this evaluation to determine how many times the solar dryer may be used effectively during the year. Since a drying model is not available in the TRNSYS library, a special subroutine was written. This component computes the equilibrium and final moisture contents, dryer system, collector and pick-up efficiencies, and the drying time. To predict the drying time, the equilibrium moisture content (EMC) for the anticipated drying conditions must first be predicted. The equilibrium moisture content of chilli was calculated using the equation proposed by Kaleemullah and Kailappan (2003) (Equation 1).

$$M_e(db) = \left[\frac{\ln\{(Rh-a)/(-b)\}}{-(c\times T_c)}\right]^{(1/d)} \quad (1)$$

where: Rh = Relative humidity (decimal)
T_c = Temperature (°C)
a,b,c,d = Dimensionless constants

The values of constants a, b, c, and d used in this study to compute the equilibrium moisture content of chilli were:

a = 0.8406; b = 0.8189
c = 0.000739; d = 1.4102

The drying rate for thin bed drying is based on Newton's law of cooling and is proportional to the difference between actual and equilibrium moisture contents (Equation 2) (Hall, 1980). Rearrangement of this equation can provide an estimate of drying time.

$$\frac{(M-M_e)}{M_o-M_e} = e^{-kt} \quad (2)$$

where M = Moisture content of sample (db)
M_e = Equilibrium moisture content (db)
M_o = Initial moisture content of sample (db)
k = Drying constant (min^{-1})
t = Drying time (min)

The drying constant '*k*' is determined by experimental studies of moisture removal at different drying conditions. It is dependent on crop and drying air properties. To determine the time taken to reduce the moisture content of chilli from 567% (db) to 10% (db), a simulation run was performed starting at 10 am and continued until the moisture content was less than 10% (db) using various values of drying constant, *k*. A value of 0.03 was found to give a drying time of 18 hours (Figure 3), which agreed well with the findings of Sitthiphong *et al*. (1989).

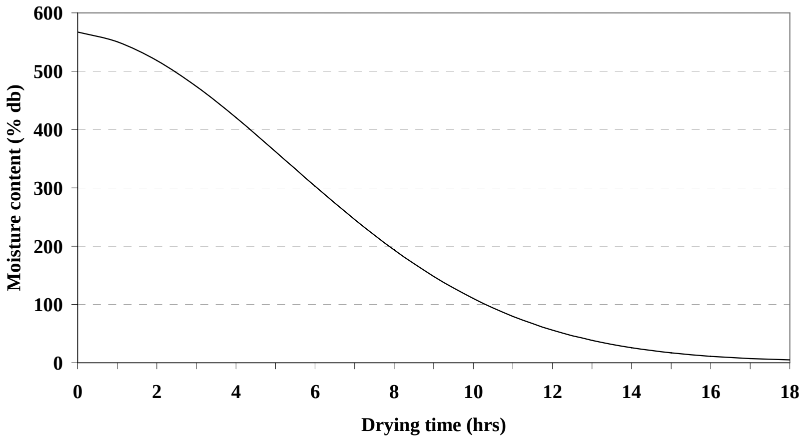

Figure 3 Drying curve of chilli

The drying time of beef could not be calculated in a similar way because no published drying constant for beef strips could be located in the literature. Experimental determination was beyond the scope of this study. Holley (1985) describes some experiments performed to establish the safe production and storage conditions for beef jerky that had been deliberately inoculated with various harmful organisms. In that research, the jerky was produced in a small electrically heated dehydrator for domestic use. The fresh meat slices were 6.4 mm thick, had initial and final moisture contents of 68% and 20% wet basis (w.b.) respectively and were dried satisfactorily for eight hours at approximately 50^0C. Harrison and Harrison (1996) dried jerky at 60^0C for ten hours to determine the survival rate of three contaminating organisms. In their experiments, the beef strips were 15 mm thick, and decreased in moisture content from 69.9% to 23.8% (w.b.) during drying. ITDG (2004) estimated the moisture content of fresh beef to be 70% (wb), while Lisse and Wack (1998) reported the moisture content of beef strips to be 80 $\pm$ 1.1% (wb). Fuller and Lu Aye (2002) also considered the initial moisture content of beef as 80%. Based on other research literature, therefore, this study assumed an initial moisture content of 80% and a drying time of beef of 8 hours at 60^0C.

3.3. Operational Parameters

As chilli is harvested during the months of August and September, it is assumed that the dryer is used exclusively for drying chilli during these two months. As there is no particular season for drying meat, it can be dried on any day during the periods January to July and October to December. However, the slaughter of animals and sale of meat in Bhutan is banned during the first and fourth months of Bhutan's lunar calendar. The quantity of chilli that can be dried per batch is assumed to be equal to the maximum capacity of the dryer i.e. 150 kg/batch. The chilli will be dried in thin layers without slicing or any other treatment before drying. Since the principle product in this study is chilli, the same dryer parameters obtained for chilli will be used for drying beef. However, unlike chilli, which is dried in layers, beef cannot be dried in layers as the airflow will be impeded and moisture cannot evaporate freely from the cut surfaces. Thus beef has to be dried by hanging with hooks over wires fixed on the surface of the dryer trough. Therefore, the quantity of beef that could be dried per batch was calculated as 100 kg/batch. The simulations were performed for both chilli and beef at a drying air temperature of 60°C, drying air velocity of 0.75 m/s and drying airflow rate of 3120 kg/hr.

3.4. Financial Parameters

The major costs of the solar dryer are the solar collector, drying trough and support structure. The estimated cost of these components in Bhutan is given in Table 2.

Table 2 Estimated cost of components of solar dryer system

Parameters	Amount (US$)
Land clearing and flooring	148
Solar collector and accessories	1 039
Dryer trough and frame	138
Duct heater, blower and ducts	817
Nails and screws	2
Installation and labour costs	199
Total	**2 343**

The parameters required for a financial analysis include discount rate, inflation rate and project lifetime. The real discount rate was calculated using the consumer price index in Bhutan as 13% based on a 2004 estimate. The inflation rate for Bhutan, as estimated by National Bureau of Statistics of Bhutan based on the base year 2003, is 5% (Dorji, 2004). This is assumed to remain constant over the project lifetime, which was assumed to be fifteen years based on the life expectancy of the timber used in the dryer.

4. RESULTS AND DISCUSSION

4.1. Chilli drying

When drying chilli, the daily collector efficiency was found to vary from 28-34%, while the average daily pick-up efficiency ranged from 21.4-24.4% during the period of drying. The average daily system efficiency ranged from 11% - 22%. The total quantity of energy required to reduce the moisture content of 4.5 tonnes of chilli from 567% (db) to 10% (db) was 78 GJ, i.e. 17.3 MJ/kg of fresh chilli. The total solar contribution to the load was 19 GJ or 24.4% of the total energy required. The daily solar fraction during chilli drying was highly variable, ranging from 5% to 50% (Figure 4). The total cost of supplementary energy for drying chilli from August to September is US$453.

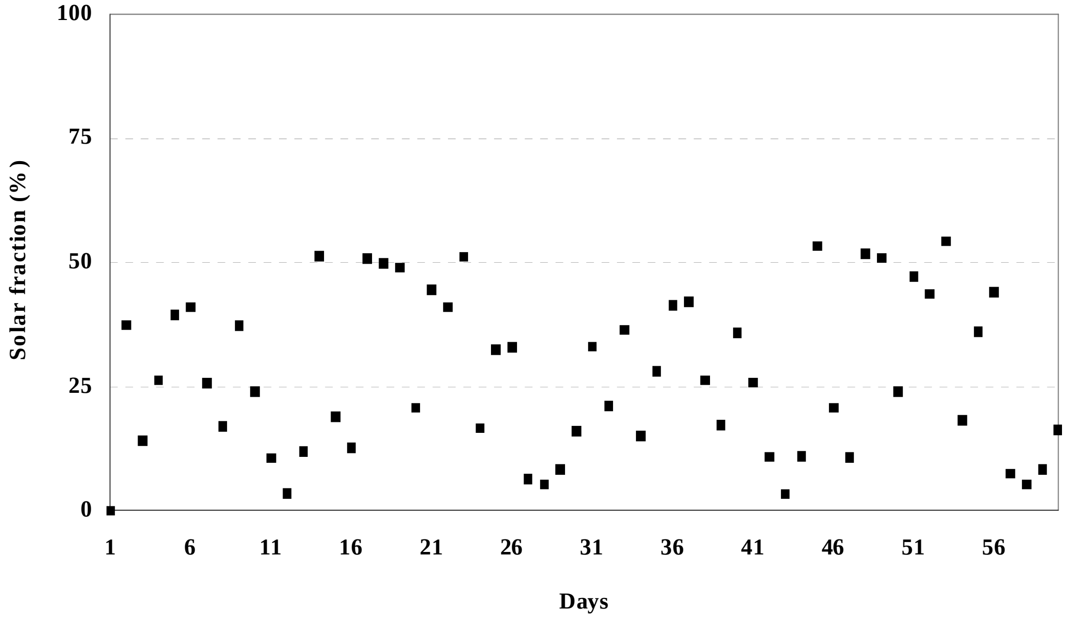

Figure 4 Daily solar fraction during the chilli drying period (August to September)

4.2. Beef drying

The total energy required to reduce the moisture content of 24.4 tonnes (i.e. 100 kg/batch x 244 batches) of fresh beef from 400% (db) to 10% (db) was predicted to be 291.7 GJ, i.e. 12 MJ/kg. The total solar contribution to the load was 69 GJ or 23.6% of the total load. Figure 5 shows daily solar fraction during beef drying. The total cost of supplementary energy for drying beef is US$1 752.

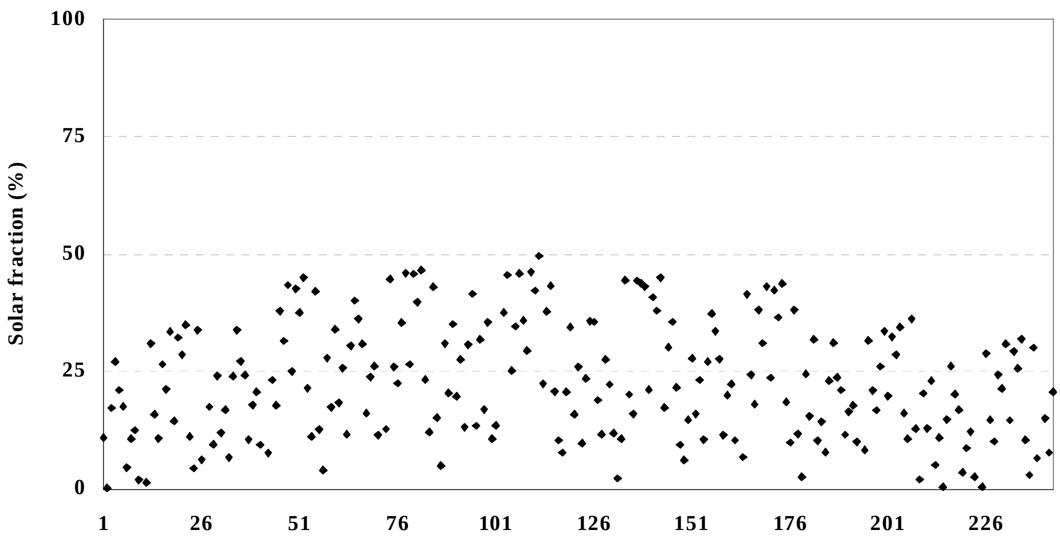

Figure 5 Daily solar fraction during the beef drying periods

Table 5 summarises the results of thermal performance for drying chilli and beef in the solar dryer in Bhutan.

Table 5 Thermal performance of solar dryer in Bhutan

Parameter	Unit	Chilli	Beef
Drying time	hours	18.0	8.0
Pickup efficiency	%	23.0	n.a.
Collector efficiency	%	30.0	40.0
System efficiency	%	14.5	17.0
Total solar energy	GJ	19.0	68.8
Solar fraction	%	24.4	23.6
Total supplementary energy	GJ	58.9	222.9
Cost of supplementary energy	US$	453.0	1 752.0

4.3. Financial evaluation

The operational cost includes the supplementary energy cost, salary for the operators and cost of fresh products to be dried. The daily operational cost varies depending on the solar fraction. The annual operating cost is US$33,352 combining both chilli and beef drying. The cost benefit analysis was performed assuming prevailing market prices for both the fresh and the dried products in Bhutan. Table 6 shows the detail cost benefit analysis. The NPV for both chilli and beef combined was found to be negative and hence there was no payback period. The negative value indicates that there is no net return from the investment in the solar dryer and thus the current design is not financially in Bhutan. Also, the benefit-cost ratio is less than one. This further suggests that an investment in the present system is not worthwhile.

Table 6 Cost benefit analysis of solar dryer in Bhutan

Parameter	Amount (US$)
Capital cost	2 343
Operating cost	34 977
Benefits	33 121
Discounted cash flow analysis	
Discounted revenue	214 043
Discounted O & M cost	226 037
Net present value	-14 262
Benefit cost ratio	0.94

5. CONCLUSIONS

The technical performance of the dryer was found to be satisfactory. Solar collector efficiencies of 30% and 40% were predicted for chilli and beef drying respectively. Pickup efficiency was 23% when drying chilli. Overall system efficiencies were lower, between 14.5% and 17%, for the two products. The solar fraction was approximately 24% for the current design. From the business point of view, however, the current dryer design is financially not viable in Bhutan. The total investment cost for a solar dryer is US$2 343, but operating costs exceed the benefits. A negative NPV and a benefit cost ratio of less than one is unlikely to attract private investors. The favourable technical performance suggests that the financial performance might be improved if the design was optimised to minimise drying costs, particularly by increasing solar collector area to better suit the climatic and financial situation in Bhutan. This optimisation will be the focus of a future study.

6. REFERENCES

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