วิศวกรรมสาร มข. ปีที่ 38 ฉบับที่ 4 (433-442) ตุลาคม - ธันวาคม 2554 บทความวิจัย
KKU Engineering Journal Vol.38 No.4 (433-442) October–December 2011

Performance analysis and economic evaluation of a greenhouse dryer for pork drying

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Abstract

This research presents experimental performances of a solar greenhouse dryer for drying of pork. The dryer has a semi-cylindrical roof and is covered with polycarbonate sheets. The base of the dryer is a concrete floor with the area of 12.6 m^2. Four DC axial flow fans powered by a 30 W PV module are used to ventilate the dryer. The dryer was installed at Kalasin province in Thailand. To investigate its performance, the dryer was used to dry pork. The drying air temperatures were varied from 40°C to 53°C. During the experiments, the pork was dried to the final moisture content of 70% db from 210% db in 260 min and it took 320 min in open sun drying, the drying time was reduced by abut 18.8%. The maximum and daily drying efficiencies of the greenhouse dryer were 55.7% and 42.8%, respectively. The economic analysis indicates that the payback period is 1.15 years.

Keywords: Drying efficiency, drying time, moisture content, payback period

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1. INTRODUCTION

Thailand is one of the countries well known for its livestock products; pork being one of them. The Office of Agricultural Economics of Thailand reported that pork products alone totaled 0.97 tons in 2010. Added value is available to fresh pork in the form of dried pork. The drying of pork can be accomplished using several different methods, i.e., open sun drying, cabinet drying, and greenhouse drying. The greenhouse dryer seems to be the best choice because it provides a controlled environment in terms of moderate temperature and humidity which is beneficial to the pork being dried more effectively thus reducing the drying time. Drying can also be accomplished with a solar cabinet dryer, but the high temperature is not desirable. Another consideration is cost; it is economically efficient to dry the same volume of pork inside the greenhouse as inside the cabinet dryer.

Solar energy is one of the most promising renewable energy sources in the world, especially in Thailand. Thailand is located in the tropical region of the Southeast Asia and receives an annual average daily solar radiation of 18.2 MJ/m^2 (Janjai et. al., 2005). Solar drying is a continuous process where moisture content, air and product temperature change simultaneously along with the two basic inputs to the system, i.e., solar radiation and ambient temperature. The drying rate is affected by ambient climate conditions. This includes temperature, relative humidity, sunshine hours, available solar intensity, wind velocity frequency and duration of rain showers during the drying period. The greenhouse dryer is a system that uses the standard greenhouse structure to work as a solar dryer during the warmer months of the year. A greenhouse is essentially an enclosed structure, which traps short wavelength solar radiation and stores long wavelength thermal radiation to create a favorable micro-climate for higher productivity. The product is placed in trays receiving solar radiation through the cover, while moisture is removed by natural convection or forced air flow. Many advantages of a greenhouse dryer are simple structure, large load capacity and relative good thermal performance (Shukla et. al., 2008). Various investigators have studied the greenhouse for drying agricultural products such as Condori et al. (Condori et. al., 2001) whom studied a tunnel greenhouse for drying sweet pepper and garlic. Kumar and Tiwari (2006) developed a thermal modeling of jiggery drying in a natural convection solar greenhouse dryer. A PV-ventilated greenhouse dryer for drying 100-150 kg of chilies was designed and tested by Janjai et al. (Janjai et. al., 2007). The same greenhouse was also used for drying peeled longan and banana (Janjai et. al., 2009). A mathematical modeling based on energy and mass balance was developed for predict the air and moisture contents of peeled longan and banana during drying. The simulation results reasonably agreed with the experimental data. Kumar and Tiwari (2007) compared the convective mass transfer coefficient of open sun drying, greenhouse dryer under natural and forced convections for drying onion flakes. It was found that the rate of moisture evaporation in case of greenhouse drying is more than that in open sun drying during the off sunshine hours due to the stored energy inside the greenhouse.

Jain (Jain, 2005) presented a transient analytical model to study the application of a greenhouse with packed bed storage to crop drying. In all of the literature reviews above the greenhouse dryers were used to dry many crops. None of these works studied the drying of meat, such as pork, using the greenhouse dryer. The objective of this study was to investigate the performance of the greenhouse dryer under prevailing climatic conditions of Thailand.

2. SYSTEM DESCRIPTION AND EXPERIMENTAL METHODS

The schematic diagram of the roof type semi-cylindrical greenhouse dryer is shown in Fig. 1.

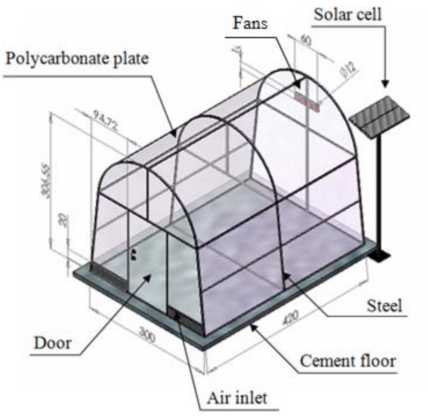

Figure 1 The structure and dimension of the greenhouse dryer

It consists of a semi-cylindrical roof structure made of polycarbonate sheets on a concrete floor. The polycarbonate sheets have many advantages over other transparent materials. First, they have high transmittance (0.8) in the short wavelength solar radiation. For thermal long wavelength radiation, the polycarbonate sheets have a transmittance of about 0.2 (Janjai and Keawprasert., 2006). The greenhouse dryer was instrumented with K-type thermocouples for measuring the

The transmittance for the short wavelength and the long wavelength indicate that polycarbonate sheets have good optical properties for the creation of the greenhouse effect. Second, polycarbonate sheets have low thermal conductivity due to the air channels in the sheets, which help reduce heat losses. Third, their low density and high flexibility facilitate the construction. Finally, they have reasonable price with a long life span of over ten years.

The greenhouse dryer is 3 × 4.2 m^2 effective floor covering area having the central height and height of walls as 3.06 m and 1.85 m, respectively. All side walls of the dryer are covered with polycarbonate sheets with the thickness of 6 mm. The front side wall of the dryer has two air inlets. The dimension of inlet air is 300 × 400 cm^2. One door of 1 × 1.85 m^2 made of glass was situated on the middle of the front side wall. To ventilate the dryer, four DC axial flow fans were installed in the wall opposite to the air inlets to suck out moist air from the inside dryer to the surrounding environment. Two channels are made at the bottom near the door to allow the outside air intake into the dryer as shown in Fig. 1. A 30 W solar cell module was installed to power the fans directly during the day. Metallic shelves with two levels of drying trays were constructed and installed inside the greenhouse dryer for placing products to be dried. The dryer was never shaded by trees or buildings. Drying experiments were carried out in the month of October 2010. The global solar radiation incident on a horizontal surface was measured using a pyranometer (Kipp and Zonen B.V. model CM 11, accuracy$\pm$10Wm^{-2}).

The greenhouse dryer was instrumented with K-type thermocouples for measuring the temperatures of the air inside the dryer, and the cover plate as shown in Fig. 1. Ambient humidity and temperature were measured using a Testo model 175-2 (accuracy $\pm$0.5°C, $\pm$3% RH). The air flow rate was calculated from the air velocity, measured by a hot wire anemometer (Testo model 445, accuracy $\pm$ 0.03 ms^{-1}) at the fans outlet (Fig. 3) and the equal area method (McMinn and Magee, 1999) was used for air velocity measurement. Weighed loss of the products during the drying period was measured with an electronic balance (Sartorius model CP3202S accuracy $\pm$0.01 g). A digital clamp tester (Kewtech model KT200 accuracy $\pm$ 0.05 V, $\pm$ 0.01 A) was used to measure the power consumption of the fan. The sun dryer control samples were weighted as well. All data were recorded at 10 min intervals. Pork was slice to dimension of 5 cm $\times$ 12 cm and 0.2 cm thick. The sliced pork was cooked before drying. The moisture contents of the pork were measured at the starting and end of each run of experiments by an air oven method using about 8 g of pork at 103°C for 72 hours (AOAC, 1990).

The sample was found to have an initial moisture content of about 210% dry basis. Pork was then spread on stainless steel screen trays in a thin layer. For each of the experimental runs the dryer was loaded to the full capacity about 40 kg of pork. The greenhouse dryer is capable of drying 40 kg of pork two times a day. Testing started at 8:30 a.m. and ended at 4:30 p.m. each day.

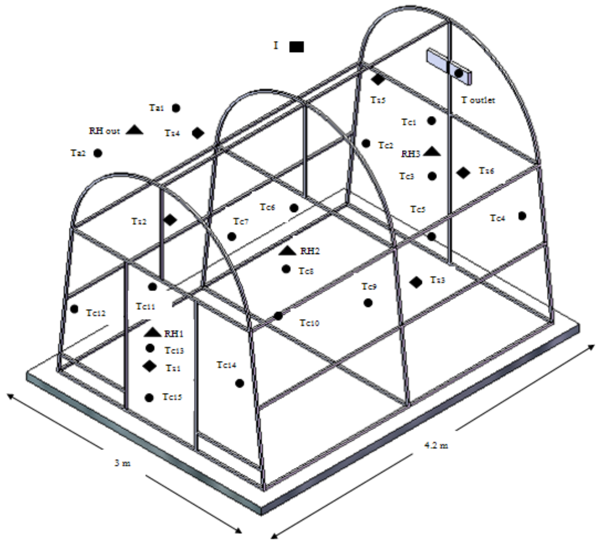

Figure 2 The dimension and the positions of the thermocouple (T), relative humidity (RH)

3. ANALYSIS

3.1 The drying efficiency

The drying efficiency of the greenhouse dryer is defined as the ratio of energy output of the dryer to energy input in the dryer. Solar radiation input on the dryer is given by:

$$Q_s = A_d \int_0^t G dt \qquad (1)$$

where Q_s is solar energy input on the dryer, J

G is solar radiation at time t, W/m^2

A_d is dryer area, m^2

t is drying time, s

The output of the dryer in terms of energy required for vaporization is given by:

$$Q_d = m_w \times h_{fg} \tag{2}$$

where Q_d is energy required for vaporization, J

m_w is moisture removed, kg

hf_g is latent heat of vaporization of moisture, J/kg

The drying efficiency of the dryer (η_d) is calculated by (Janjai et. al., 2007)

$$\eta_d = \left(\frac{Q_d}{Q_s + Q_c}\right) \times 100 \tag{3}$$

where Q_c is energy output from the solar cell module, J

3.2 Quality analysis

Hardness

A texture analyzer model TA.XT plus was used to measure the hardness of dried pork. The sample was fixed on the platform having a hole with diameter of 0.5 cm at the center. The distance between platform and base was 80 mm and 50 mm from probe to sample. The needle probe with 0.2 mm diameter penetrated through the sample.

The program was returned to start and set with speed of probe 2 mm/s moving forward and 5 mm/s for moving back. The force in Newton (N) was required to record as the peak load.

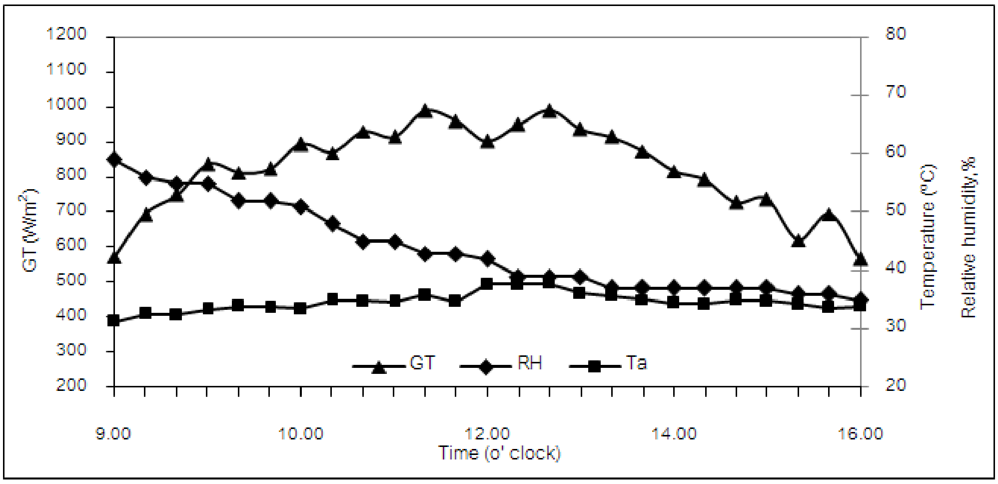

Figure 3 Variation of ambient temperature (Ta), relative humidity

Shrinkage

Shrinkage was evaluated by displacement in n-heptane according to the method of Yan et al. (Yan et. al., 2008). Shrinkage percentage was defined as the percentage change in the volume of a sample. It was calculated as follows:

$$S = \left(1 - \frac{V}{V_o}\right) \times 100 \tag{4}$$

where S is the shrinkage percentage, %

V and V_o are the volume of the dried and before drying sample, respectively, cm^3

Color values

The colorimetric data used to characterize the surface color of dried pork were the L a b values from hunter scale using Mini Scan XE Plus. L represents the lightness, 0 is dark and 100 is bright. The positive a is the red direction, negative a is the green direction and positive b is the yellow [illegible]on.

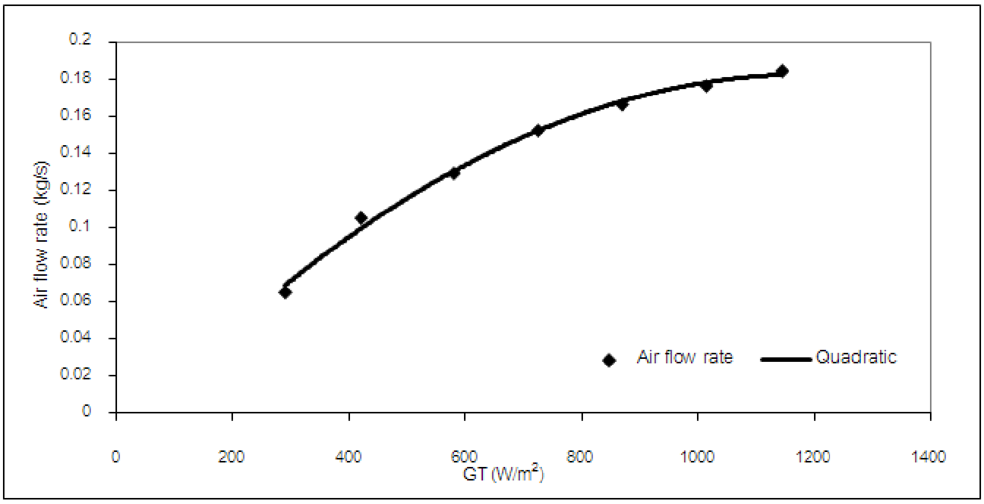

Figure 4 Relation between the air flow rate and solar radiation

4. RESULT AND DISCCUSION

4.1 Drying performance analysis

During 30 days of experiments, the variations of the solar radiation, ambient temperature and relative humidity are shown in Fig. 3 for a typical day of October 2010 in Kalasin. During the drying experiment, the daily mean values of ambient air temperature (Ta), relative humidity (RH) and solar radiation (GT) were 34.7°C, 44% and 823.3 W/m^2, respectively. The ambient temperature and solar radiation reached the highest figures between 11:30 and 13:30, whereas relative humidity reached the lowest figures at 16:00.

Fig. 4 indicates that the variations of the air flow rate which was powered by the solar cell module for operating the fans providing the required air flow rate inside the dryer. The air flow rate increases as the solar radiation increases, the maximum air flow rate was 0.18 kg/s at solar radiation of 1144.7 W/m^2, while the minimum air flow rate was 0.065 kg/s at solar radiation of 289.8 W/m^2. The average air flow rate was 0.153 kg/s during the day of experiment.

Fig. 5 shows the variations of average drying air temperature and relative humidity of the greenhouse dryer. The drying air temperature and

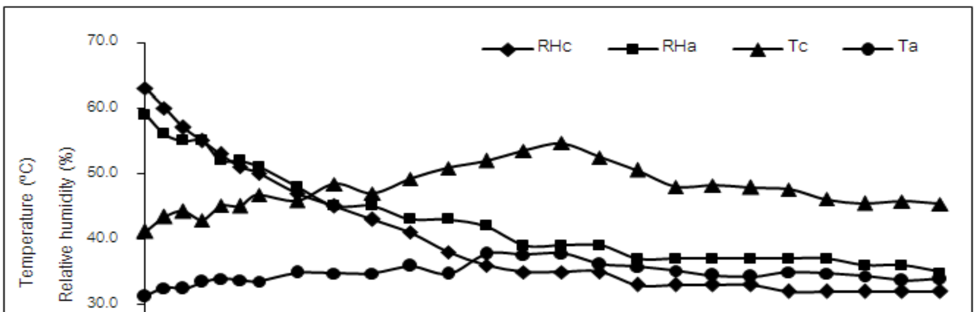

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Table 1 Physical properties of dried pork by greenhouse dryer and o

Drying conditions	Hardness ns (N)	Shrinkage ns (%)	Color values		
			L ns	a	b ns
Open Sun on 24/10/10	2.59 ± 1.05	45 ± 3	28.37±0.99	15.21±0.84 b	11.84±0.84
Greenhouse dryer on 24/10/10 (morning)	2.64 ± 1.08	45 ± 2	28.01±0.93	14.72±1.47 b	11.78±0.99
Greenhouse dryer on 24/10/10 (afternoon)	2.56 ± 1.14	42 ± 2	28.64±1.16	16.38±0.96 a	11.65±1.08

relative humidity in the greenhouse dryer changed continuously from morning to evening. It was observed that the drying air temperature in the dryer was higher than the ambient temperature; whereas, the relative humidity in the dryer was lower than that the ambient humidity. Also, there was a significant difference between the values of the temperature and relative humidity. This difference for the temperature and relative humidity was about 12.8°C and 2.5% during the experimental time, respectively. This explicitly indicates that the drying rate in the greenhouse drying will be higher that open sun drying.

The drying curves of pork in the greenhouse dryer and open sun drying process in the morning are presented in Fig. 6. As shown in Fig. 6, the initial moisture content of around 210% db was dried to the final moisture content of about 70% db in 260 min, while the open sun drying was about 320 min. Greenhouse dryer had a shorter drying time compared to open sun drying. In other words,

drying time was reduced to about 18.8% by the greenhouse dryer according to open sun drying.

Janjai et al. (Janjai et. al., 2009) reported that the drying efficiency of the greenhouse dryer

increase linearly with the loading capacity, and this implies that the dryer should be operated at the highest permissible efficiency. Therefore, The 40 kg of pork (the highest load) was dried in the greenhouse to obtain the highest drying efficiency. The dryer can dry the pork two times a day. The maximum drying efficiencies of the greenhouse dryer in the morning and afternoon were 53.7% and 55.7%, respectively. No significant difference was found between the drying efficiency in the morning and afternoon.

4.2 Quality

The values of hardness, shrinkage and color are presented in Table 1. The color of dried pork from the greenhouse drying in the afternoon was more red (a) than that in the morning and open sun drying. This might be because the accumulated heat in greenhouse in the morning until in the afternoon resulted in the high temperature leading to the high a value. This is involved with the non-enzymatic browning reaction

which is accelerated by several factors such as time, temperature, pH, water activity and high pressure (Romero et. al., 2007). From this experiment, the temperature plays an important role on the high a value.

ns = not significantly different (p>0.05) by DMRT

Means with the same letter within a column are not significantly different (p>0.05) by DMRT

Hardness describes the texture of dried pork after drying. It was found that the compression force to penetrate the slice sample from all conditions is very low. This is due to the texture still being soft as there is about 70% db. Water remaining in the sample this moisture content level is not low enough for safe storage (water activity is over 0.7). As, it is not the final product, it needs to be cooked again before consuming. For the shrinkage, the water reduction causes the collapse of structure resulting in the changes of sample dimensions. In this study, though the drying time was different, there was a similar amount of water loss during drying with a slow drying rate. The great change of shrinkage was found in fast drying as reported by Sa-adchom et al. (Sa-adchom et. al., 2011).

4.3 Economic evaluation

An evaluation of the economic viability of the payback period of the greenhouse dryer for drying pork is determined and it is usually measured in years (n). The formula used here is given by (Newnan, 1983):

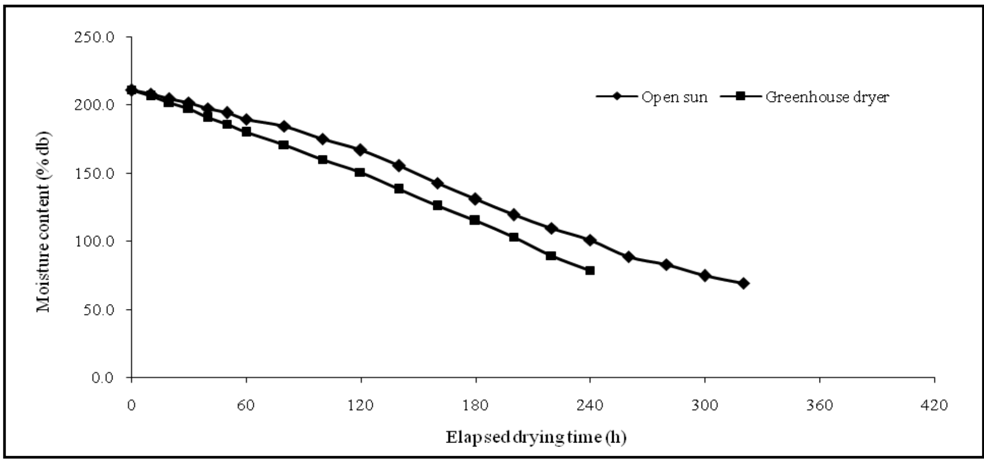

Figure 6 The moisture content of pork dried in the greenhous

$$J = B\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad (5)$$

Where J is the initial investment cost of the solar tunnel dryer, B is the annual net undiscounted benefits, i is the interest rate and n is the payback period. In general, three different seasons in Thailand can be recognized as follows: summer season is about three months, from mid-February to mid-May. The rainy season occurs from mid-May to mid-October, and the winter season also occurs from mid-October to mid-February (Lertsatitthanakorn et. al., 2010). Therefore, it is assumed that the greenhouse dryer is operated during summer and winter seasons, the operating time was 240 days a year. During January to March 2011, the interest rate of the Thai bank was approximately 7%. Table 2 shows an economic evaluation of the greenhouse dryer for drying pork. The total cost is the summation of the capital cost of the dryer, the costs of maintenance, labour, fresh pork and depreciation. It is noted that the payback period is 1.15 years.

Table 2 Computation of payback period of the greenhouse dryer

Items	Values
Fresh pork	125 Baht/kg
Dried pork	450 Baht/kg
Product net weight	0.6 kg/ kg of fresh pork
Drying batch	480 batch/year
Capacity of drier	40 kg/batch
Capital cost of dryer	49,500 Baht
Life of drier	10 years
Depreciation	4,950 Baht
Cost of maintenance	1,000 Baht
Labour cost 6×155×240	223,200 Baht
Cost of fresh pork 80×125×240	2,400,000 Baht
Total income 80×0.6×450×240	5,184,000 Baht

Total cost	2,678,650 Baht
Net income/year	2,505,350 Baht
Payback period	1.15 Years

Note: 1 US Dollar ≈ 30.0 Baht.

5. CONCLUSIONS

A greenhouse Dryer was developed and tested. The drying system proved efficient and economic for drying pork. The dryer was loaded with 40 kg of pork. The moisture content was reduced from 210% db to 70% db in 260 min, whereas the open sun drying took only 320 min. Most physical properties of dried pork by greenhouse drying and open sun drying were not significantly different. The capital investment of the dryer was 49,500 Baht and the payback period of the dryer was found to be 1.15 years, which quite short considering the life of the system.

6. ACKNOWLEDGEMENTS

This research work reported in this paper was supported by the Thailand Research Funds (TRF). The authors would like to thank Dr. Taworn Usub for his assistance related to building the greenhouse dryer.

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