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Evaluation of technology transfer to rural communities for drying using LPG and solar energy cabinet dryer

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The purpose of this paper was to test the performance of the cabinet dryer, and then transfer the technology to those rural communities which are far away from the city and which do not have public electricity. The dryer could be used to dry fruits and vegetables. In the experiment, peeled bananas were loaded into the drying chamber with a capacity of 19 kg per batch, drying air temperature of 57±8.7°C, average air flow rate of 0.6 m^3/s, and air recycle of 95%. In the first period, the drying process was performed continuously for 13 hours. In the second period, the drying process was suspended for 12 hours. For the final period, the drying process was continued for 5 hours. The results are as follows: the consumption of the liquefied petroleum gas (LPG) was 2.10±0.11 kg, the electrical power for the blower was 21.3±3.2 W, the average drying rate was 0.54±0.10 kg_{water}/h, and the average energy consumption was 11.08±1.40 MJ/kg_{water}. As for the quality of bananas, their color was comparable to that of fresh bananas, and it was found that the lightness had decreased from 64.48±3.80 to 43.44±2.25. The redness and yellowness were observed to have increased from 2.98±0.94 to 13.38±0.61 and 25.03±1.01 to 34.42±1.42, respectively. This attempt at technology transfer to rural communities was the integration of cooperation from several sectors, including lecturers, students, and staff of the Faculty of Engineering, Chiang Mai University. The goal was to publicize the research results according to the needs of the community. The findings will be useful in the development of the well-being of the people in the community for a better lifestyle. Two dryers were installed at Doi Sarm Muan and Namru villages in the Chiang Mai province. The results of the present work were very well received.

Keywords: dryer, LPG, solar energy, technology transfer

Introduction

The Ban Namru villages are located at Moo 5 Mueang Klong sub-district, Chiang Dao district, Chiang Mai. The Sarm Muan village is located at Moo 6 Mueang Haeng sub-district, Wiang Haeng district, Chiang Mai. These

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communities have no public electricity. Most of the people rely on agriculture, which yields large quantities of produce; however, it is extremely difficult to sell the produce of these villages in the city, especially in the rainy season, due to the ineffective transportation system which causes the produce to become rotten, for example, produce such as persimmons, mangos, peaches, plums, corns, and bananas. To tackle the issue, one of the alternative solutions is to process these by drying. However, the drying cabinets sold in the market need electricity. As a result, our drying engineering research laboratories at the Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, proposed the concept of developing a cabinet dryer under such conditions. The purposes of this project were (1) to conduct research and development and to evaluate a cabinet dryer which uses solar energy with LPG; (2) to provide academic knowledge by transferring the knowledge of using an LPG cabinet dryer to that of using a solar energy powered cabinet dryer to those communities that have no public electricity so that they can be knowledgeable about the installation, repair, and maintenance, including the drying method until they are able to help themselves sustainably; and (3) to improve the learning and teaching, as well as the research and academic services of the Faculty of Engineering, Chiang Mai University. Related research results show that Sumet *et al.*, 2002 designed, built, and evaluated the performance of fruit-drying ovens using LPG as the fuel to heat and to circulate hot air. In order to evaluate the performance of the cabinet dryer, we consider the power consumption, the quality of the product color, and the distribution of the hot air inside the drying chamber by measuring the hot air temperature and the humidity distribution of the products. From the experimental results of drying bananas at the hot air temperature of 60°C, the flow rate of 0.6 m^3/s, and with the proportion applying the hot air recirculation at 81.6%, it was found that the initial moisture content of 342% db. (dry basis) had decreased to 52.6% db. The specific primary energy consumption was 51.6 MJ/kg_{water}. The color quality of the fruit after drying was satisfactory, and the estimated costs of electricity and LPG were between 2.43 and 2.47 baht per kg of water evaporated.

Materials and methods

Development of Cabinet Dryer using LPG and Solar Energy

An LPG cabinet dryer functioning on solar energy, as shown in Figure 1, has an external dimension of 67x85x185 cm^3 with 12 trays of dimension 40x60 cm^2, and contains the following major components.

The maximum flow rate of the LPG cylinder with the safety valve is 0.6 kg/h, and it has a safety system to prevent the gas transmission line from falling off if the flow of gas is higher than normal.

A 12 V battery regulator can be used with a maximum current of up to 10 A, and it has a short circuit, or overloaded current protection, and the control device will disable the circuit and switch it back on automatically. However, if disabled 3–4 times repeatedly, it will restart after a while.

Fig. 1. An LPG cabinet dryer that uses solar energy

A deep cycle battery sized 12 V 130 Ah will work for approximately 25–50 hours when fully charged.

A 130 W solar panel with voltage up to 17.2 V gives a maximum electric current of 7.56 A, and the panel size is 1500x675x35 mm^3.

A 12 V DC motor has the highest current of 9 A. This motor drives a centrifugal blower which has a diameter of 14.5 cm and a length of 15 cm. It has a speed control circuit to adjust the flow rate of hot air with the required speed, electric current, voltage, and power, as shown in Table 1. To install the motor, the outside air must be able to pass through to help cool the motor in order to enable it to run more effectively, as well as to extend its lifetime.

The LPG nozzle is an energy source to heat the air controlled by the flow rate of LPG in order that it controls the temperature of the hot air.

Table 1. Relationship between Round Speed, Electric Current, Voltage, and Power

Round Speed (rpm)	Current (A)	Voltage (V)	Power (Watt)
1920	2.1	6.1	13.1
2240	3.9	7.4	28.7
2500	4.5	8.4	37.4
2850	5.4	9.6	52.2
3075	6.2	10.5	65.2

Cabinet Dryer Performance Evaluation

Experiment Procedure

We peeled ripe bananas and stored them in 20 trays, 40 bananas in each tray. Then, we placed them in two LPG cabinet dryers with solar energy, 10 trays in each. We turned on the battery control switch and the blower switch, and controlled the motor speed at approximately 2100 rpm, allowing the flow of hot air to be equal to 0.127 m^3/s. We adjusted the fire on the nozzle valve for the highest rate of gas flow of approximately 0.6 kg/h to increase the air temperature up to 60°C (Aphirak and Phairoach, 2011).

When the air temperature reaches 60°C, the cabinet dryer controller must adjust the valve so that the flow rate of the gas would reduce to maintain the air temperature at 60°C. The primary stage of drying was about 4 hours. The valve must be frequently adjusted because the energy was not constant, but after the first 4 hours, the energy would become relatively constant. Therefore, the controller may have to monitor the temperature of the hot air during prolonged periods of time.

The temperatures of the bananas and hot air were measured using with a Testo 650 (Lenzkirch, Germany) at various positions, as shown in Figure 2. In other words, it was to measure at the bottom (Tray 1), in the middle (Tray 5), and at the top (Tray 10) in order to analyze and compare the temperature of the bananas and the temperature of the hot air at different positions in the cabinet dryers.

The determination of moisture content were conducted by weighing the bananas using the scale with an accuracy of 0.001 gram, six samples per tray, as shown in the sample positions in Figure 2. The weights of the banana samples were recorded at the start and the end of the drying process in Tray 1, Tray 5, and Tray 10. They were compared for the consistency in the dehumidification of the bananas inside the dryer. The overall weights of the bananas were also recorded by using the scale with an accuracy of 0.1 kg.

The calculation of the electricity used to drive the blower was carried out by measuring the electric current and the voltage with a multi-meter and the calculation of the heat energy used to warm the hot air was carried out by weighing the amount of LPG using the scale with an accuracy of 0.1 kg.

The measuring for the determination of the quality of color using the standard color system, “L*,” “a*,” and “b*,” where “L*” stands for “light,” “a*” is defined as a core color from green (-a*) to red (+a*), and “b*” is defined as a core color from blue (-b*) to yellow (+b*), is done by recording the color values of the banana samples randomly selected at the beginning, after thrashing, upon suspending, and at the end of the drying process.

Performance Analysis

As far as the evaluation of the performance of the cabinet dryer is concerned, we can use the average drying rate (DR), the specific energy consumption (SEC), and the color quality as benchmarks to evaluate the performance of the cabinet dryer. We can calculate the rate of drying and the specific energy consumption by using equation (1) and equation (2), respectively.

$$\mathrm{DR} = \frac{Total\ water\ evaporated\ from\ product}{Drying\ Time} \quad (1)$$

$$SEC = \frac{P_b + \dot{Q}}{Total\ water\ evaporated\ from\ product} \quad (2)$$

$\dot{Q}$ is the thermal energy rate of the total LPG consumption, and P_b is the power of the blower motor. These can be calculated from equation (3) and equation (4), respectively.

$$\dot{Q} = \dot{m}_{gas} \times HHV \quad (3)$$

$$P_b = EI \quad (4)$$

where $\dot{m}_{gas}$ is the mass flow rate of LPG

HHV is the high heating value of LPG

E is the DC voltage

I is the electric current

As for the calculation of the reduction of moisture ratio, it is defined and calculated as the value of the difference of the initial and the final moisture contents divided by the initial moisture content, as shown in equation (5).

$$\text{Reduction of moisture ratio} = \left[\frac{\sum M_{in} - \sum M_f}{\sum M_{in}}\right] \times 100 \quad (5)$$

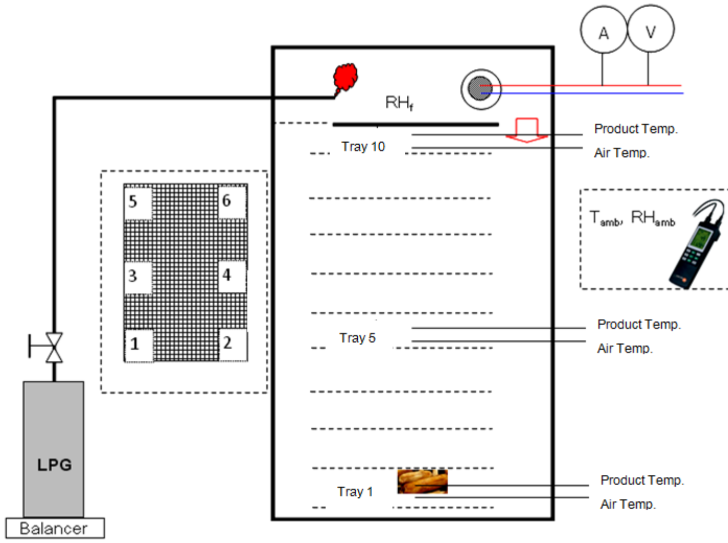


Fig. 2. The data measurement position of the LPG cabinet dryer that uses solar energy

Workshop Evaluation Analysis

A workshop participation form was used for the evaluation. The form consisted of two parts: Part 1, which included the status of the respondents — participant, gender, age, education, and aim of joining the workshop — and Part 2, which covered customer satisfaction evaluation, as follows:The degree of satisfaction with the process and procedures for providing services are, such as public relations and information, and the suitability of the lecture topics.

The degree of satisfaction with the staff or personnel who provide services (which can be classified as polite and friendly staff), and those who give advice and answer questions well.

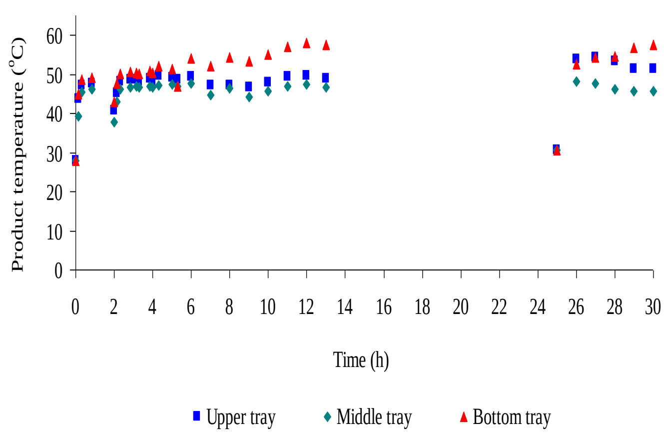
The degree of satisfaction with the facilities, such as the suitability of the venue, and food and drink.

The degree of satisfaction with the quality of customer service, such as knowledge and benefits gained, and achievement of the objective from attending the workshop.

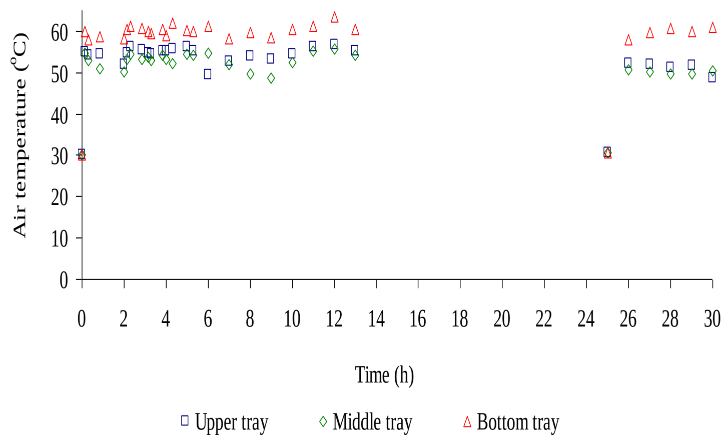
The analysis was conducted by interviewing the workshop participants two times. The first part was about the status of the respondents using percentage for the analysis. The second part was about customer satisfaction using mean)$\bar{x}$) and standard deviation (SD), as well as by showing the level of the evaluation according to the criteria given by Boonchom (1992).

Results and discussions

From the experiment of drying bananas, the data regarding the temperature of the banana and the temperature of the hot air were obtained, as shown in Figure 3. The results showed that the average temperature of the banana and the temperature of the hot air were 49.3±7.2°C and 57.0±8.7°C, respectively. The reduction of moisture ratios of the sample bananas in the lower, middle, and upper trays were 76.08%, 77.18%, and 78.27%, respectively. In addition, the findings also showed that the reduction of the moisture ratios of the sample bananas on the right and left of the dryer were 77.18% and 77.21%, respectively. Table 2 shows the results of the experiments and the data analysis. The peeled banana of 19.12±1.01 kg were dried until the final weight of 8.75±0.14 kg and the drying time of 18 hours. The calculated results were the drying rate of 0.54±0.09 kg_{water}/h and the specific energy consumption of 11.08±1.40 MJ/kg_{water}. Table 3 shows the results of the banana color analysis. It was found that when the moisture content of the bananas decreased, the lightness (L*) decreased, the redness (a*) increased, and the yellowness (b*) increased when compared with the same of the bananas before and after 12 hours of drying. After that, the tendency slightly declined. This was due to the influence of the heat and the high humidity in the dryer, as well as because of the technique of softening the bananas before drying to accelerate the sweetness.



Banana temperature



Hot air temperature

Fig. 3. The temperature of the bananas and the hot air temperature inside the cabinet dryer

Table 2. Results and Data Analysis

Item	Number
Primary material weight, kg	19.12 ± 1.01
Weight after thrashing and suspending, kg	10.50 ± 0.048
Final material weight, kg	8.75 ± 0.14
Banana drying time excluding suspending time, h	18
Humidity of hot air from the dryer	49.78 ± 7.27
Ambient air temperature, °C	33.6 ± 1.1
Ambient air humidity, %	57.0 ± 2.4
Average voltage, V	6.248 ± 0.44
Average current, A	3.396 ± 0.36
Amount of LPG consumption, kg	2.1 ± 0.1
Average electrical power used for blower motor, W	21.30 ± 3.22
Average drying rate, kg_{water}/h	0.54 ± 0.09
Average specific power consumption, MJ/kg_{water}	11.08 ± 1.40

Table 3. Banana Color Analysis Results

Color	Before drying	After 12 hours of suspending	Dried banana
L*	64.48 ± 3.80	53.45 ± 1.39	43.44 ± 2.25
a*	2.98 ± 0.94	9.57 ± 3.13	13.38 ± 0.61
b*	25.03 ± 1.04	34.93 ± 0.55	34.42 ± 1.42

Transfer of Drying Technology to Communities without Public Electricity

Technology transfer calls for the integration of the several different sectors consisting of lecturers, students, and staff of the Faculty of Engineering, Chiang Mai University, and communities. As a result, the research results will be published in the community to meet the needs of the community. The procedures are as follows.

Implementation of Technology Transfer

The operators and lecturers were personnel from the drying engineering research laboratories, Department of Mechanical Engineering, Chiang Mai University. The target group of the workshop was the farmer group from Ban Sarm Muan, Moo 6, Mueang Haeng, Wiang Haeng, Chiang Mai, and Ban Namru, Moo 5, Mueang Khong, Chiang Dao, Chiang Mai. The training venue was the Knowledge Management Center, under His Majesty the King's Initiatives at Ban Sarm Muan, and a public area at Ban Namru. As far as the workshop management is concerned, the Board had designed two workshops. The first workshop was "The transfer of technology using LPG cabinet dryer with solar energy," and the second workshop was "Installation and banana drying using a solar cabinet dryer with LPG." Figure 4 and Figure 5 show the atmosphere of the training. More details can be viewed in the media clip, "The development of solar energy cabinet dryer with LPG for the use in communities without public electricity" (source: http://www.youtube.com/watch?v=fAhdlVKdQrQ)

Fig. 4. The atmosphere of the first training at Ban Sam Muan

Fig. 5. The atmosphere of the second training at Ban Namru.

Evaluation of Technology Transfer

Regarding the first part, the status of the respondents, most of the workshop attendees were general, common people (69.57%), followed by students (17.39%). Most of them were male (52.17%) aged between 31 years and 40 years, which accounted for 30.43%, followed by people aged more than 50 years (26.09%), which accounted for 39.13%, and those whose level of education was below a bachelor's degree (34.78%). Most of them aimed to attend the event to enhance their knowledge and for the use of the technology in the future (91.3%), as shown in Table 4.

Regarding the second part, the satisfaction of the workshop participants, it included the satisfaction as regards facilities, staff or service personnel, and service quality. The results were found to be at the highest level. As far as satisfaction in terms of service process and procedures is concerned, the results were observed to be at a high level, as shown in Table 5.

Table 4. Respondent Status Analysis Results

1.1 Participant	**Number**	**Percentage**
- Student	4	17.39%
- General people	16	69.57%
- Observer	3	13.04%
1.2 Gender	Number	Percentage
- Male	12	52.17%
- Female	11	47.83%
1.3 Age	Number	Percentage
- Below 20 years	1	4.35%
- 20–30 years	5	21.74%
- 31–40 years	7	30.43%

- 41–50 years	4	17.39%
- Above 50 years	6	26.09%
1.4 Education	Number	Percentage
- Others)None(	9	39.13%
- Below a Bachelor's Degree	8	34.78%
- Bachelor's Degree	2	8.70%
- Master's Degree	4	17.39%
1.5 Purpose of Participation	Number	Percentage
- To enhance the present work	2	8.70%
- To enhance knowledge for future use	21	91.3%

Table 5. Satisfaction of Workshop Attendee Analysis Results

Satisfaction	$\overline{x}$	**SD**
1. Satisfaction of service process and procedures	4.39	0.51
2. Satisfaction of staff or service personnel	4.80	0.31
3. Satisfaction of facilities	4.63	0.56
4. Satisfaction of service quality	4.60	0.47

Note: using a rating scale which included five levels (Boonchom, 1992)
4.51–5.00 refers to the highest level, 3.51–4.50 refers to a high level.
2.51–3.50 refers to a moderate level, 1.51–2.50 refers to a low level

Conclusion

Technology transfer using LPG cabinet dryer with solar energy is the integration of research, academic service, teaching, and learning from the university to the community. This was achieved by teaching the participants how to dry fruits and vegetables, and the techniques of maintaining the cabinet dryer for drying 19.12 ± 1.01 kg of bananas at an air temperature of 57.0 ± 8.7°C using partial open-air system by releasing hot air by 4.24 ± 0.78%. It was found that the differences in the temperatures of the hot air at the bottom, middle, and upper trays of the dryer were not above 8.7°C. The hot air temperature in the dryer was higher than that of the bananas by around 11°C with the use of 2.10 ± 0.11 kg of LPG for 18 hours (excluding 12 hours of time suspending). The average drying rate was 0.54 ± 0.09 kg_{water}/h, and the average specific energy consumption was 1.08 ± 1.40 MJ/kg_{water}. As far as the color quality is concerned, when the moisture of bananas decreased according to the drying time, the lightness (L*) decreased, but the redness (a*) and the yellowness (b*) increased when compared with the same of the bananas before drying and 12 hours after drying. Then the tendency slightly declined. After transferring the technology to two villages (Ban Namru and Ban Sarm Muan) and evaluating by using an evaluation form with a total of 13 participants, it was found that the participants understood and could use the LPG cabinet dryer with solar energy.

In addition, the evaluation revealed that the overall satisfaction was at the highest level.

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