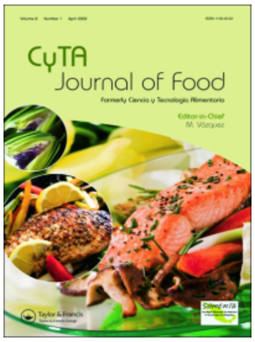

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Comparison of efficiency between liquefied petroleum gas (LPG) and electric hot air dryer: case study of dried pork slice

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ABSTRACT
To reduce the foods spoilage in remote areas of Thailand where electricity is inaccessible, drying processes must be applied. This research developed an LPG hot air dryer under insufficient electricity supply and investigated its performance on dried pork slice under different air velocities (1, 1.5 and 2 m/s) and temperatures (50, 55 and 60°C). The results were compared with those of an electric hot air dryer, under the same conditions, to determine the optimal device. The drying rate from both dryers increased with an increase in temperature and air velocity. This mostly fitted with Avhad and Marchetti model. However, the lowest specific energy consumption was found in LPG hot air dryer. The moisture in dried pork slices was lower than 30%, regardless of different dryers. This agreed with Thai community product standard. Therefore, the LPG hot air dryer could be used as an alternative instrument for drying pork slice.

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KEYWORDS
LPG hot air dryer; drying process; drying efficiency

1. Introduction

Most of the remote areas in Thailand have no public electricity. The populations in these areas rely on agriculture which produces large quantities of raw food materials. However, the goods are difficult to sell in the city due to an ineffective transportation system. This causes the produce to become rotten (Achariyaviriya et al., 2014). In order to tackle the issue, an alternative solution is to process the foods by drying (Zhang et al., 2016).

Drying is one of the oldest and most widely used food preservation methods (Campidelli et al., 2019; Doymaz et al., 2015; Ramarao et al., 2021). It is a thermal process which simultaneously couples heat and mass transfer (Campidelli et al., 2019; Ramarao et al., 2021). The driving force for heat transfer is defined by the temperature difference between the physical systems (a higher thermal energy transferring to lower thermal energy), whereas mass transfer involves the migration of material between a boundary surface and a moving fluid. In the drying process, temperature is predominantly important. An increase in temperature results in a decrease in drying time (Kosasih et al., 2020; Nazmi et al., 2018; Ndukwu, 2009), until an equilibrium moisture content is reached. However, a high temperature might cause a serious problem for food quality because the moisture content in dried food fails to reach the equilibrium due to a case hardening effect. Thus, a moderate temperature difference between the core and surface of food materials is preferred.

Apart from sun drying, several drying techniques such as vacuum drying, ultrasound assisted vacuum drying and freeze drying have been used (Aksoy et al., 2019). In this regard, drying at a constant temperature and relatively low humidity using electric dryer significantly improved the product quality (Hamdani & Muhammad, 2018). These techniques also expensive and consume a lot of energy (Lakshmi et al., 2019).

Most of the drying cabinets sold in the market need electricity. As a result, the development of a non-electric dryer is important. There have been studies that support the idea of a non-electric system or low energy consumption during food drying. Dębowski et al. (2021) compared the energy consumption of two industrial continuous flow grain dryers powered by LPG and hard coal. Their results showed that LPG gas had lower energy consumption than hard coal. Murali et al. (2020) developed an energy efficient solar dryer suitable for continuous shrimp drying which was called solar LPG hybrid dryer. Their results revealed that the moisture content of shrimp was reduced within 6 hours and the dryer was more economical.

As per the literature review, this study purposed to develop an LPG hot air dryer under insufficient electricity supply. Its performance was investigated via the process of drying pork slice under different air velocities and temperatures. The results were also compared with those of an electrical dryer under the same conditions. The objective of this work was to find the appropriate non-electrical dryer which would save the operating costs for small and medium enterprises (SMEs) in remote areas.

2. Materials and methods

2.1. Experimental equipment

The LPG hot air dryer was developed at the Centre of Academic Service department of Mechanical Engineering, faculty of Agriculture and Technology, Rajamangala University of Technology Isan Surin Campus, Surin province, Thailand. This instrument was built with steel structure. The dryer walls were made from aluminium sheet. The total capacity of the LPG hot air dryer was 0.36 m^3. The LPG tank was placed outside the dryer and was connected to

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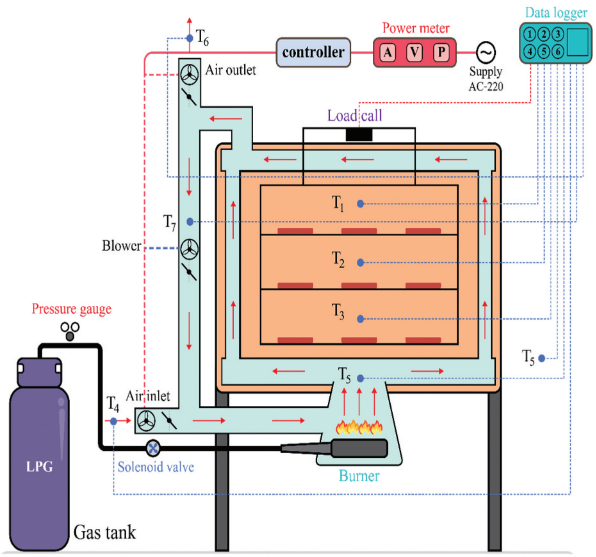
a gas burner, which was built beneath the dryer's bottom. The gas flow to the burner was controlled using a solenoid valve. The temperature inside the dryer was controlled using a thermostat system, whereas the moisture of samples was measured using load cells. The real-time data of the drying process were shown on the dryer display. There were three central processing unit (CPU) cooling fans which were combined at the bottom, above and side of the dryer. The fans were used for transferring, ventilation, and re-consumption of hot air for the dryer. All electric instruments which were thermostat, load cells and fans were operated using energy from solar cells. Thus, this dryer could save energy and production costs due to the recycling of hot air. The LPG hot air dryer is illustrated in Figure 1.

2.2. Slice pork drying process

Pork leg muscle was cut into small pieces (4 × 50 × 4 mm), and then washed thoroughly prior to draining the water.



(a)

(b)

Figure 1. Schematic diagram of LPG hot air dryer (a) and actual image of LPG hot air dryer (b).

Their initial moisture contents were analysed using in-house method that was modified from AOAC (2016). The sliced pork samples were then placed on trays for drying and processed using three different temperatures (50, 55, and 60°C) and 3 different air velocities (1, 1.5 and 2 m/s). The temperature of the drying air was modified from the range of temperature used in beef drying processing (Shi et al., 2021), while the choice of drying air velocity was modified from the previous study that specified the range of the air velocity used (1.5 and 2.5 m/s) (Muga et al., 2020). During the drying, the temperature inside the drying chamber was monitored every 10 min, paralleling one inside the sliced pork samples. The drying process was completed when the moisture of dried pork slice was constant. The dried pork slice was then cooled down and packed in an aluminium laminated bag.

2.3. Specific energy consumption (SEC)

In the electric hot air dryer, consumed energy is considered by a digital electricity counter. The meter is connected directly from the power supply and load where all the energy going into the heating elements can be measured. Energy consumption by LPG hot air dryer was determined by weighting the gas in tank. The mass of LPG gas was recorded using a gas meter before and after the food was inserted into the dryer. The electric energy supply of blowers, load cells and thermostat were recorded using digital energy meter (solar cell). Therefore, the energy used in LPG hot air dryer is considered with gas LPG and solar cell. The SEC (expressed in MJ/kg) is calculated as follows (Lawrence et al., 2019):

$$SEC = \frac{T}{M_w}. \tag{1}$$

Here, T is the energy used (MJ); M_w is the product's amount (kg).

2.4. Mathematical model for sliced pork drying process

A mathematical model can be used to predict the behaviour of a system as well as the results. During the drying process, the moisture ratio of pork slices was calculated as the following equation (Aregbesola et al., 2015):

$$MR = \frac{M_t - M_e}{M_i - M_e}. \tag{2}$$

Here, MR is the moisture ratio; M_t is the moisture content; M_i is the initial moisture content; M_e is the equilibrium moisture content.

Due to the long drying period, the values of equilibrium moisture content are small compared to $M_t$andM_i. Hence, we can assume the value of M_e as zero. The new formula of moisture content is $MR = M_t/M_i$. The mathematical models for prediction of sliced pork drying were shown as moisture ratio versus drying time and equations are in Table 1.

2.5. Determination of appropriate model

Mathematical modelling for sliced pork can be used to investigate both the optimum drying parameters and drying performance. In this research, the drying models which predicted the drying behavior are presented in Table 1. Statistical parameter values were performed to assess the

Table 1. The mathematical models of sliced pork.

Model name	Model equation
Lewis	MR = exp (−kt)
Logarithmic	MR = a exp(−kt)+b
Henderson and Pabis	MR = a exp(−kt)
Avhad and Marchetti	MR = a exp(-kt^n)
Diffusion	MR = a exp(−kt)+(1-a)exp(−kbt)

Note: t is the drying time in min; a, b and n are the drying constants; k is the drying rate constant (min^{-1}).

fitness of empirical models to the experimental drying data among different models. Many researchers have worked on finding the goodness of fit of model based on similar statistical parameters, including coefficient of determination (R^2), root mean square error (RMSE), and sum of squares due to error (SSE) (Younis et al., 2018). R^2 is a statistical measure of the validity of the model that indicates the percentage of variation in the dependent variable that can be explained by the independent variable. In this sense, a better suitable model should have a larger R^2. RMSE is considered to measure the differences between the observed values and the predicted values. RMSE identifies the accuracy of the tested models. In addition, the SSE indicates the variation of modelling errors. This means, it describes how the variation in the dependent variable in a fitted model cannot be explained by the model. Thus, smaller RMSE and SSE values illustrate a more appropriate model.

Hence, the three parameters to evaluate a suitable model can be expressed as:

$$R^2 = 1 - \frac{\sum_{j=1}^{N}\left(MR_{pre,j} - MR_{exp,j}\right)^2}{\sum_{j=1}^{N}\left(MR_{exp,j} - \overline{MR}_{exp}\right)^2} \tag{3}$$

$$RMSE = \left(\frac{\sum_{j=1}^{N}\left(MR_{exp,j} - MR_{pre,j}\right)^2}{N}\right)^{1/2} \tag{4}$$

$$SSE = \sum_{j=1}^{N}\left(MR_{exp,j} - MR_{pre,j}\right)^2 \tag{5}$$

where, $MR_{exp,j}$ is the experimental moisture ratio of j^{th} data; $MR_{pre,j}$ is the predicted moisture ratio of j^{th} data; $\overline{MR}_{exp,j}$ is the average of the experimental moisture ratio; N is the number of observations.

Ideally, the model with the highest R^2, and the lowest SSE and RMSE values implies the best fitted model to describe the drying characteristics.

2.6. Analysis of dried pork slice qualities

2.6.1. Moisture content

The analysis of moisture content in dried pork slice was adapted from AOAC (2016), with slight modifications. Briefly, 3 g of sliced pork was placed into an aluminium dish, and then was dried in the oven at 105°C to a constant weight. After that, the sample was transferred to a desiccator to cool at ambient temperature. The moisture content of dried pork slice was based on a wet basis (M_{wb}) in percentage, as expressed by following equation.

$$M_{wb} = \frac{m_0 - m_d}{m_0} \times 100 \tag{6}$$

Where, m_0 is an initial mass (g) of the sample; m_d is a dried mass (g) of the sample.

2.6.2. Water activity (a_w)

The analysis of a_w in dried pork slice was done using in-house method. Briefly, the dried pork slice (3 g) was cut into small pieces, and then placed into a measuring container. The a_w was analysed at 25 ± 0.5°C using AwTherm (Rotronic, Singapore).

2.6.3. Colour

The colour of dried pork slice was determined with portable colorimeter (3nh, China) using the Commission internationale de l'éclairage (CIE) system. The samples were placed into the measuring area for the instrument to measure the colour of dried pork slice surface. For evaluation, the values of L* means black (0) or white (100); a* means green (-) or red (+); and b* means blue (-) or yellow (+). The D65 light source was applied for this experiment. This method was modified from Lopez et al. (2011).

2.7. Statistical analysis for dried pork slice qualities

In this section, the moisture content, water activity and colour properties of pork slice dried using an LPG hot air dryer and an electric hot air dryer at each drying condition, were compared. In order to find the optimal instrument from both dryers, a two sample independent t-test was done. The difference between the mean values was considered at 95% confidence interval. The data were presented as mean ± standard error. Each analysis of dried pork slice quality was done in five replications.

3. Results and discussion

3.1. Drying characteristics of sliced pork

The drying curve for sliced pork product using different drying temperatures and air velocities in gas LPG and electric hot air dryer are presented in Figure 2. The results for both dryers showed that: i) the moisture ratio decreased exponentially with respect to time, ii) an increase in drying temperature and air velocity resulted in a decreased moisture of sliced pork. These were due to the driving force for heat and mass transfer in the system. The moisture removal rate declined since the available water remaining on the surface was less. Similar behaviour was observed in several food products such as chicken meat (Çakmak et al., 2014), Eland Jerky (Kucerova et al., 2015) and poultry meat (Javeed & Omre, 2017). Moreover, the drying time of LPG hot air dryer was close to that of the electric hot air dryer in each experimental condition.

3.2. Fitting of the drying curves using mathematical modelling

Statistical analysis of sliced pork observed in the drying experiment under the different conditions were fitted to five models: Lewis model, Logarithmic model, Henderson and Pabis model, and Avhad and Marchetti and diffusion model, as listed in Table 1. The results of different models are shown in Table 2 for LPG hot air dryer and Table 3 for electric hot air dryer. The moisture content of sliced pork samples was converted into moisture ratio for studying the mathematical modelling.

As indicated in the tables, selecting an appropriate statistical model was determined by SSE, R^2 and RMSE. The results showed that most of the tested models had given consistently

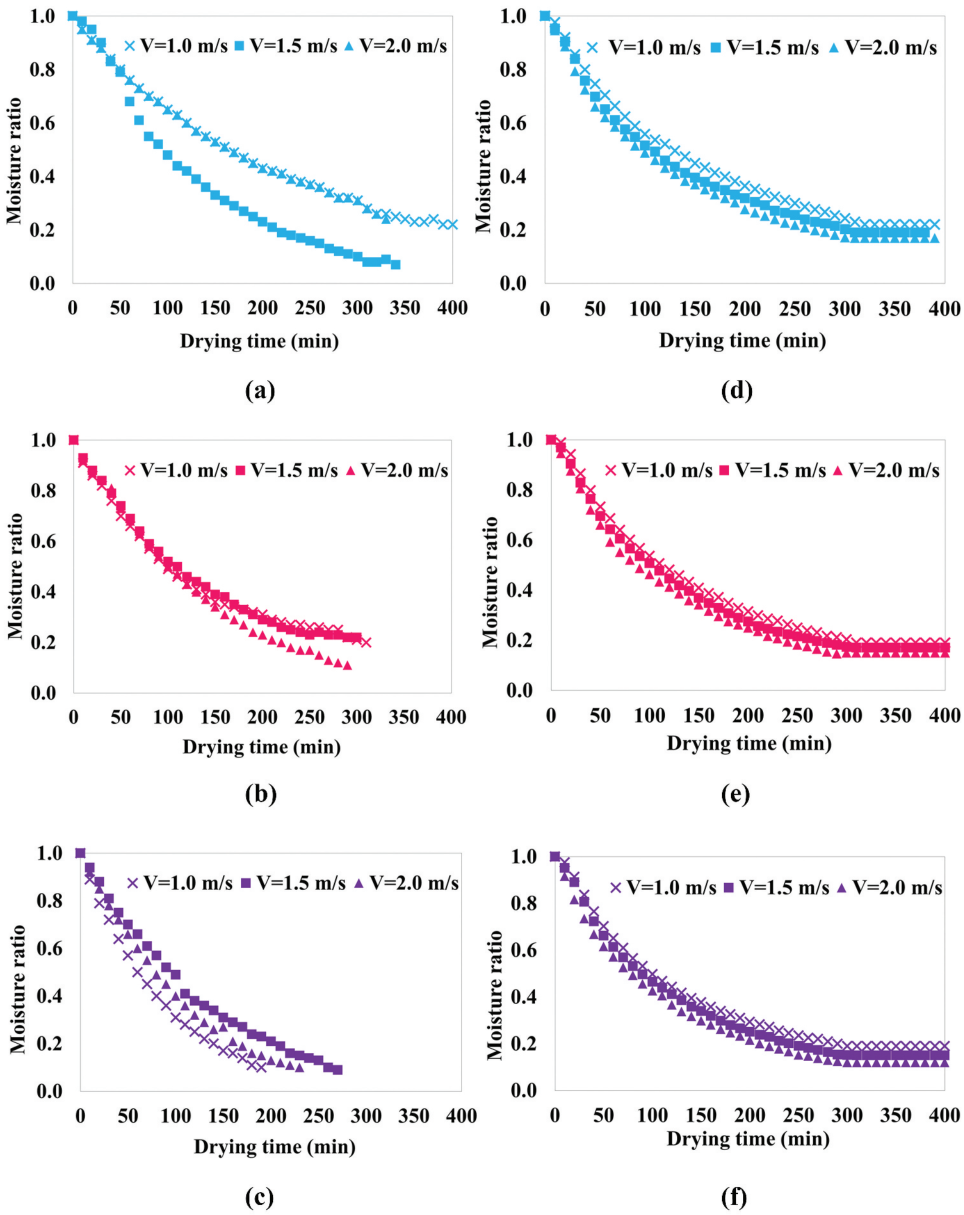


Figure 2. The moisture ratio of sliced pork dried using LPG hot air dryer at different temperatures (50°C (a), 55°C (b), and 60°C (c)) and different air velocities (1, 1.5, 2 m/s). The moisture ratio of sliced pork dried using electric hot air dryer at different temperatures (50°C (d), 55°C (e), and 60°C (f)) and different air velocities (1, 1.5, 2 m/s).

low coefficients of SSE and RMSE and high coefficient of R^2. This means that all models could describe the behaviour of drying process very well. Therefore, the best drying curve modelling for sliced pork among the five models was Avhad and Marchetti model. For this model, the SSE, R^2 and RMSE values for LPG hot air dryer were 0.000, 0.999 and 0.04, respectively, while the SSE, R^2 and RMSE values for electric hot air dryer were 0.001, 0.999 and 0.006, respectively. This model has been very successful in describing drying kinetics of various foods and agricultural products (Avhad & Marchetti, 2016). However, the results from this research were different from Çakmak et al. (2014) who investigated mathematical modelling and thin layer drying of chicken meat enriched baguette bread slices. They found that Midilli model was the best model for layer drying of chicken. On the other hand, Javeed & Omre (2017) found that Page's model and two-term exponential model had good correlations with drying of poultry meat.

3.3. Specific energy consumption (SEC)

The SEC for LPG and electric hot air dryers with different drying temperatures and air velocities are presented in Figure 3. The SEC decreased with an increase in temperature and air velocity in both dryers. This implied that less energy went to waste when the temperature and air velocity were high. The relationship between SEC and temperature of this study agrees with the results of Charoenvai et al. (2013), who analysed the energy consumption in the drying process of particleboard using a combined multi-feed microwave convective air and continuous belt system. Figure 3 shows the SEC of LPG hot air dryer slightly increased when lower temperature was applied. This was 6.64 MJ/kg at air velocity of 2 m/s and reached 12.84 MJ/kg at 1 m/s, as shown in Figure 3(a). The SEC of electric hot air dryer was 19.28 MJ/kg at air velocity of 2 m/s, and reached 23.27 MJ/kg at 1 m/s, as shown in Figure 3(b). In comparison, drying sliced pork with electric hot air dryer used more than twice SEC of LPG hot air dryer.

Table 2. Statistical results from different models for LPG hot air dryer.

Model name	Air velocity	Temperature	Parameters			SSE	R^2	RMSE
Lewis	1	50	k = 0.000			0.015	0.995	0.017
		55	k = 0.006			0.032	0.979	0.033
		60	k = 0.010			0.027	0.980	0.039
	1.5	50	k = 0.007			0.095	0.967	0.053
		55	k = 0.006			0.018	0.990	0.024
		60	k = 0.007			0.042	0.980	0.039
	2	50	k = 0.006			0.033	0.973	0.034
		55	k = 0.006			0.026	0.981	0.030
		60	k = 0.007			0.027	0.980	0.031
Logarithmic	1	50	a = 0.923	b = 0.085	k = 0.005	0.002	0.999	0.008
		55	a = 0.963	b = 0.078	k = 0.007	0.004	0.998	0.998
		60	a = 1.092	b =−0.074	k = 0.007	0.003	0.998	0.011
	1.5	50	a = 0.958	b = 0.065	k = 0.005	0.002	0.999	0.008
		55	a = 0.942	b = 0.058	k = 0.007	0.001	0.999	0.007
		60	a = 1.097	b =−0.079	k = 0.008	0.002	0.999	0.010
	2	50	a = 0.828	b = 0.186	k = 0.009	0.003	0.998	0.010
		55	a = 1.051	b =−0.054	k = 0.006	0.001	0.999	0.008
		60	a = 1.024	b =−0.027	k = 0.011	0.001	0.999	0.005
Henderson and Pabis	1	50	k = 0.004	a = 1.009		0.015	0.995	0.017
		55	k = 0.006	a = 1.001		0.032	0.979	0.033
		60	k = 0.012	a = 1.128		0.001	0.999	0.006
	1.5	50	k = 0.008	a = 1.167		0.017	0.994	0.022
		55	k = 0.006	a = 1.042		0.012	0.993	0.021
		60	k = 0.008	a = 1.117		0.007	0.997	0.016
	2	50	k = 0.005	a = 0.939		0.021	0.982	0.028
		55	k = 0.006	a = 0.956		0.020	0.985	0.027
		60	k = 0.006	a = 0.931		0.014	0.990	0.022
Avhad and Marchetti	1	50	a = 3.758e^{-6}	k=−13.31	n=−0.025	0.825	0.733	0.129
		55	a = 1.201	k = 0.032	n = 0.703	0.010	0.993	0.019
		60	a = 1.104	k = 1.042	n=−0.009	0.001	0.999	0.005
	1.5	50	a = 1.126	k = 0.005	n = 1.075	0.015	0.995	0.021
		55	a = 1.121	k = 0.013	n = 0.855	0.007	0.996	0.016
		60	a = 1.052	k = 0.004	n = 1.138	0.003	0.999	0.011
	2	50	a = 1.159	k = 0.038	n = 1.159	0.000	0.998	0.004
		55	a = 3.815e^{-6}	k =−13.04	n =−0.023	0.317	0.768	0.108
		60	a = 1.102	k = 0.029	n = 0.730	0.000	0.999	0.004
Diffusion	1	50	a = 0.981	k = 0.004	n = 0.111	0.010	0.997	0.014
		55	a = 0.852	b = 1.119	k = 0.006	0.032	0.979	0.034
		60	a = 1.001	b = 0.010	k = 0.608	0.027	0.980	0.041
	1.5	50	a=−0.225	b = 0.103	k = 0.079	0.009	0.997	0.016
		55	a = 0.822	b = 0.916	k = 0.006	0.018	0.990	0.025
		60	a = 1.908	b = 0.845	k = 0.006	0.036	0.982	0.038
	2	50	a = 0.546	b = 0.220	k = 0.011	0.003	0.998	0.010
		55	a = 1.008	b = 0.756	k = 0.007	0.004	0.998	0.012
		60	a = 0.001	b = 0.291	k = 0.040	0.001	0.999	0.007

3.4. The qualities of dried pork slice

3.4.1. Moisture content

The moisture content of different dried pork slices is shown in Table 4. The initial moisture content of fresh slice pork was 75.62 ± 0.61%, whereas the moisture content of dried pork slice produced using LPG and electric hot air dryers was less than 30%. This was in agreement with Thai community product standard of moisture content in dried beef (297/2547). From this, an increase in drying temperature and air velocity resulted in a decreased moisture content in dried pork slice, regardless of the dryer. The increased temperature promoted the dehydration of drying sample (Campidelli et al., 2019). Moreover, a positive relation between air velocity and moisture content was found. Kaveh et al. (2020) showed that an increased velocity resulted in increased energy utilization and evaporation of moisture from inside the sample to its surface. These results were similar to those studied by Chinenye (Ndukwu, 2009), who showed that the drying constant increased with an increase in drying temperature and air velocity. Their relationship was found as linear regression. However, the effect of temperature on the drying process was greater than that of air velocity. To find the best drying method for sliced pork, the drying process from the two different dryers were compared. It was found that the moisture content in dried pork slice from LPG hot air dryer was not significantly different with those from electric hot air dryer. On the other hand, there was no significant difference in other temperatures. This showed that the LPG hot air dryer could dehydrate the sliced pork similar to an electric hot air dryer.

3.4.2. Water activity (a_w)

The a_w is a measurement of the ratio of the vapor pressure of water in a sample to the vapor pressure of pure water at identical temperature and environmental conditions. A lower a_w (<0.7) can prevent spoilage caused by microorganisms. To prolong the shelf life of food and agricultural products, a_w is minimized to a lower range, resulting in a less deterioration rate (Hebbar et al., 2021). In this study, a_w of different dried pork slices was close to 0.7 (Table 4). An increase in drying temperature and air velocity resulted in a decrease in a_w in dried pork slice, regardless of the dryer. According to this, there was a relationship between moisture content and a_w. This could be explained by the fact that fresh pork contained higher free water, resulting in its higher moisture and a_w

Table 3. Statistical results from different models for electrical hot air dryer.

Model name	Air velocity	Temperature	Parameters			SSE	R^2	RMSE
Lewis	1	50	k = 0.005			0.017	0.989	0.024
		55	k = 0.006			0.013	0.991	0.021
		60	k = 0.006			0.022	0.985	0.028
	1.5	50	k = 0.005			0.030	0.980	0.032
		55	k = 0.007			0.010	0.993	0.019
		60	k = 0.007			0.015	0.990	0.023
	2	50	k = 0.006			0.033	0.978	0.033
		55	k = 0.007			0.017	0.989	0.024
		60	k = 0.008			0.022	0.984	0.028
Logarithmic	1	50	a = 0.858	b = 0.175	k = 0.008	0.003	0.998	0.010
		55	a = 0.929	b = 0.132	k = 0.008	0.002	0.999	0.008
		60	a = 0.905	b = 0.151	k = 0.009	0.002	0.999	0.009
	1.5	50	a = 0.870	b = 0.148	k = 0.009	0.003	0.998	0.011
		55	a = 0.932	b = 0.102	k = 0.008	0.002	0.999	0.009
		60	a = 0.923	b = 0.100	k = 0.009	0.003	0.998	0.011
	2	50	a = 0.879	b = 0.126	k = 0.009	0.005	0.997	0.013
		55	a = 0.923	b = 0.096	k = 0.009	0.005	0.997	0.014
		60	a = 0.894	b = 0.073	k = 0.009	0.003	0.998	0.011
Henderson and Pabis	1	50	k = 0.005	a = 0.980		0.015	0.990	0.023
		55	k = 0.006	a = 1.007		0.012	0.992	0.021
		60	k = 0.006	a = 0.981		0.021	0.986	0.027
	1.5	50	k = 0.006	a = 0.957		0.016	0.988	0.024
		55	k = 0.006	a = 0.988		0.010	0.994	0.019
		60	k = 0.007	a = 0.971		0.013	0.991	0.022
	2	50	k = 0.006	a = 0.946		0.017	0.988	0.024
		55	k = 0.007	a = 0.968		0.015	0.990	0.023
		60	k = 0.007	a = 0.927		0.009	0.994	0.018
Avhad and Marchetti	1	50	a = 1.141	k = 0.025	n = 0.712	0.001	0.999	0.006
		55	a = 1.191	k = 0.037	n = 0.660	0.002	0.999	0.008
		60	a = 1.147	k = 0.024	n = 0.762	0.001	0.999	0.005
	1.5	50	a = 1.140	k = 0.031	n = 0.718	0.001	0.999	0.005
		55	a = 1.920	k = 0.034	n = 0.700	0.002	0.999	0.007
		60	a = 1.147	k = 0.029	n = 0.737	0.001	0.999	0.007
	2	50	a = 1.126	k = 0.031	n = 0.721	0.002	0.999	0.007
		55	a = 1.125	k = 0.027	n = 0.762	0.003	0.998	0.010
		60	a = 1.059	k = 0.024	n = 0.788	0.001	0.999	0.006
Diffusion	1	50	a = 0.515	b = 0.963	k = 0.005	0.017	0.986	0.025
		55	a = 0.759	b = 0.118	k = 0.008	0.007	0.994	0.017
		60	a = 0.971	b = −0.39	k = 0.007	0.006	0.996	0.015
	1.5	50	a = 0.684	b = 0.238	k = 0.010	0.003	0.998	0.010
		55	a = 0.948	b = −0.28	k = 0.008	0.007	0.994	0.017
		60	a = 25.55	b = 0.999	k = 0.007	0.018	0.988	0.026
	2	50	a = 0.396	b = 0.209	k = 0.015	0.003	0.998	0.011
		55	a = 0.504	b = 0.358	k = 0.012	0.005	0.997	0.014
		60	a = 0.240	b = 0.246	k = 0.026	0.001	0.999	0.006

Table 4. Moisture content and a_w of sliced pork dried using LPG and electric hot air dryers under different temperatures (50°C, 55°C, and 60°C) and air velocities (1, 1.5, 2 m/s).

Drying condition		Moisture content (%)			a_w		
Temperature (°C)	Air velocity (m/s)	LPG	Electric	Sig	LPG	Electric	Sig
50	1	24.71 ± 1.42	24.62 ± 1.71	ns	0.667 ± 0.015	0.678 ± 0.019	ns
	1.5	24.42 ± 0.99	24.57 ± 1.62	ns	0.684 ± 0.018	0.676 ± 0.025	ns
	2	24.41 ± 0.34	24.01 ± 1.44	ns	0.695 ± 0.019	0.674 ± 0.022	ns
55	1	24.31 ± 1.08	24.25 ± 1.04	ns	0.697 ± 0.06	0.714 ± 0.034	ns
	1.5	23.96 ± 1.81	23.96 ± 1.60	ns	0.784 ± 0.017	0.694 ± 0.028	ns
	2	23.66 ± 1.00	23.33 ± 1.08	ns	0.712 ± 0.025	0.685 ± 0.025	ns
60	1	23.02 ± 1.25	23.18 ± 1.26	ns	0.689 ± 0.032	0.694 ± 0.018	ns
	1.5	22.62 ± 0.84	23.10 ± 1.35	ns	0.673 ± 0.023	0.689 ± 0.028	ns
	2	22.15 ± 1.01	22.89 ± 1.57	ns	0.658 ± 0.018	0.673 ± 0.024	ns

The data was presented as mean ± standard error of five replications.

Sig means significantly different whereas ns means not significantly different at 95% confidence ($p < 0.05$).

values. However, the dehydration process by drying decreased its free water via evaporation resulting in its lower moisture and a_w values. This is in agreement with Hebbar et al. (2021), who showed that the moisture content and a_w of areca nut samples, including dried red and chali had a linear relationship. In the present study, the a_w of samples dried using LPG hot air dryer was not significantly different from those dried using electrical hot air dryer. Thus, the LPG hot air dryer could be used as an alternative for sliced pork drying.

3.4.3. Colour

A colorimeter was used to measure the colour characteristics of sliced pork dried using different drying conditions and dryers. As shown in Table 5, an increase in temperature resulted in an increase in lightness (L*) and yellowness (+b*), while redness (+a) decreased. This can be explained by the increased temperature during drying process causing the fade of colour and darkness appearance, regardless of the dryer. These results were similar with Aksoy et al. (2019), who showed that a high drying

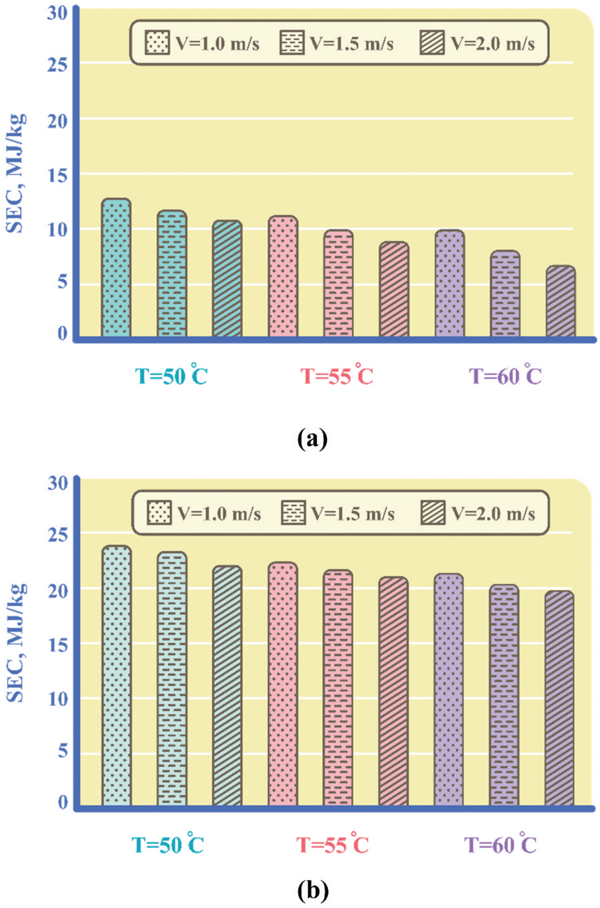


Figure 3. Specific energy consumption (SEC) of sliced pork drying process using LPG hot air dryer (a) and electric hot air dryer (b) under different temperatures (50°C, 55°C, and 60°C) and air velocities (1, 1.5, 2 m/s).

temperature resulted in a decrease of colour in dried minced meat. Firstly, a variation from dark red to pink was observed at nearly 60°C. After that, a grayish colour was observed between 60°C and 70°C. Finally, a light brown colour appeared between 70°C and 80°C (Kondjoyan et al., 2014). There was no significant difference between the colour of dried pork slice using LPG and electric hot air dryers. This showed that the type of drying machine did not affect the colour of dried pork slice.

4. Conclusions

For the drying process study, the drying curves and the equilibrium moisture content from LPG and electric hot air dryers were determined using different temperatures and air velocities. The analysis of the results showed that an increase in temperature and air velocity resulted in a decrease in the drying time and moisture content, regardless of the dryers. Additionally, five different mathematical modelling were fitted to find the optimisation of drying characteristic for sliced pork. The results showed that Avhad and Marchetti model was the most suitable model for both dryers. However, the LPG hot air dryer consumed less energy; half as much as that of the electric hot air dryer.

An increase in temperature and air velocity resulted in a decrease in moisture content and a_w. The moisture content and a_w in dried pork slice were in the range of 22.15–24.71% and 0.658–0.784, respectively. These were not significantly different between both dryers. The analysis of colour showed that a higher temperature resulted in an increase in lightness and blue colour, whereas the redness was reduced. These scenarios were found in both dryers.

In conclusion, the LPG hot air dryer could be used as an alternative dryer for manufacturers in remote areas due to non-electrical energy consumption and reducing the processing costs, while maintaining the same level of food quality as is produced with an electric hot air dryer for drying.

Table 5. Colour of sliced pork dried using LPG and electric hot air dryers under different temperatures (50°C, 55°C, and 60°C) and air velocities (1, 1.5, 2 m/s).

	Drying condition		Colour value		
Colour	Temperature (°C)	Air velocity (m/s)	LPG	Electrical	Sig
L*	50	1	16.53 ± 0.33	16.20 ± 0.54	ns
		1.5	16.61 ± 0.77	16.94 ± 0.98	ns
		2	17.61 ± 0.66	18.27 ± 0.56	ns
	55	1	29.31 ± 1.25	29.98 ± 1.37	ns
		1.5	30.06 ± 1.10	30.26 ± 0.91	ns
		2	31.20 ± 2.11	31.87 ± 1.78	ns
	60	1	30.48 ± 0.42	31.75 ± 0.05	ns
		1.5	30.75 ± 0.60	32.14 ± 0.12	*
		2	32.11 ± 1.14	33.11 ± 1.01	ns
a*	50	1	26.27 ± 5.38	26.61 ± 4.21	ns
		1.5	25.86 ± 1.21	25.86 ± 0.32	ns
		2	22.78 ± 0.32	23.12 ± 1.10	ns
	55	1	20.25 ± 0.23	19.59 ± 0.32	ns
		1.5	17.57 ± 1.19	17.24 ± 1.62	ns
		2	16.38 ± 1.36	16.38 ± 2.13	ns
	60	1	16.94 ± 0.40	17.60 ± 0.72	ns
		1.5	15.60 ± 0.50	15.26 ± 0.43	ns
		2	14.68 ± 0.33	15.01 ± 0.10	ns
b*	50	1	3.35 ± 0.52	4.02 ± 0.24	ns
		1.5	3.47 ± 0.52	4.30 ± 0.13	ns
		2	3.63 ± 0.29	4.47 ± 0.27	ns
	55	1	4.40 ± 0.53	4.73 ± 0.56	ns
		1.5	5.66 ± 0.44	5.66 ± 0.51	ns
		2	6.15 ± 0.85	5.82 ± 0.49	ns
	60	1	8.25 ± 0.64	7.99 ± 0.98	ns
		1.5	8.32 ± 0.86	8.91 ± 0.75	ns
		2	8.53 ± 0.70	9.19 ± 0.87	ns

The data was presented as mean ± standard error of five replications.

Sig means significantly different whereas ns means not significantly different at 95**%** confidence ($p < 0.05$).

However, a less capacity of LPG hot air dryer was a limitation in this study. This affected on an increase of batch productions. Therefore, the LPG hot air dryer in this study could be further developed in the future to achieve more practical applications for food drying by increasing in a capacity and employing dual systems (LPG-solar hybrid dryer). This would be useful for start-up manufacturers who need to decrease the LPG costs, which fluctuate based on world economy.

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No potential conflict of interest was reported by the authors.

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