Effect of the initial moisture content of the paddy drying operation for the small community

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Abstract

After the harvest, the paddy would contain high and unequal initial moisture content, depending on the season and harvest time. As a result, the dehydration was caused by using the dryer while feeding the paddy grain unequal moisture content, the dryer should be properly adjusted to retain the final moisture content as per the rice mill and storage requirements and low specific energy consumption (SEC) were used for the drying operation per one cycle product. The objective of this paper was to study the paddy drying operation by using a continuous cross-flow dryer at a different initial grain moisture content. The research was divided into two steps, the first step began with the drying operation with levels of the initial moisture content 20.0%wb that involved the adjustment of the parameters of an average hot-air temperature 150°C, the speed rotation of an eccentric set of 11.52 rad s^{-1}, the airflow rate 0.016 m^3 s^{-1}, and speed rotation of rotary valve 0.21 rad s^{-1} (approximately feed rate 36 kg h^{-1}), by the application of these parameters, from the obtained results, it was found that grain moisture content of paddy was reduced from 20.0%wb to 14.3%wb as desired, and SEC of 3.60 MJ kg^{-1} water was evaporated. Then the second step, these parameters were tested in terms of the drying operation that the initial grain moisture content decreased and increased 18.1%wb and 23.0%wb, respectively. The results showed that when the initial grain moisture content decreased, the paddy drying operation reduced the moisture of the paddy until the final grain moisture content became 12.9%wb which was lower than the desired expectation, On the contrary, when the initial moisture content increased, the final grain moisture content became 16.1%wb. This was not sufficient for storage or planting in the next crop year which required re-drying operation as well. Furthermore, the results can be used as reference data and a guideline for small communities in Thailand to appropriate decisions with the drying cost and the value-added tax.

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Introduction

Thailand has 62 million Rai (99,200 m^2) of rice plantation area nationwide, which yield annual paddy output of 31 million tones (Rice Industry, 2016) of the paddy rice in many regions such as the north-eastern region, northern region, central region and southern region (Titapiwatanakun, 2012). When the harvest seasons are due, fresh paddy rice contains different moisture, depending on seasons and harvesting time. The paddy rice is usually harvested at a high moisture content, between 18-24%wb (Lu *et al*., 1995; Ashfaq *et al*., 2016). After the harvest, the paddy has to be dehydrated to destroy bacteria and prevent grain deterioration. The dehydration can reduce seed respiration from transpiration on the appropriate level (14-15%wb), then the paddy will be ready for exports, preservation, trade, and grain storage (Brooker *et al*., 1992).

Paddy drying operation in Thailand

After the harvest, fresh paddy from the community is sold to the rice mill industries, a selling price depends on the moisture content or initial moisture content (IMC) of the paddy, which can be measured by the digital grain moisture tester "Kett" (Riceter F512) model: compression type with an accuracy of 0.5%. For the paddy that contains over 15% moisture content, the reducing weight and selling price will be set according to The Department of Internal Trade in Thailand as shown in (Table 1).

When the high moisture paddy was sold, the price was reduced with the increased moisture content. As a result, there would be another effective tool to solve the problem of the farmers to adjust the suitable moisture content then the farmer can gain a better selling price or more income as well as extending the paddy preservation. However, a rice paddy dryer costs a lot of money and therefore, it is a financial burden for the farmers' budget. The small community or cooperative of the paddy enterprise should be established to conduct the paddy drying tasks for all members of a community.

Problems of a continuous cross-flow dryer

The operation of a machine is to use hot air flow to cross the continuous movement of the bed layer on the distributor plate along with the drying chamber, caused by the speed rotation of an eccentric set. This kind of artificial dryer was called a cross-flow dryer (Billiris and Siebenmorgen, 2014; Billiris *et al*., 2014), In Thailand, it is called *a must flow dryer* (Yapha *et al.*, 2014; Pongsatit Sonpakdee *et al.,* 2016). Problems found in the drying operation of this dryer concerns the adjustment of the parameters, such as feed inlet, volume hot air flow rate, and hot air chamber temperature, that should be done properly with initial grain moisture and property of surrounding air. These parameters make the final grain moisture content (FMC) of the paddy after drying available for trading, preservation, and grain storage. Practically, the initial moisture content of the paddy fed in the dryer might be different in each cycle production. Therefore, the experienced experts in parameter adjustment are needed to help farmers controlling the expected FMC while saving energy. In the previous study, a must flow dryer was presented as a set guideline in (Table 2).

A case study of a small community in Suphan Buri province revealed that the most freshly harvested paddy was sold to the local mills because the community cannot provide enough space for natural paddy drying (Teter, 2012). As a result, the community had to sell the paddy which had high moisture content to the rice mills and the selling price was reduced according to the agreement (Table 1), as all the paddy grains have been sold, farmers could not keep those grains for planting in the following years. This caused the community to lack the unity of local Thai rice varieties (Promsomboon and Promsomboon, 2016).

Base on the above data related to the drying operation in Thailand and the problems found from a continuous cross-flow dryer. The objective of this paper is to study the effect of the initial moisture content of the paddy drying operation for the small community by considering the parameter adjustment to be suitable for drying operation which was related to the energy consumption per one cycle product.

Materials and methods

To study the effect of the initial moisture content (IMC) on paddy drying operation to the final moisture content (FMC), in the experiment, a continuous cross-flow dryer was used.

A continuous cross-flow dryer

A dryer was a prototype for the small community in Thailand which was fabricated in the Department of Mechanical Engineering at SWU. This dryer has been applied for drying of granular materials in an agriculture product. Figure 1 illustrates the schematic diagram of a continuous cross-flow dryer as shown the components of the dryer, which consists of a 100 mm × 700 mm infrared catalytic gas burner burned (Gouda and Shanmukha Swamy, 2014) with airflow from an air inlet (9) at the downside of

Table 1. Selling price at various moisture levels (Department of Internal Trade in Thailand, information year 2013/14).

Paddy MC (%) or IMC (%wb)	Reducing weight (kg)	Net weight (kg)	Selling price (THB ton^{-1})	Price differential (THB ton^{-1})
Not exceed 15	0.0	1000	15,000°	0.00
16.0	15.0	985	14,775	225.00
17.0	30.0	970	14,550	450.00
18.0	45.0	955	14,325	675.00
19.0	60.0	940	14,100	900.00
20.0	75.0	925	13,875	1125.00
21.0	90.0	910	13,650	1350.00
22.0	105.0	895	13,425	1575.00
23.0	120.0	880	13,200	1800.00

*The reducing selling price caused by over 15% moisture content; °THB 15,000 ton^{-1} (USD 482.60) (Poramacom, 2014).

Table 2. Setting guideline of a must flow dryer.

No.	Parameters	Reference Yapha *et al.*, 2014	Pongsatit Sonpakdee *et al.*, 2016	Unit	Remark
1.	Hot air temperature	150	160	°C	Due to the heat source, it could produce height temperature, without damaging the quality of drying material (Gouda and Shanmukha Swamy, 2014)
2.	Feed rate	20	0.5	ton h^{-1}	If more feed rate, that would adjust the speed rotation of the eccentric set to get to high and need more airflow for mass transfer (Lu *et al.*, 1995; Titapiwatanakun, 2014; Ashfaq *et al*., 2016)
3.	Speed rotation of an eccentric set	29.3	12.6	rad s^{-1}	
4.	Airflow rate	5.04	0.20	m^3 s^{-1}	

the hot air chamber (2). Then, the hot air flows through the air distributor plate (3) and the paddy layer to the top side of the drying chamber (4). The fan motor drives hot air to the air outlet (10). After that, the paddy is fed into the drying chamber by rotary valve feeder (7), and the paddy layer moves from the left side to the right side by motor driver eccentric set (8). The dryer is supported by leaf spring (11), and a data logger is used to store data (12).

The drying operation of the dryer has a limited range of parameters adjusted as shown in Table 3. The information is shown in two sections, the first section explained the approximate dimensions of the machine and the main equipment while another section presented the main parameter setup and value range according to the ability of the machine, which this paper, the main parameters would be adjusted according to a guideline of the previous researcher as presented in Table 2. After that, the final moisture content of the paddy was considered sufficiency for selling to rice mills and for storage.

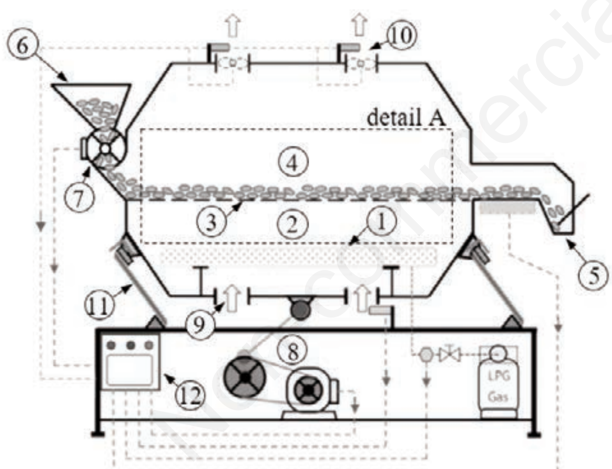
The operation begins by switching on the fan motor and the infrared catalytic gas burner. Then, the hot air flows through the air distributor plate to the drying chamber, and the temperature level can be controlled by the gas pressure and gas flow rate. The temperature is measured by a thermocouple type K, with 10-point installations along the drying chamber as shown in detail A. There are five points (No. 1-5) in the hot air chamber with a temperature of about 145-155°C, and another five points (No. 6-10) in the drying chamber, a thermocouple connects to a data logger with an accuracy of 1°C. In the experiment, the hot air temperature was adjusted at the highest temperature level as the heat source could produce, without damaging the quality of the drying material.

Before the drying operation, the hot air temperature flows through the air distributor plate from the hot air chamber to the drying chamber as shown in (Figure 2A), while the heat losses during drying operation as shown in (Figure 2B).

During the drying operation, the hot air flows through the air distributor plate and the paddy layer from the hot air chamber to the drying chamber as shown in Figure 3A, while the heat losses and transfer to the paddy during the drying operation as shown in Figure 3B.

Materials

Thai Jasmine Rice rice is called *Thai Hom Mali Rice* or DR 105, which is one of the most popular varieties in the central region of Thailand. According to the American Society of Agricultural Engineers Standard (Standard A.S352.2, 2003), after the harvest, the fresh paddy was cleaned to remove straw stones and dust, then the fresh paddy was wetted, mixed and stored 3-5°C in plastic bags for five days before the drying experiment to reach the uniform moisture content (Khanali *et al.*, 2018), the moisture can be mea-



No.	Components
(1)	Infrared catalytic gas burner
(2)	Hot air chamber
(3)	Air distributor plate
(4)	Drying chamber
(5)	Paddy outlet
(6)	Feed inlet
(7)	Rotary valve feeder
(8)	Eccentric set
(9)	Air inlet
(10)	Air outlet
(11)	leaf spring
(12)	Data logger and controler

Figure 1. Schematic diagram of a must flow dryer.

Table 3. Specification of a must flow dryer.

Dimensional	Parameter setup and adjustment
Dryer size (W×L×H):	Hot air temperature:
- 400×1400×1800 mm	- 130, 150°C, ±5°C
Drying chamber length	Speed rotation of eccentric set:
- 1000 mm	- 11.52-12.56 rad s^{-1}
Air distributor plate (W×L×t):	Feed rate:
- 15×1000×2 mm	- approximate capacity: 32-90 kg hr^{-1} at speed rotation of rotary valve of 0.21-0.63 rad s^{-1}
Infrared catalytic gas burner (W×L):	Air flow rate:
- 100×700 mm	- volume flow rate: 0.016-0.024 m3 s–1 at velocity of air flow 2.0-3.0 m s^{-1}

sured by a moisture detector '*KETT*' (Riceter F512) model: compression type with an accuracy of 0.5 percent. After that, it can be divided into three-grain moisture content levels: 18-19%, 20-21%, and 22-23% based on a wet basis, respectively. Each experiment has been conducted in three replications.

Moisture content (MC)

The moisture content is measured based on a wet basis and a dry basis, which can be calculated by using Eq. 1 and 2 (Motevali *et al.,* 2014):

$$MC_D = \frac{W_W - W_D}{W_D} \quad (1)$$

$$MC_W = \frac{W_W - W_D}{W_W} \quad (2)$$

where, MC_D the paddy moisture is based on a dry basis (%db), kg water/kg dry matter; MC_W the paddy moisture is based on a wet basis (%wb), kg water/kg wet matter; W_W is the sample weight, kg, during drying; W_D is dried sample weight, kg.

Moisture ratio

Moisture ratio (MR) is defined as the change in water content in the paddy about the initial moisture content (Horwitz *et al.*, 1970). It can be calculated by using the following Eq. 3, and the equilibrium moisture content can be calculated by Henderson, 1952, as Eq. 4

$$MR = \frac{M(t) - EMC}{IMC - EMC} \quad (3)$$

$$EMC = \frac{1}{100}\left[\frac{\ln(1-RH)}{(-3.146\times10^{-6}\times T_{abs})}\right]^{\frac{1}{2.646}} \quad (4)$$

where MR is the dimensionless moisture ratio, M(t) is the moisture content at the time t, IMC is the initial moisture content, EMC is

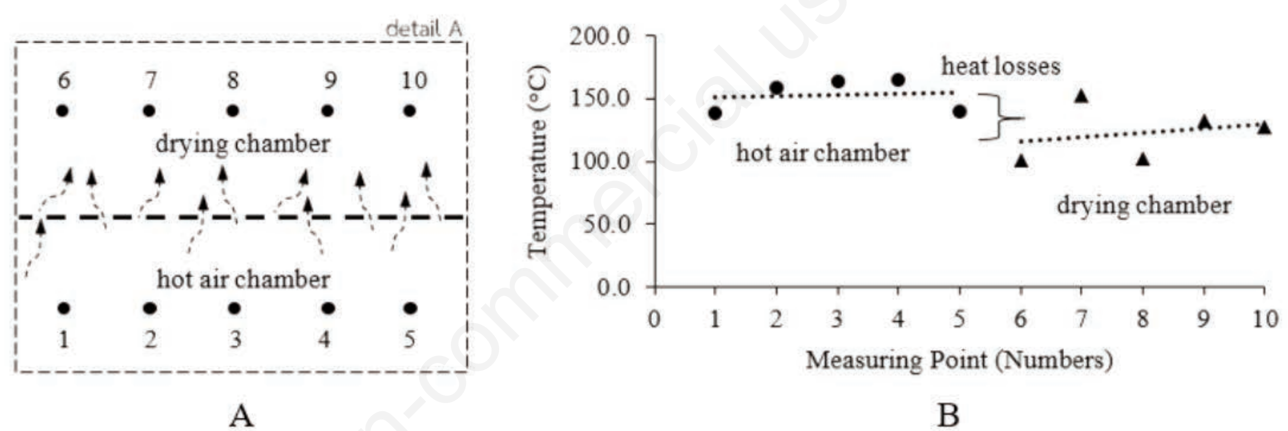


Figure 2. A) Position of air temperature measuring point and B) The distribution of air temperature (in case: without paddy).

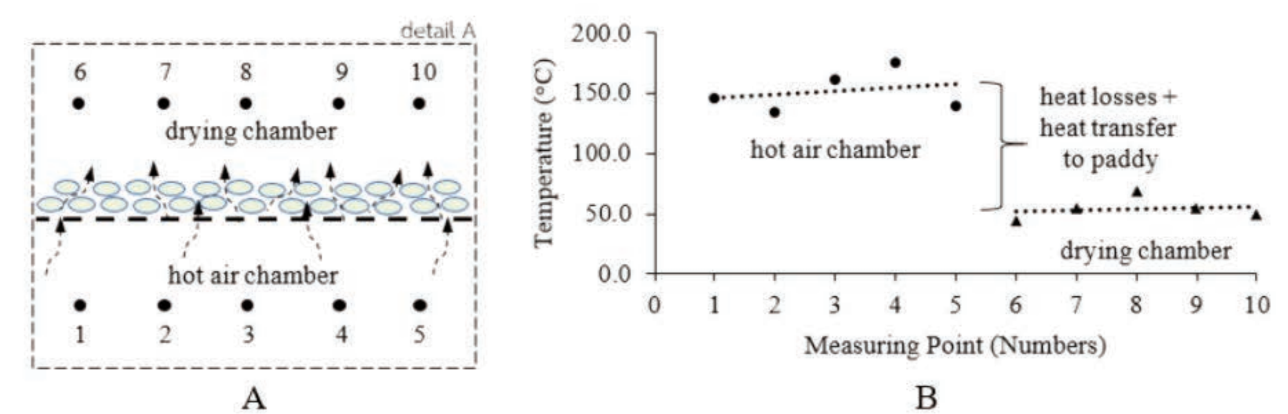


Figure 3. A) Position of air temperature measuring point and B) The distribution of air temperature (in case: paddy drying).

the equilibrium moisture content on a wet basis (%wb), RH is a relative humidity of drying air (%RH) and T_{abs} is absolute air temperature, K.

The energy consumption of the dryer

The specific energy consumption (SEC) in the paddy drying operation can be defined as the required energy to evaporate the unit mass of water from the drying product in a dryer. It is a key indicator for evaluating the performance of dryers (Firousi *et al.*, 2017). The better performance of the dryer can be observed from the lower consumption of specific energy per cycle (Sarker *et al.*, 2014). In the study of a continuance cross-flow dryer, energy consumption includes thermal energy for warming up the air with an infrared catalytic burner and electrical energy for the driving motor at the set: a rotary valve, an eccentric rod, and a circulation fan at the air outlet. The SEC is determined as the ratio of summation of thermal and electrical energy divided by the amount of water removal from IMC to FMC of drying operation, as shown in the following Eqs. 5-7.

$$E_{total} = E_{thermal} + (3.6 \times E_{electrical}) \tag{5}$$

$$E_{thermal} = [m_{LPG} \times (HV)] \tag{6}$$

$$SEC = \frac{E_{total}}{m_w} \tag{7}$$

where, E_{total} is the total energy input to the dryer operation (MJ), $E_{thermal}$ is the thermal energy to dry paddy (MJ), $E_{electrical}$ is the electrical energy (MJ), m_{LPG} is the mass of LPG (kg), HV is the heating value of LPG was defined as 50 MJ kg^{-1} (Demirbas, 2002; Nagle *et al.*, 2010), m_w is the mass of water removed (kg), SEC is the specific energy consumption (MJ kg^{-1}).

Note: Thermal energy used for an entire test is calculated by reducing the mass of liquefied petroleum gas (LPG) use (kg), which is measured by a digital scale with its accuracy of 0.01 g, electrical energy is measured by kilowatt-hour meter. Due to the units of electrical energy which was measured in units (kW h), it could not be summed between the thermal energy and electrical energy. Therefore, the units (kJ s^{-1} h) times to 3600 (s h^{-1}) and divided by 1000 (MJ kJ^{-1}) to convert unit (kW h) to (MJ) or take 3.6 times to the units (kW h) as Eq.5.

The amount of water removed during each paddy drying operation is calculated based on the following Eq. 8 (Maier and Bakker-Arkema, 2002).

$$m_w = \frac{m_i \times (IMC - FMC)}{(100 - FMC)} \tag{8}$$

where, IMC and FMC are the initial and final moisture grain content of paddy dried (%wb), respectively. m_w and m_i are the mass of water removed (kg) and the initial mass of paddy dried lot (kg), respectively.

Experimental setup

A continuous cross-flow dryer has experimented; the procedure starts from a dryer set up. Figure 4 showed the experiment flow chart of the paddy drying operation. There are two steps.

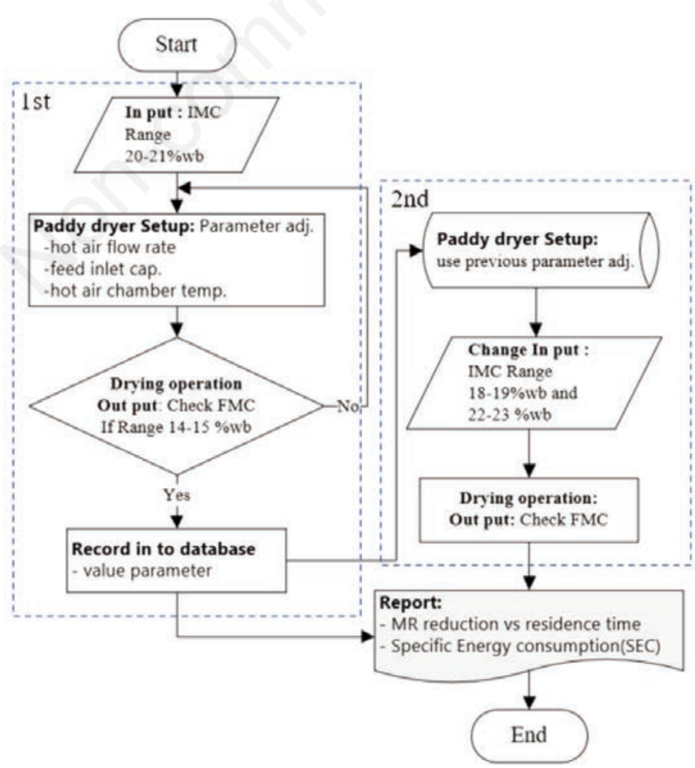


Figure 4. Experimental flow chart of the paddy drying operation.

The first step, the paddy (30 kg) which contains an initial grain moisture content (IMC) range of 20-21%wb was fed into the drying chamber. The dryer operator adjusted the parameters of the dryer until it could reduce the final grain moisture content of the paddy in the range of 14-15%wb as the desire of small communities, it took about 49 min for the whole paddy to be moved through the drying chamber in the one cycle product. Then, the appropriate parameters were recorded in the paddy dryer set up and final moisture content, as well as SEC, were reported. If the final grain moisture content cannot reach the range, the user must start the experiment and re-adjust the parameter again.

In the second step, the experiment was conducted repeatedly by feeding the paddy into the drying chamber in case IMC range of lower (18-19%wb) and higher (22-23%wb). By using the parameter as per the previous step.

There are some tips for adjusting parameters. Firstly, the hot air temperature was set at 150°C (as above mentioned). Next, the speed rotation of the eccentric set was adjusted at the low value at 11.52 rad s^{-1}. If the speed is increased too fast, it causes the paddy to move through the drying chamber fast as well. The poor heat and mass transfer caused by these, cause the paddy to move fast. Finally, the user has to set the paddy feed rate input and airflow rate by adjusting the speed rotation of the rotary valve at 0.21 rad s^{-1} (approximate capacity: 36 kg h^{-1}) and velocity of airflow at 2.0 m s^{-1}. To measure the paddy moisture content at each drying experiment is divided into two sections, the first section is measured by the moisture content from the start to finish of the drying operation process and the second section is measured by the moisture content while the dryer operating is steady, the flow of the paddy through the drying chamber was stopped suddenly, after that (the paddy was held up in the drying chamber), measuring was performed at ten points along the drying length from the drying chamber inlet. The moisture content was determined off-line by using a moisture detector. At each drying experiment, the measuring of the paddy sample was performed five times, then calculated the average value and deviation value.

Results and discussion

The moisture reduction of the continuous cross-flow dryer

The experiment setup as mentioned above made the paddy layer move on the air distributor plate through a 100 cm along with the drying chamber which takes about two minutes (the paddy is moved from the beginning at zero meters to the end one meter of the drying chamber as referred to in Table 3). For one cycle product or one drying operation, the 30 kg paddy is fed into the drying chamber. It takes 49 min that could estimate the product for one day equal to 36 kg h^{-1}. Generally, the small community has been performed by a moisture detector that the accuracy was suitable as a *Guide document on rice moisture measurement* (Forum APLM, 2017) and Hossain *et al.* (2016), which was conducted to find out a precise moisture meter. This moisture detector has an advantage such as a small size, lightweight, easy operation, and rapid measurement. Figure 5 shows the moisture content (MC) at the inlet and outlet of the dryer (Figure 1). It is noted that the inlet and outlet MC refer to the MC of the paddy grain at the initial moisture content (IMC) and final moisture content (FMC), respectively. The MC of the paddy was measured by using a moisture detector (Riceter F512). The MC of the paddy was measured from the start to finish of the drying process. The IMC and FMC of each cycle product for the five drying tests carried out and represented the average MC and the deviation of the measure.

As per the experiment, the first step: the dryer was adjusted by the parameter, followed by a guideline, the proper adjustment of parameters of a dryer while it was operating as follows: the average hot air temperature of 150°C, the average hot air volume flow rate of 0.05 m^3 s^{-1}, the average speed rotation of an eccentric set of 11.52 rad s^{-1}, and the speed rotation of rotary valve 0.21 rad s^{-1}. From the adjusted parameters, when the paddy with IMC of 20.0% with a deviation of ±0.6 was fed, the drying operations reduced the moisture of the paddy as the FMC became 14.3% with a deviation

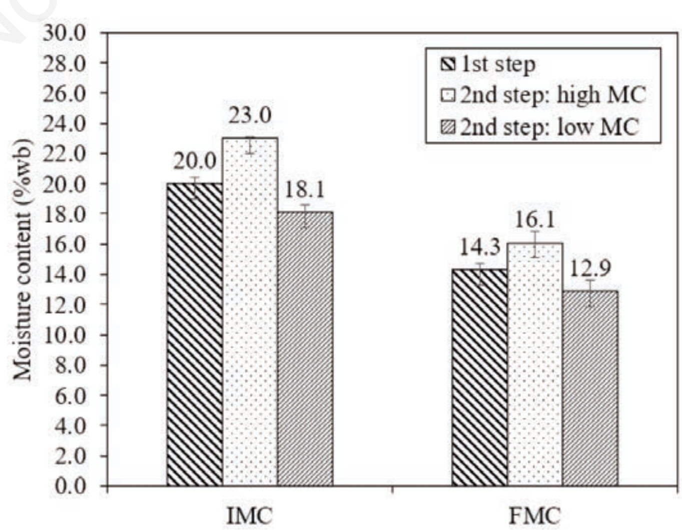


Figure 5. A moisture detector (Riceter F512).

of ±0.5. This moisture level met the requirements of the rice mill as mentioned in Table 1.

On the contrary, the second step in case of more MC: when the operation was repeated by feeding the paddy with IMC 23.0% with a deviation of ±0.4, The drying operations reduced the moisture content as the FMC became 16.1% with a deviation of ±0.6. The paddy with this moisture level almost meets the requirements and can be sold to the rice mill. However, it is not sufficient for storage or planting in the next crop year. In the case less MC: The paddy with IMC 18.1% with a deviation of ±0.4, it reduced the moisture content as the FMC became 12.9% with a deviation of ±0.5. The paddy with this moisture level is suitable for storage and planting in the next crop year. However, it is not suitable for selling because the moisture content of the paddy is less than the requirements of the rice mill and the selling weight is also reduced. Similar results have been previously reported in terms of moisture content along with the drying chamber. Yapha *et al*. (2014) dried fresh paddy by Must Flow dryer at a hot air temperature of 150°C and presented the moisture content was reduced along with the drying chamber (Yapha *et al.*, 2014).

Axial profile of paddy moisture content

Based on the experimental observations, a uniform and stable movement of the paddy across the entire bed with the bed height at one centimetre's cross-section during the drying process was succeeding. While the dryer operating was at a steady-state, the user had suddenly stopped the dryer, after that (the paddy held up in the drying chamber which quid the same size with the dryer length), measuring was performed at ten points located along the drying length from 0.1 to 1.0 m. The paddy grain samples were taken out of the dryer and measured the same as the previous experiment. Figure 6 shows a typical drying curve of the moisture content and moisture ratio along the drying chamber length at different moisture. As shown, the initial stage at zero centimetres to ten centimetres, the moisture content has decreased considerably, then gradually continuous slight decrease. When increment in the moisture content leads to a slight increase in final moisture content (Figure 6A). It is due to the thermal energy in form hot air temperature which transfers to the paddy grain caused the temperature of paddy grain to get higher, which driving force for water evaporation from a surface to the hot air until the completion of the cycle product. In addition, the result of moisture measurement from the beginning to the end of the drying experiment was explained in previous tests. From Figure 6B is demonstrated the drying behaviour of moisture ratio *versus* dryer length. The results showed that the paddy with the IMC 20.0%wb, that has been adjusted to the proper parameter settings. On the contrary, when the paddy with less IMC 18.1%wb and more IMC 23.0%wb was fed in the operations, the moisture ratio was reduced to 0.84 and 0.82 respectively. It is due to the rapid evaporation from a wet surface to hot air at the beginning (0 to 10 cm) with the same as (Figure 6A).

Specific energy consumption in a dryer

Table 4 shows the specific energy consumption (SEC) and primary drying cost in the drying operation per one cycle product. First of all, the mass of water removed (Sookramoon and Khamwachirapithak, 2016) at the end of the drying process was calculated using Eq. 2 (which requires essential variable as follow: m_i, IMC, and FMC), then calculated the thermal energy ($E_{thermal}$) by using Eq. 6 and the electrical energy (E_{elec}). The total energy requirements ($E_{thermal} + E_{elec}$), similar to the values reported by Hellevang and Reff (1987), and Billiris *et al*. (2014).

The parameters were set, the IMC of 20%wb was fed, the moisture level was reduced to the proper level. The SEC was consumed of 3.60 MJ kg^{-1} and the primary drying costs were calculated from the mass of LPG (m_{LPG}) use multiply by LPG price and the electric power price as shown in the drying cost column in Table 3, a one cycle product, 30 kg of the paddy was carried out by a continuous cross-flow dryer which took 49 minutes, these data can be used to estimate the drying cost in Thai baht (THB) per one thousand kilograms as well. As a result, the primary drying cost was 103 THB ton^{-1}. When the operation was repeated by feeding the paddy increase MC at IMC of 23.0%wb made the SEC slightly decreased to 3.52 MJ kg^{-1} or the SEC has decreased 2 percentage. So, in case the MC increasing would reduce the energy consumptions per amount of evaporated moisture unit and the primary drying cost was 120 THB ton^{-1}or it has increased 14 percentage. Due to the paddy with high MC, water evaporate from a wet surface would be easy, the primary drying cost caused by the paddy increase MC, it would take a bit longer to dry. On the contrary, the operation was repeated by feeding the paddy decrease MC at IMC of 18.1%wb made the SEC slightly increased to 3.89 MJ kg^{-1} or it

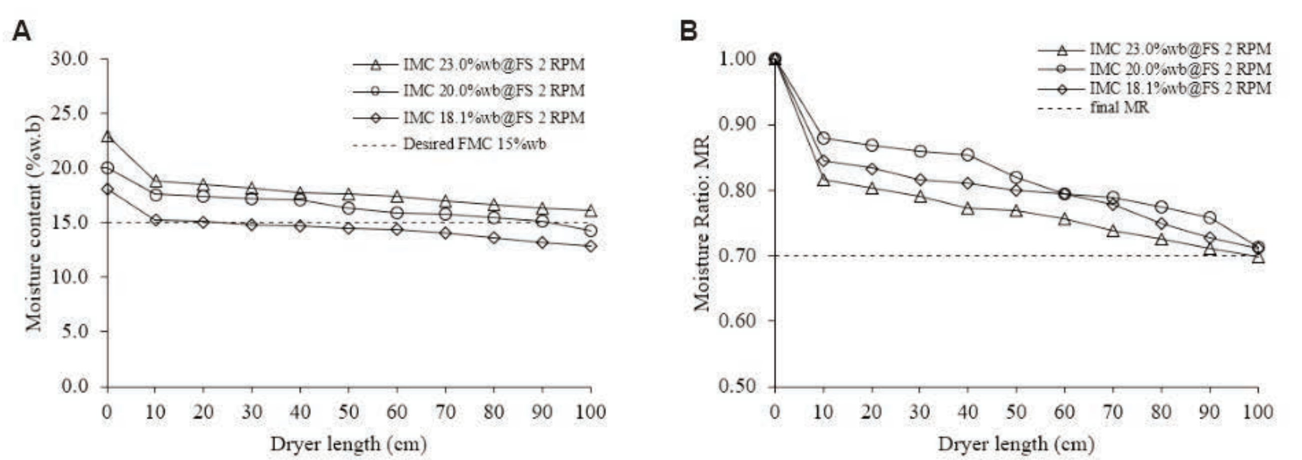


Figure 6. Drying curves of paddy at various IMC: A) moisture content vs dryer length, B) moisture ratio *vs* dryer length.

has increased 7 percentage, and the primary drying cost was 98 THB ton^{-1}. Also, the increase and the decrease of the average primary drying cost depended on the MC of the paddy contained less moisture which took shorter drying time while more moisture content caused paddy longer time for drying operations.

Furthermore, when considering the value-added tax after the drying operation was shown in the selling price column in Table 3.

Conclusions

A cross-flow dryer was invented to encourage the small community to use the drying operation of the paddy before selling it to the rice mill or storing it for planting in the next crop year.

In this study, a differential of the initial moisture content of the paddy was dried in a cross-flow dryer at the parameters of the dryer suitably adjusted, then the operation was repeated by feeding the paddy with more and less IMC. The results showed that the paddy after drying operation with less IMC is suitable for storage or to keep for planting in the next crop year, but it is not suitable for selling. On the contrary, the paddy with more IMC after passing the drying operation would gain a better selling price, although the moisture content is not sufficient for storage or planting in the next crop year. Moreover, the appropriate parameters should be adjusted relatively with IMC. This study can be a guideline for the small community to use a dryer efficiently and the findings can be beneficial to design automatic drying operation systems in the future.

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