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CROSS-FLOW PADDY DRYER APPLICATION USING INFRARED GAS BURNER

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ABSTRACT

Paddy is an economic crop that produces income for Thailand. After the harvest, the paddy would contain high moisture content (MC). Therefore, drying of the paddy is critical to prevent insect infestation and quality deterioration of the paddy. The objective of this paper was to construct a cross-flow paddy dryer application using an infrared gas burner and monitor the moisture that is reduced, and the energy consumption is included. The dryer installed an input temperature and humidity sensor (DHT22) in the air inlet and sensor (EE31) in hot air outlet to read and record data values. Arduino microcontroller was used as the main processor that receives input from a DHT22, EE31 sensor. After that, the processor would calculate the humidity ratio of air and indicate the MC level of the paddy that is reduced. The drying condition used in this study were: paddy initial MC range 20-21% wet basis (wb), a feed rate of 60 kg/h (speed of rotary valve 2 rev/min), the average hot-air temperature of 130 °C, average drying air velocities of 2 m/s, and the average eccentric speed of lift 110 rev/min. The results showed that the system could process and display MC of the paddy that was reduced from the initial MC to the final MC, and alerted the dryer to the user. The dryer was applied to the infrared gas burner, the dryer consumed fairly low energy: 5.85 MJ/kg water evaporated.

Key words: Cross-flow dryer, Infrared gas burner, Moisture content, Temperature and humidity sensor

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1. INTRODUCTION

Rice is an important economic crop and the main staple food economic crop and the main staple food [1]. Each year, the average outputs of Thai paddy rice run to 31-33 million tonnes [2], and the moisture content (MC) is generally stated on a wet basis (wb). The paddy rice is usually harvested at a high MC, ranges 20-25% wb. On these ranges, quality deterioration from microbial growth and respiration is high [3], which should be dried to 15%wb MC for trade to the rice mill (without deducting the trade price due to MC). If MC is lower than this, it is suitable for storage. In general, farmers still use sun drying or drying on the nets to reduce MC. However, if there is no sunlight or during the rainy season, sun drying would not be possible. The principle of a cross-flow dryer is the materials move through the drying chamber. Meanwhile, the hot air flows through the bed perpendicularly to the movement of the material of the materials. The applications cross-flow dryer was presented and tested as follows:

Recently, Pongsatit S., Natthawud D., Churat T., Tanate C., and Rameshprabu R.[4] were studied paddy dryers, and tested a prototype of a cross-flow dryer was called a must flow paddy dryer (MFD), the dryer applications using biomass for the small community with a capacity of 4 tons/day. The test drying conditions were: air flow rate 0.05-0.3 m^3/s, the eccentric speed of lift 120 rpm, and the average drying air temperature of 155-165 $^{\circ}C$. It was found that MC of paddy was reduced from initial MC of 24.0-24.5%wb to final MC of 15.3%wb at residence time 117 sec that was used the electrical energy consumption of 14.32 kWh/day and biomass consumption of 105 kg/day. Moreover, Yapha et al. [5] tested paddy drying by MFD and studied the opportunity for diabetes patients to consume rice which this dryer application using a conventional gas burner. The test drying conditions setup were the hot air temperature of 150 $^{\circ}C$, the eccentric speed of lift of 280 rev/min, the velocity of hot airflow of 0.6 m/s. The results showed that the initial MC of 28.1-38.3%wb was reduced to the final MC of 14.9-15.1%wb at drying capacity of 20 tons/h. Also, the course rice was appropriate for the diabetic patient to consume since carbohydrate in form of monosaccharide is immersed into the fiber and gradually absorbed through an intestinal wall that would be advantageous to control the appropriate level of sugar in the blood. As a result,

In this paper, the researcher attempted to save energy of the drying process by applying an infrared gas burner and monitor the moisture was reduced. The system of the moisture content monitoring by installed the temperature and humidity sensors for checking surrounding airflow at the inlet and outlet of the dryer to show the reducing moisture levels

2. METHODS

2.1. Measurement of Temperature and Humidity

The ambient air temperature (T) and relative humidity (RH) were measured by using DHT22 digital temperature and humidity sensors which the researchers applied [6], [7] and T and RH of the hot air after pass drying chamber of the continuous cross-flow paddy dryer that was measured by E+E Elektronik: serie EE31 humidity and temperature transmitter. Both sensors were connected and communicated to Arduino Uno (a microcontroller unit (MCU) based on the ATmega328P 8 bit), it has 6 analog input pin and 14 digital I/O pin. DHT22 and EE31 sensors are connected to the digital pins and the analog pin respectively as shown in Fig. 1.

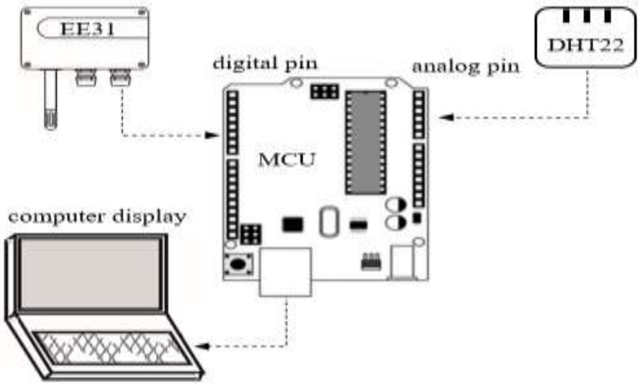

Figure 1 The connection of the sensors to MCU

2.2. Estimation of the amount of Moisture Removed

Drying is the process that removes water out from the grain paddy to a proper level for selling to the rice mills. Therefore, the calculation amounts of water that must be removed from the grain paddy can be calculated by using the equation (1) as well as [8].

$$m_w = (w_d - w_a) \times \left(\frac{A \times V_{air-flow}}{v_{air-flow}} \right) \times n \tag{1}$$

Where; m_w is the amount of moisture removed in kg, A is an area of outlet hot air duct in m^2. $V_{air\text{-}flow}$ is the velocity of hot air flow in m/s. $v_{air\text{-}flow}$ is a specific volume in m^3/kg, n is the pickup factor (in this paper using n of 0.4) and w is humidity ratio (kg of water per kg of dry air), and the subscript d and a are humidity ratio of outlet hot air and ambient air respectively.

2.3. Estimation of Energy Consumption of the Dryer

The efficiency of the dryer can be observed from the lower consumption of specific energy per one product cycle [9], [10]. The specific energy consumption (SEC) in 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 [11]. In the study of a continuous cross-flow dryer, energy consumption includes thermal energy for warming up the air with an infrared catalytic burner and electrical energy for driving motor at the set which includes rotary valve, eccentric rod, and 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 initial MC to final MC of drying operation, as shown in the following equations (2), (3), and (4).

$$E_{total} = E_{thermal} + (3.6 \times E_{electrical}) \tag{2}$$

$$E_{thermal} = m_{LPG} \times LHV \tag{3}$$

$$SEC = \frac{E_{total}}{m_w} \tag{4}$$

Where, E_{total} is the total energy input to the dryer operation (MJ), $E_{thermal}$ the thermal energy to dry paddy (MJ), $E_{electrical}$ the electrical energy (MJ), m_{LPG} the mass of LPG (kg), LHV is the lower heating value of LPG, it to be used in this paper was 46.607 MJ kg^{-1}, m_W the mass of water removed (kg), SEC the specific energy consumption (MJ/kg water removed). Note: Thermal energy used for an entire test is calculated by reducing the mass of LPG use (kg), which is measured by a digital scale with its accuracy of 0.01 g, and electrical energy is measured by kilowatt-hour meter.

3. MATERIALS AND EXPERIMENT

3.1. Materials

The test selected local fresh paddy in the central region of Thailand as the rice, cultivar RD31 (Pathum Thani 1)[12]. Then, the paddy was packed in a plastic bag to maintain moisture by keeping it in the refrigerator at 4 °C. Before the experiment, the fresh paddy was taken off the refrigerator which was left at the ambient air to grain thermal balance for 20 min[13].

3.2. Cross-flow Paddy Dryer

The dryer was a prototype for the small community in Thailand that was created in the department of mechanical engineering at SWU. Fig. 2. represents a schematic diagram of the dryer and the location of the main equipment used in this test. The operation of the dryer started from, feeding the paddy into the drying chamber by rotary valve feeder, and then the paddy layer moves from the left to right side by motor driver eccentric set. The dryer has a drying chamber size (wide x long) of 0.15 m x 1 m which contained an air distributor plate made of stainless-steel with 30% open area, hole 3 mm diameter, and 2 mm the thickness. Meanwhile, the hot air from the infrared gas burner (IRB) is produced from the infrared gas burner that flows from the air inlet at the downside to the top side of the hot air chamber. This process directed perpendicularly or crossed the hot airflow. This process of a continuous cross-flow dryer was called "a Must Flow Dryer" [4], [5].

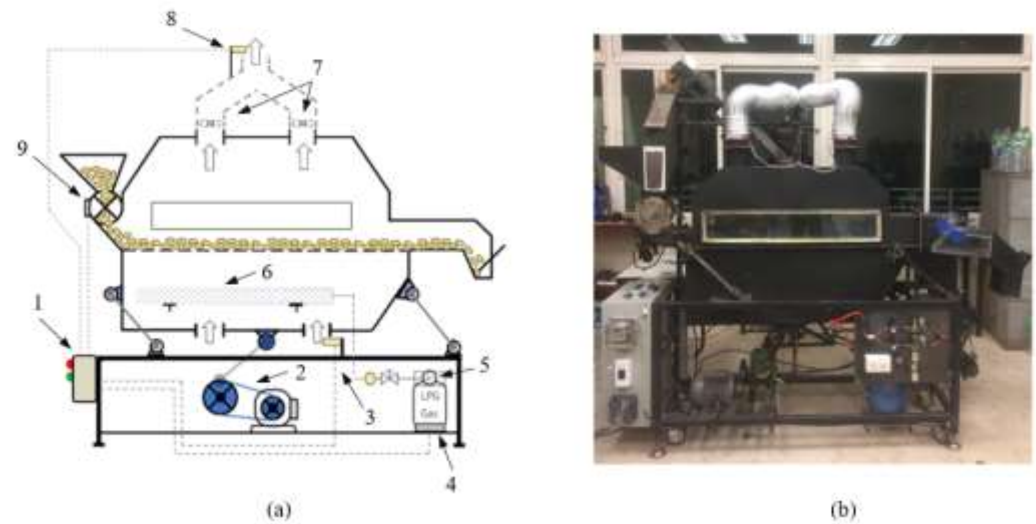

Figure 2 The cross-flow dryer; (a) A schematic diagram of the dryer consists of the unit as follows. 1) Control panel; 2) Motor driver eccentric set; 3) Temperature & humidity sensor (air inlet: DHT22); 4) Digital scales; 5) Cooking gas cylinder; 6) Infrared gas burner; 7) Axial fan; 8) Temperature & humidity sensor (air outlet: EE31); 9) Rotary valve feeder; 10) Hot air chamber and (b) Real image of a cross-flow paddy dryer.

3.3. Experimental Set-Up

In a continuous cross-flow dryer testing, the procedure started from a dryer setup. Fig. 3 showed the experimental flow chart of the drying operation. Firstly, the fresh paddy which contains an initial MC range of 20-21%wb was poured in the hopper. Before testing, the user adjusted the parameter as follows: the hot air temperature of 130 °C, the eccentric speed of lift of 110 rev/min, and the velocity of hot airflow of 2 m/s which was measured by EXTECH Instruments: model AN100 thermo-anemometer, Thailand with air velocity ± 3% m/s basic accuracy. During testing, the user turns on switch to feed paddy into the drying chamber at speed rotation of rotary valve 2 rev/min (approximate capacity: 60 kg/h). In each drying cycle, 7 kgs of the fresh paddy were used. After testing, all paddy would be weighed to find the weight loss that was reduced, and the thermal and electrical energy were reported. Finally, the testing was conducted repeatedly by adjusted the velocity of hot airflow of 2.5 m/s and 3.0 m/s respectively.

The initial MC and final MC of material were determined using the digital grain moisture tester "KETT" (Riceter F512) model: compression type with an accuracy of 0.5 percent, and temperature inside the hot air chamber are measured by a thermocouple type K, with 5-point installations along with chamber as shown in detail A, a thermocouple connects to a data logger with an accuracy of ± 1 °C.

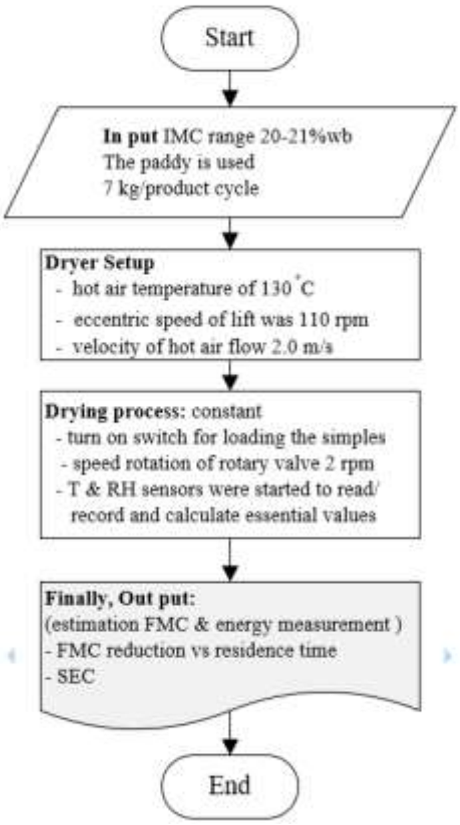

Figure 3 The experimental flow chart

Before drying operation, the hot air flows through air distributor plate from hot air chamber to the drying chamber as shown in Fig. 4., the thermal energy used for an entire test is calculated by reducing the mass of liquefied petroleum gas (LPG) in a unit (kg), which is measured by a digital scale with its accuracy of 0.01 g.

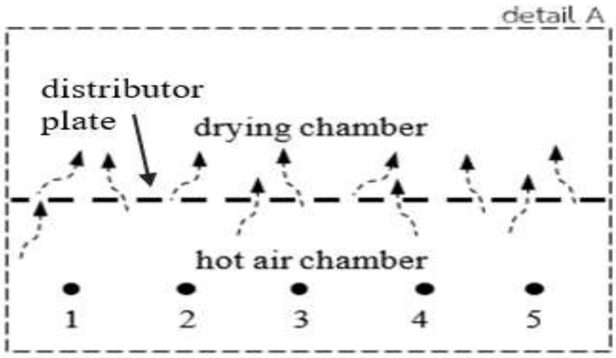

Figure 4 Position of air temperature measuring point

4. RESULTS

4.1. Air Properties

As the experimental setup, DHT22 and EE31 are used to read the temperature (T) and relative humidity (RH) values. T and RH of ambient air were measured by the DHT22 sensor as shown in Fig. 5. The upper lines show the T of ambient air and the lower line shows the RH of ambient air that was consistent throughout the experiment. The T has fluctuated between 27.7 °C, 30.4 °C with an average temperature value of 29.3 °C, whereas the RH has fluctuated between 46.2 %, 52.9 % with an average humidity value of 49.2 % as shown in the ambient air column in Table I1. Since the study was conducted in a closed room, the T and RH were slightly increased.

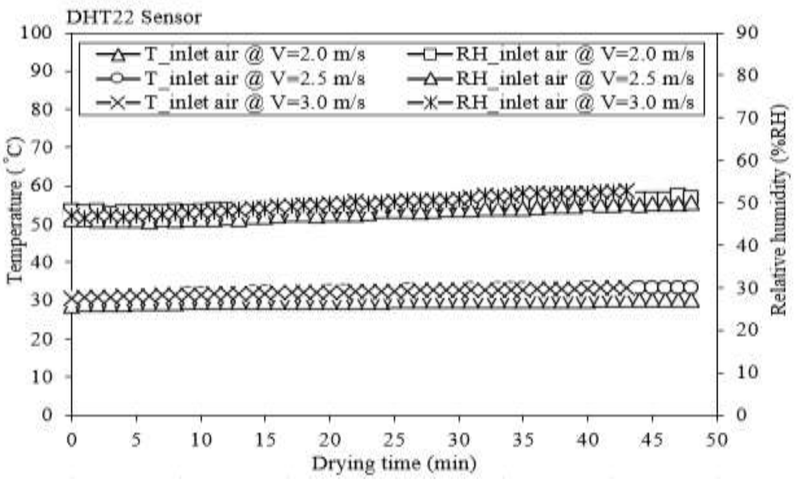

Figure 5 Graph of temperature and humidity of ambient air (inlet) at various velocity of airflow

The T and RH of hot airflow through the drying chamber then flows into the 4-inch pipe diameter at the hot air outlet which was measured by the EE31 sensor. Figure 6(a) shows the plot of the T reduction while drying operation at the hot air outlet. The trend of the T rapidly decreases within 10 minutes from the beginning of drying. After that, the T was slightly increased according to the exhaust velocity that was adjusted at 2.0 m/s, 2.5 m/s, and 3.0 m/s. This also caused T to rise from 45.8 °C to 50.5 °C at exhaust velocity of 2.0 m s^{-1}, 44.1 °C to 51.9 °C at exhaust velocity of 2.5, and 48.9 °C to 57.2 °C at exhaust velocity of 3.0 m s^{-1}, respectively.

Besides, the increasing of the exhaust velocity of hot air of the 3.0 m/s would make the drying times decrease. On the contrary, the exhaust velocity set of 2.0 m/s and 2.5 m/s, the drying time was not noticeably changed. Figure 6(b) shows the plot of the RH with drying time. The trend of RH rapidly increased from the beginning of drying time. After that, the RH was slightly decreased according to the exhaust velocity that was adjusted at 2.0 m/s, 2.5 m/s, and 3.0 m/s. This also caused the RH decreased from 42.4 % to 33.4 % at a hot air velocity of 2.0 m s^{-1}, 46.3 % to 33.4 % at a hot air velocity of 2.5, and 34.8 % to 24.7 % at a hot air velocity of 3.0 m/s, respectively.

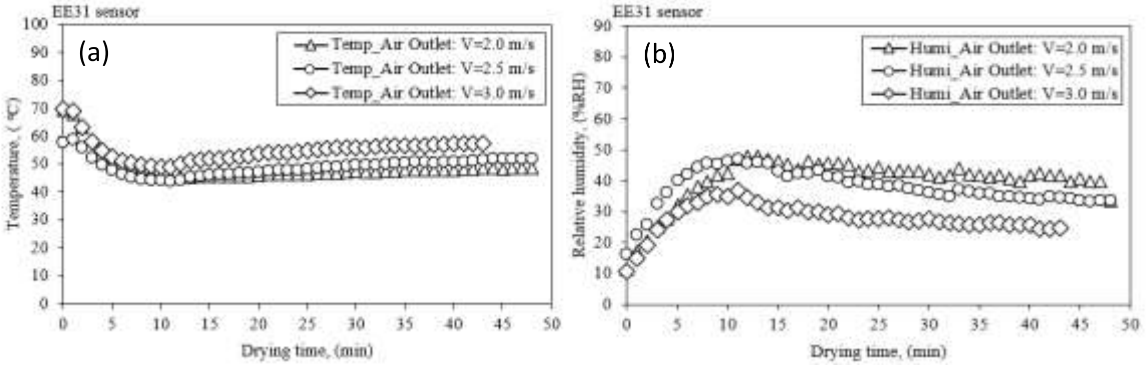

Figure 6 (a) Graph of the temperature of hot air (outlet) ,and (b) Graph of humidity of hot air (outlet*)*

Moreover, the increase in the velocity of exhaust velocity would be caused the RH higher. As the airflow increases, the heat and mass transfer within the drying chamber would also increase. The data value of air property was shown in the hot air outlet column in Table 1. The property of air ambient and exhaust air was measured by DHT22 and EE31 sensors which could find the humidity ratio by using the psychometric chart in the humidity ratio column in Table I. Since the ambient air was heated by IRB which maintained the hot air temperature 130 °C constantly throughout the experiment period, the average humidity ratio at the outlet of exhaust air was approximately the same.

Table 1 Temperature and humidity measurements on the sensors

Drying condition	**Drying time**	**DHT22 senror**		**EE31 sensor**		**Humidity ratio (ω) (kg water/kg dry air)**		
(m/s)	**(min)**	**T_3 (°C)**	**RH_3 (%)**	**T_4 (°C)**	**RH_4 (%)**	**ω_3**	**ω_4**	**(ω_4 - ω_3)**
V = 2.0 m/s	(begin)	28.8	48.0	69.3	11.3	0.012	0.022	0.010
	10	29.5	48.0	45.8	42.4	0.012	0.027	0.015
	20	29.7	49.0	46.0	45.8	0.013	0.030	0.017
	30	29.9	50.0	47.3	42.0	0.013	0.029	0.016
	40	30.1	51.1	48.0	41.7	0.014	0.030	0.016
	(finish) 48	30.4	51.2	48.4	33.4	0.014	0.024	0.010
V = 2.5 m/s	(begin)	27.6	46.1	57.5	16.1	0.011	0.018	0.007
	10	28.5	46.2	44.1	46.3	0.011	0.027	0.016
	20	29.1	47.4	47.2	41.5	0.012	0.029	0.017
	30	29.6	48.3	49.6	36.2	0.013	0.028	0.016
	40	29.9	49.8	50.7	34.1	0.013	0.028	0.015
	(finish) 48	30.1	50.0	51.9	33.4	0.013	0.029	0.016
V = 3.0 m/s	(begin)	27.6	47.0	69.6	10.6	0.011	0.021	0.010
	10	28.4	47.8	48.9	34.8	0.012	0.026	0.014
	20	29.0	49.7	53.5	28.9	0.012	0.027	0.015
	30	29.5	50.8	55.8	27.6	0.013	0.029	0.016
	40	29.8	52.3	57.3	25.6	0.014	0.029	0.015
	(finish) 43	29.9	52.9	57.2	24.7	0.014	0.028	0.014

4.2. Moisture Content Reduction

The figure 7(a) is represented the moisture reducing of a cross-flow dryer by plotting the percentage of the paddy moisture content versus drying time. Drying time or residence time in the dryer is an essential parameter to estimate the performance of paddy dryers [14] because the dryer would take more energy consumption. The moisture reduced from the range of initial MC of 20.6-20.7 % wet basis (wb) (IMC was measured by a moisture detector as shown in fig9.) until the final MC of 15.3 %, 13.9% and 13.8 % at the exhaust velocity of 2.0 m/s, 2.5 m/s, and 3.0 m/s, respectively. When the exhaust velocity 2.0 m/s and 2.5 m/s (FMC was displayed as shown in fig8., which was calculated by using (1)), it took 48 minutes for the drying process. On the contrary, at the exhaust velocity, 3.0 m/s it took 43 minutes for the drying process. Increasing the exhaust velocity would also increase the flow rate through the paddy layer in the drying chamber. In addition, from Figure 7(a), it is possible to estimate the MC of the measurement as previously results.

Figure 9 and Table 2 show the IMC and FMC by using a moisture detector, indicating the beginning and finish the drying process MC. The deviation of the MC detector of IMC is recorded to be ± 0.8, ±0.5, and ±0.7 and FMC is recorded to be ± 0.5, ±0.6, and ±0.4 at the exhaust velocity of 2.0 m/s, 2.5 m/s, and 3.0 m/s, respectively.

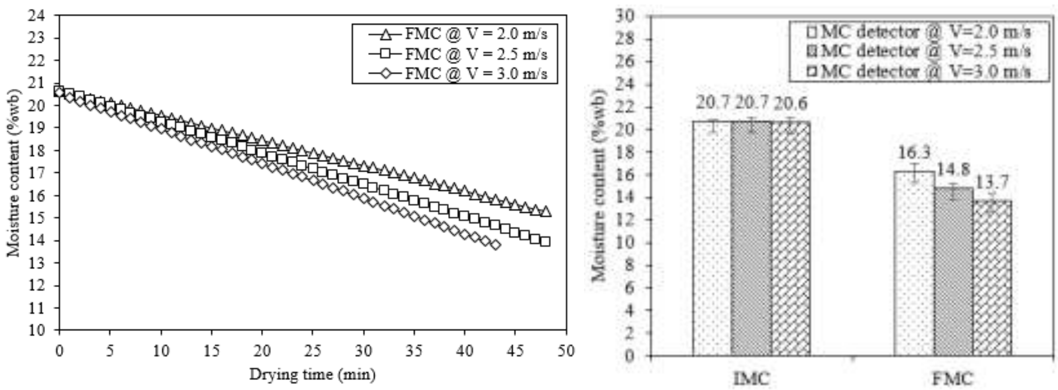

Figure 7 (a) Reduction of paddy moisture content, and (b) The paddy moisture content at the beginning and finish

Table 2 The final moisture content comparisons

drying condition		final moisture content (FMC)				% error
hot air temp.	velocity air flow	grain detector		estimated		
		avg.	dev.	avg.	dev.	
130	2.0	16.3	0.8	15.3	0.5	6.1
	2.5	14.8	0.5	13.9	0.6	6.1
	3.0	13.7	0.7	13.8	0.4	0.7
average error						4.3

When the comparison between the estimation was calculated by using eq. (1) and was measured by a moisture detector. As a result, it found that the trend of moisture is reduced in the same direction, and the user could be considered the moisture content and energy consumption further.

Table 3 The specific energy consumption (SEC)

Drying condition	Avg. mass of water removed	Energy consumption		SEC
		E-thermal	E-electrical	
hot-air velocity (m/s)	(kg)	MJ	MJ	MJ/kg
2.0	0.42	2.42	0.54	6.99
2.5	0.57	2.80	0.54	5.85
3.0	0.55	2.98	0.50	6.34

4.3. Specific Energy Consumption: SEC

Table 3 shows the SEC in the drying operation per cycle product when the experiment and the velocity of the hot air outlet or exhaust velocity were set. After the drying process was done on the condition of 2.0 m/s of exhaust velocity or hot-air velocity, 0.42 kg water removed, while the thermal energy and electrical energy were used of 2.42 MJ and 0.54 MJ respectively. When the exhaust velocity was 2.5 m/s, the mass of water removed of 0.57 kg, and 2.80 MJ the thermal energy and 0.54 MJ of electrical energy were consumed. And the exhaust velocity was 3.0 m/s; the mass of water removed from 0.55 kg, and 2.98 MJ of the thermal energy, and 0.50 MJ of electrical energy were consumed. According to the data, the energy consumption and the mass of water removed were calculated as SEC that the exhaust velocity of 2.0 m/s, 2.5 m/s and 3.0 m/s would be 6.99, 5.85 and 6.34, respectively.

However, the least SEC was used when the exhaust velocity was 2.5 m/s. Therefore, less exhaust velocity would be insufficient to the mass flow rate of the hot air which affects the mass of water removed. On the contrary, more exhaust velocity would be sufficient to the mass flow rate of hot air although it would cause more heat loss.

5. DISCUSSION

In this paper, the cross-flow dryer was developed in part of heat generating by using an infrared gas burner (IRB) which studied and tested the moisture reduction and energy consumption which would compare with the same working principle type of dryer. Pongsatit Sonpakdee, 2016 and Yapha et al., 2014 were tested the drying operation of a cross-flow dryer as well, and the dryer was called “a Must Flow Dryer”.

Our results presented in aspects of the moisture was reduced during dryer operation when compared with the ability of the moisture reduction to the appropriate level for sold and stored, the results are similar. In terms of the specific energy consumption (SEC), it could not compare clearly. Since the previous research as mention has not studied the SEC in drying operation that a typical commercial dryer SEC values between 3.7 to 8.7 MJ/kg water removed was reported [15], [10].

6. CONCLUSIONS

From the results of the continuous cross-flow paddy dryer application by using IRB experiment, it can be concluded as follows:

- DHT22 and EE31 sensors can read and record the data of temperature (T) and relative humidity (RH) at the ambient air and the exhaust air and the estimation of the moisture content was successfully carried out.
- Infrared gas burner (IRB) could provide sufficient heat air for the drying process.
- The less specific energy consumption (SEC) of 5.85 MJ/kg could reduce the moisture content (MC) from the initial MC of 20.6 % wet basis to the final MC of 14.8% wet basis within 48 minutes.

Therefore, the dryer application using IRB and installation the sensors features easy-to-obtain hardware and open-source Arduino software, making it accessible to use for the development of the systems more precision of their design and use, this improvement makes the dryer more suitable for each expected application, such as the monitoring of the dryer process, smart dryer, smart farm as well. However, subsequent improvements are subject to further research.

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