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Drying Performance Evaluation of a Commercial Batch Mixed-Flow Seed Drying System

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Information on the performance of commercial grain dryers in Malaysia especially for paddy seed drying in terms of published reports are still lacking. This study was therefore undertaken to evaluate the performance of a commercial, mixed-flow, batch type grain dryer at *Loji Pemprosesan Benih Padi Sah (A) Telok Chengai*, Kedah. Five type of performance indices under three different fan configurations were studied, namely drying efficiency (DE), heat utilization factor (HUF), effective heat efficiency (EHE), coefficient of performance (COP) and specific energy consumption (SEC). From the results obtained, the average values for the performance indices for the seed dryer measured as DE. HUF, EHE and COP were found to range between 0.521 to 0.596, 0.695 to 0.708, 0.477 to 0.515 and 0.292 to 0.305 respectively. Depending on the fan's configurations, the SEC values registered by the dryer ranged between 5.677 to 6.896 MJ/kg water removed. This study also showed that different performance indices are suited for different conditions of the drying. As for an instance, HUF, EHE and COP are more suited for in-field drying evaluation while DE is more suited for a comprehensive evaluation of a dryer. SEC, on the other hand provides the most comprehensible results among the methods.

Keywords: mixed-flow seed dryer; performance indices; drying efficiency; heat utilization factor; effective heat efficiency; coefficient of performance; specific energy consumption

I. INTRODUCTION

Quality seeds in the form of certified seeds play an important role in increasing rice yield. (Mat, *et al*., 2000). The seeds should possess the important inherent quality attributes of high germination rate and vigour that must be preserved effectively during processing for farmers' benefits. The most effective and economical way of preserving seed quality is through drying.

Syarikat Perniagaan Peladang MADA Sdn. Bhd. (MADACorp), a subsidiary of the Muda Agricultural Development Authority (MADA) operates a commercial seed processing plant, the *Loji Pemprosesan Benih Padi Sah at Telok Chengai*, Kedah to supply certified seeds to farmers within the MUDA area and its vicinity. Seed integrity is one of the ultimate goals of the processing plant. However lately, most of the 13 units of batch dryers of the plant, having a holding capacity of 130 tonnes, showed a decline in their performance efficiency. The average drying time for the majority of the dryer has risen steadily from 20h per batch to approximately 35h per batch and the rate of certification has drop to an average of 91% as compared to the earlier batches of about 97%. The increased in drying time have caused the production cost of the paddy seeds to increase by 39%, from RM 200/tonne to RM 278/tonne. At the same time, there was also growing concerns among the farmers on the unevenness in the germination of the paddy seeds. Being a commercial entity that accounted for approximately 40% of the total annual income of MADACorp, a dip in the overall efficiency in the drying plant can have a significant impact on the overall profitability. Considering a plant of almost 40 years in operation, a comprehensive review of the drying system and the determination of its performance level must therefore

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*Corresponding author's e-mail: zaharan@mada.gov.my be carried out to determine its efficiency and to identify potential opportunities for performance enhancement in terms of energy and cost savings. This paper form the first component of the evaluation exercise written solely to establish the performance levels of the dryers using different commonly used performance indices such as drying efficiency (DE), heat utilization factor (HUF), effective heat efficiency (EHE), coefficient of performance (COP) and specific energy consumption (SEC).

II. MATERIALS AND METHODS

A. *Seed Dryer System*

The experiments were conducted *using one of the commercial seed dryers available at the Loji Pemprosesan Benih Padi Sah (A) Telok Chengai*. The seed dryer used was a mixed-flow batch type having a holding capacity of 15 tonnes. The cross-sectional area of the dryer was 3.65 m x 2.55 m and the height of the dryer is 7.90 m. The dryer was connected to an 11.0 kW, 15.0 HP backward-curved centrifugal blower fan. The atmospheric air was heated through the use of a direct diesel-fired burner with a burning capacity of 320,000 BTU or 80,000 kcal.

B. *Preparation of Seed Samples for Drying Trials*

Freshly harvested paddy seeds of “MR 220 CL2” and “Siraj 297” varieties were collected from MADA Corp’s seed growers’ fields within the states of Kedah and Perlis during the harvesting of the second season of 2017. The initial moisture content (MC) of the freshly harvested paddy seeds varied between 24.4 to 16.9%. The MC was measured as part of the normal production procedure according to the approved Standard Operating Procedure (SOP) by MADA Corp.

C. *Measurement of Temperature and Relative Humidity of Air*

The ambient air temperature and relative humidity (RH) were measured using a temperature and RH data logger (TEN 1720) and recorded at hourly interval. The heated and exhaust air temperatures and RH were also measured hourly at five different levels using a data logger thermal hygrometer (RIX 670).

D. *Measurement of Air Flow Properties*

The air parameters such as velocity, volumetric flow rate and its pressure components were measured using a pitot tube anemometer/differential manometer (CEM 0001). The measurement was carried out using log-Tchebycheff for a transverse circular duct method. The readings were recorded at a specified time interval at 10 designated points and the average values were calculated. For the heated air, data was collected at the inlet point while for the exhaust air data was taken at outlet. The pitot-tube anemometer/differential manometer was calibrated before use.

E. *Measurement of Electrical Energy*

The electrical energy consumption of the blower fan was calculated from a direct reading of the average three-phase voltage and current used during a drying experiment. On the other hand, the electrical power consumption for the burner was taken from the motor rated power.

The formula used was as recommended by Billiris and Siebenmorgen (2014).

$$E_{elec.} = E_f + E_b \qquad (1)$$

where,

$E_{elec.}$ = total electrical energy (kJ)

E_f = electrical energy consumed by fan (kJ)

E_b = electrical energy consumed by burner (kJ)

$$E_f = \left(\sqrt{3VIcos\emptyset}\right) \times t \qquad (2)$$

where,

V = line voltage (V)

I = line current (A)

$Cos\ \emptyset$ = power factor

t = operating time (h)

$$E_b = P_b \times t \tag{3}$$

where,

P_b = burner rated power (W)
t = operating time (h)

F. *Measurement of Thermal Energy*

The thermal energy consumption of the dryer was calculated as product of the rate of fuel consumption, its calorimetric value and the time required to complete the drying process. The calorific or calorimetric value (LHV) for the diesel was 42.6 GJ/metric ton. The formula used was as recommended by Ibrahim *et al.* (2015).

$$E_{th} = F.C \times C_{diesel} \times t \tag{4}$$

where,

E_{th} = total thermal energy (kJ)
$F.C$ = diesel fuel consumption (tonne)
C_{diesel} = calorific or calorimetric value of diesel (MJ/kg)
t = operating time (h)

G. *Dryer Performance Evaluation*

The performance of a drying system can be represented in many forms. Some are suitable for analysing the overall energy consumption in drying, while others are used to compare different dryer types such as the drying capacity and drying rate and others are better suited for analysing the energy utilization across the drying process (Jokiniemi, 2016). Drying efficiency is a general term defined as the ratio of its useful outputs to its supplied inputs. Its outputs and inputs usually in the form of power or energy (Beigi, 2016; Bern, and Hurburgh, 2002). The analysis of DE involved the utilization of information derived from psychrometric chart to establish the ambient, drying and exhaust air properties. The evaporated moisture (useful output) was converted into energy equivalent units, defined by the product of drying rate and the air's latent heat of vaporization. The power to the fan and burner were used as the required inputs in this drying system as described by Bern and Hurburgh (2002).

$$DE = E_d/(E_f + E_b) \tag{5}$$

where,

E_d = drying power output (kJ/h)
E_f = input power to fan (kJ/h)
E_b= input power to burner (kJ/h)

$$E_d = 60QL(w_e - w_o)/v_o \tag{6}$$

where,

Q = volumetric air flow rate (m^3/min)
L = latent heat of evaporation (kJ/kg)
w_e= absolute humidity of exhaust air (g moisture/kg dry air)
w_o = absolute humidity of ambient air (g moisture/kg dry air)
v_o= specific volume of air entering fan (m^3/kg dry air)

$$E_b = 60Q\,(h_a - h_o)/v_o \tag{7}$$

where,

Q = volumetric air flow rate (m^3/min)
h_a = enthalpy of heated air (kJ/kg dry air)
h_o= enthalpy of ambient air (kJ/kg dry air)
v_o = specific volume of air entering fan (m^3/kg dry air)

$$E_f = 3.6Q/Q_w \tag{8}$$

where,

Q = volumetric air flow rate (m^3/min)
Q_w = air flow efficiency (m^3/min/W)

Specific Energy Consumption (SEC) describes the total energy efficiency in the drying process. It refers to the relation between the supplied energy and mass of evaporated water. SEC was calculated based on the diesel fuel consumed and the electricity used through the drying process. The amount of moisture evaporated (m_w) was obtained from the dynamics of MC of the sample of paddy seeds determined at specific intervals. The final values, representing the total amount of energy used to reduce the freshly harvest initial MC to its final MC of about 14%, represented the actual level of SEC. The formula for SEC used is:

$$SEC = \Sigma(E_{th} + E_{elec.})/m_w \qquad (9)$$

where,

E_{th}= total thermal energy (kJ)
E_{elec}= total electrical energy (kJ)
m_w= amount of water removed (kg)

On the other hand, the evaluation for drying performance indices such as Heat Utilization Factor (HUF), Effective Heat Efficiency (EHE) and Coefficient of Performance (COP) were calculated using formula as reported by Chakraverty and Singh (2014).

$$HUF = (T_{heated} - T_{exhaust})/(T_{heated} - T_{ambient}) \qquad (10)$$

$$EHE = (T_{heated} - T_{exhaust})/(T_{heated} - T_{heated(wet-bulb)}) \qquad (11)$$

$$COP = (T_{exhaust} - T_{ambient})/(T_{heated} - T_{ambient}) \qquad (12)$$

H. *Drying Experiment*

The drying experiments were conducted at three different fan configurations, namely the full speed (50 Hz), medium speed (45 Hz) and low speed (40 Hz). Temperature and RH of ambient, heated and exhaust air were taken 1 hour after the start of the drying process - assuming the drying system has achieved its steady state. The fan's drying air characteristics were also taken 1 hour after the start of the drying experiment. The MC of the paddy seed was taken at 2 locations, namely at the bottom and the top of the dryer and measured using a calibrated moisture meter (SS-6). The drying process was stopped when the average MC of the paddy seeds has reached below 14%.

III. RESULTS AND DISCUSSION

A. *Air Properties*

Tables 1 and 2 show the record and the analysis of the ambient, heated and exhaust air properties based on the instrument readings and values extracted from the psychrometric chart. They were expressed in terms of average, maximum and minimum values.

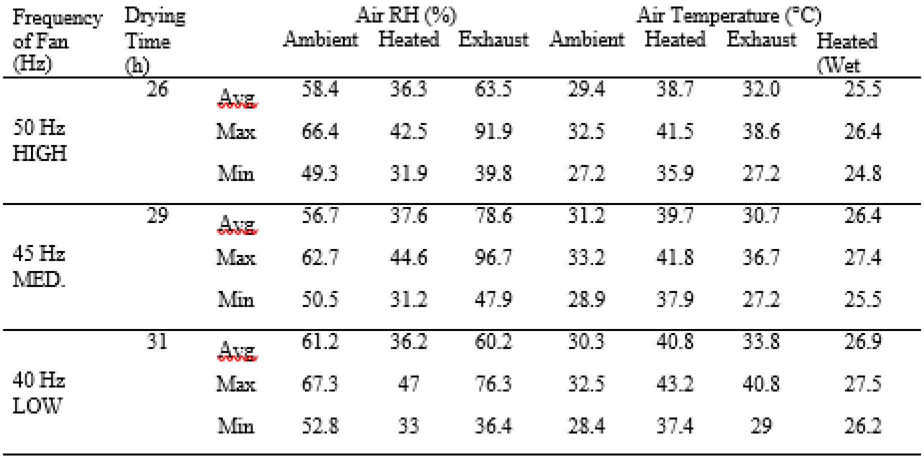
B. *Categorization of Performance Indices*

In the current study, the performance efficiency indices were categorized into three broad terms to reflect the scope of possible modification that could be recommended in order to optimize the drying system performances in the future. The categories are air-properties-based efficiency, temperature-based efficiency and overall energy efficiency. DE falls into the air-properties-based efficiency; HUF, EHE and COP are categorized as temperature-based efficiency while SEC is associated as overall energy efficiency. Table 3 shows the analysis of the performance indices for the drying system.

C. *Air Properties-Based Efficiency*

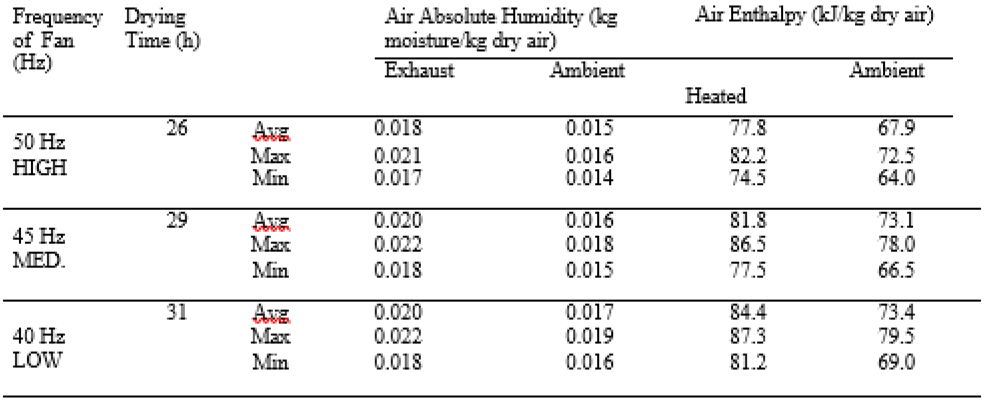
One of the air properties-based efficiency index measured was DE. It is defined as the ratio of the product of the evaporation rate and the latent heat to the supplied energy, represented by the differences in the enthalpy of the drying air and also from the energy of the blower fan, represented by the fan efficiency (Q/Q_w). It was noted that, in all three experiments, the average DE of the dryer system was found to be between 52.1 to 59.6%. From Figure 1, 2 and 3, three distinct outcomes were detected when the speed of the fan was reduced from HIGH to LOW; the first reaction was the decrease in the DE from 54.6 to 52.1%, the second being presence of an increased constant rate period (CRP) while the third was the

Table1. RH and temperature of the ambient, heated and exhaust air



Frequency of Fan (Hz)	Drying Time (h)		Air RH (%) Ambient	Heated	Exhaust	Air Temperature (°C) Ambient	Heated	Exhaust	Heated (Wet
50 Hz HIGH	26	Avg	58.4	36.3	63.5	29.4	38.7	32.0	25.5
		Max	66.4	42.5	91.9	32.5	41.5	38.6	26.4
		Min	49.3	31.9	39.8	27.2	35.9	27.2	24.8
45 Hz MED.	29	Avg	56.7	37.6	78.6	31.2	39.7	30.7	26.4
		Max	62.7	44.6	96.7	33.2	41.8	36.7	27.4
		Min	50.5	31.2	47.9	28.9	37.9	27.2	25.5
40 Hz LOW	31	Avg	61.2	36.2	60.2	30.3	40.8	33.8	26.9
		Max	67.3	47	76.3	32.5	43.2	40.8	27.5
		Min	52.8	33	36.4	28.4	37.4	29	26.2

Table2. Absolute humidity and enthalpy of the ambient, heated and exhaust air



Frequency of Fan (Hz)	Drying Time (h)		Air Absolute Humidity (kg moisture/kg dry air) Exhaust	Ambient	Air Enthalpy (kJ/kg dry air) Heated	Ambient
50 Hz HIGH	26	Avg	0.018	0.015	77.8	67.9
		Max	0.021	0.016	82.2	72.5
		Min	0.017	0.014	74.5	64.0
45 Hz MED.	29	Avg	0.020	0.016	81.8	73.1
		Max	0.022	0.018	86.5	78.0
		Min	0.018	0.015	77.5	66.5
40 Hz LOW	31	Avg	0.020	0.017	84.4	73.4
		Max	0.022	0.019	87.3	79.5
		Min	0.018	0.016	81.2	69.0

extension of drying period from 26 to 31h as the fan speed was reduced from HIGH to LOW. All the three outcomes were believed to have caused by the decrease in the static pressure and the volume of air (volumetric flow rate) of the drying air as the speed of the fan was reduced. The first outcome could be traced in the reduction of drying rates under the different fan configurations; where drying rates were 53.50, 52.80 and 45.10 kg moisture/h at HIGH, MED and LOW fan speeds respectively. Higher DE was recorded during the MED fan speed which was believed to have caused by the low static pressure of 39.06 mm H_2O (383 Pa) couples with a relatively higher volumetric flow rate of 8,569 cfm (14,559 m^3/h). This low static pressure cum high volumetric flow rate caused the slow movement of the wetted air to the exhaust. It was also noted that during the MED fan speed, DE values reached unity (1.0). This shows that at this particular stage of drying, more energy is available in the drying capabilities of the system than it is required, as explained by Bern and Hurburgh (2002). The second outcome showed that by decreasing the speed of the fan, generally the dryer system became less efficient in its drying process due to the existence of CRP in the drying rate curve as indicated in Figure 2 and 3. The presence of CRP in the drying rate caused the drying period to be extended and this extension was directly proportional to length of the CRP. From the experimental data, it can be concluded that DE represents how well energy is utilized for heating and evaporating the moisture. As DE analysis capitalizes on the psychrometric conditions of the ambient, heated and exhaust air, the performance efficiency of the drying system is more thoroughly represented compared to other indices. Based on DE, the scope of any improvements on a dryer could therefore be limited only in exploiting the air

Table 3. Grain Drying Performance Indices

Frequency of Fan (Hz)	Drying Time (h)	DE	HUF	COP	EHE	SEC (kJ/kg water removed)
50 Hz HIGH	1	0.994	1.343	(0.343)	0.887	(2,834)
	4	0.893	1.132	(0.132)	0.863	-
	7	0.668	0.937	0.063	0.712	-
	10	0.535	0.711	0.289	0.539	9,732
	13	0.382	0.437	0.563	0.342	6,829
	16	0.311	0.400	0.600	0.276	6,175
	18	0.302	0.280	0.720	0.188	5,441
	22	0.285	0.322	0.678	0.192	5,431
	26					5,677
Avg.		0.546	0.695	0.305	0.500	
Max		0.994	1.343	0.720	0.887	
Min		0.285	0.280	(0.343)	0.188	
45 Hz MED.	1	1.014	1.440	(0.440)	0.844	(5,117)
	4	1.015	1.309	(0.309)	0.977	-
	7	0.608	0.788	0.212	0.593	-
	10	0.577	0.690	0.310	0.549	18,479
	13	0.529	0.429	0.571	0.229	10,615
	16	0.473	0.608	0.392	0.336	8,053
	19	0.357	0.265	0.735	0.174	6,950
	25	0.192	0.128	0.872	0.116	6,468
	29					6,896
Avg.		0.596	0.707	0.293	0.477	
Max		1.015	1.440	0.872	0.977	
Min		0.192	0.128	(0.440)	0.116	
40 Hz LOW	1	0.689	1.250	(0.250)	0.822	(20,573)
	4	0.799	1.043	(0.043)	0.658	-
	7	0.667	0.954	0.046	0.614	-
	10	0.688	0.903	0.097	0.721	7,513
	13	0.618	0.776	0.224	0.634	6,787
	16	0.462	0.569	0.431	0.471	6,574
	19	0.355	0.417	0.583	0.352	6,355
	21	0.246	0.238	0.762	0.208	6,389
	29	0.167	0.224	0.776	0.153	7,028
	31					6,776
Avg.		0.521	0.708	0.292	0.515	
Max		0.799	1.250	0.776	0.822	
Min		0.167	0.224	(0.250)	0.153	

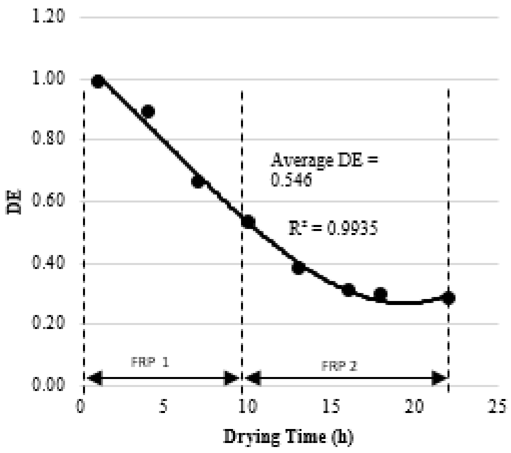


Figure 1. DE at High Fan Speed

psychrometric parameters. As such, the possible improvement available to enhance the efficiency are namely through improving the dryer insulation property, reducing heat losses, recycling of exhaust air or installing heat recovery or changing operating parameters. As for an instance, dryer insulation has shown a 3-year savings of 16% to 21% as compared to uninsulated (Jokiniemi and Ahokas, 2014).

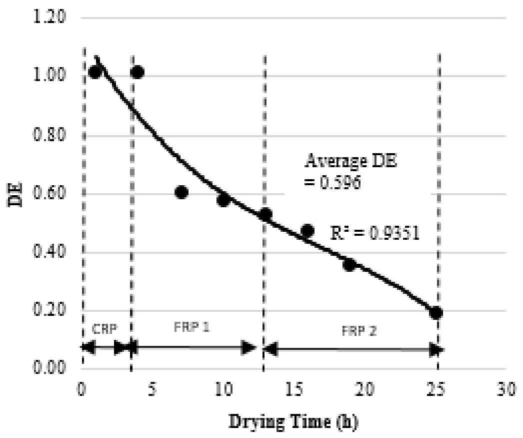


Figure 2. DE at Medium Fan Speed

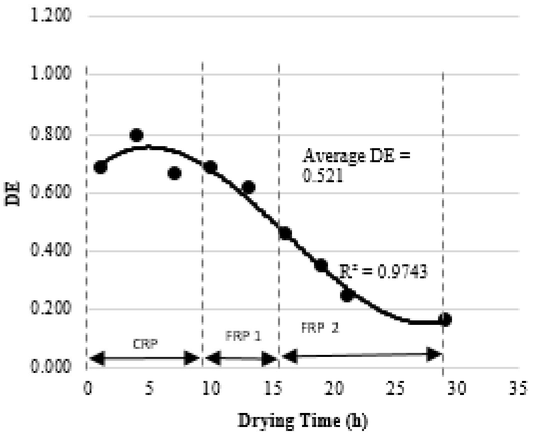


Figure 3. DE at Low Fan Speed

D. Temperature-Based Efficiency

The temperature-based performance indices are represented by HUF, EHE and COP which indicate how well energy conversion in a system in term of thermal energy. It can be represented by temperature differences between ambient air, heated air and the exhaust air (Strumiłło *et al.*, 2007; Chakraverty and Singh, 2014; Billiris and Siebenmorgan, 2014). HUF, also known as Sensible Heat Utilization Efficiency (SHUE) is a measure of the degree of the utilization of sensible heat in the drying air manifested by the condition of the ambient air and any heat added to the drying air by the fan as well as heat supplied by the combustion of fuel. HUF can be represented by the ratio of temperature decrease due to cooling of the air during drying to the temperature increase due to heating of the air (Chakraverty and Singh, 2014; Dissanayake, *et al.*, 2015; Jokiniemi, 2016).

Effective Heat Efficiency (EHE) is another commonly used term to describe the drying system performance. EHE can also be viewed as DE as it capitalized on the available heat from the sensible heat used to dry the paddy seeds (Bintoro, 2013). Therefore, by definition EHE always has a smaller value than HUF at any given time. According to Bern and Hurburgh (2002), EHE capitalizes on the spread of wet bulb depression of the drying air; the larger the spread, the greater the evaporation will take place. As shown in Figures 4, 5 and 6, both HUF and EHE values became smaller as the drying process progressed. This is attributed by the increased in the exhaust air temperature during the later stages of drying which was due to the progressive reduction in the loss of moisture of the paddy seeds.

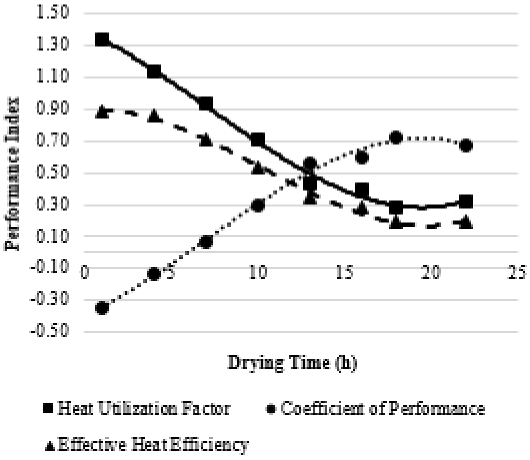


Figure 4. HUF, EHE and COP at High Fan Speed

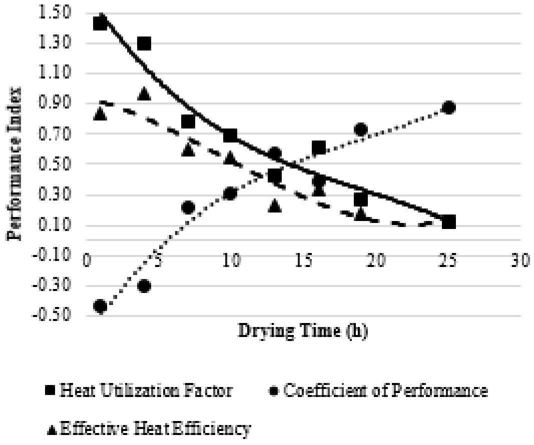


Figure 5. HUF, EHE and COP at Medium Fan Speed

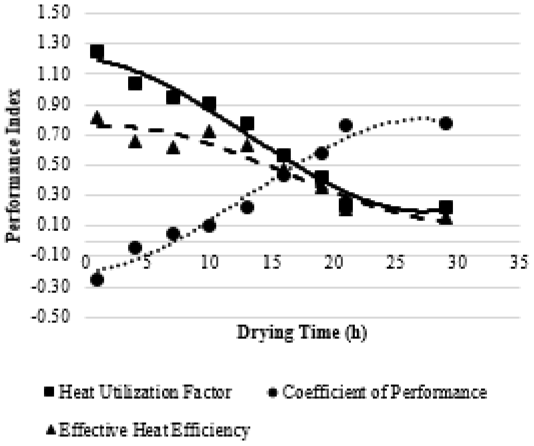


Figure 6. HUF, EHE and COP at Low Fan Speed

The increased in the exhaust air temperature can be viewed as the loss of sensible heat to the exhaust air, indicating that there is a reduction in the heat utilization inside the drying chamber. This situation can also be traced to smaller temperature difference between the drying air and the exhaust air. It was also noted that between 1 to 4h of drying, HUF indexes recorded more than 1.0 for all three fan speeds experiments whilst EHE were maintained below the 1.0 threshold value. This implies that the amount of sensible heat available in the drying system during those periods is more than required to dry the paddy seeds. In term of utilization of effective heat during those periods, the percentage utilization was between 65.8 to 97.7% for the three fan speeds. This condition was also observed by Dissanayake et. al. (2016) and Kallai (2011) in their respective studies. The average HUF for HIGH, MED. and LOW fan speeds were 0.695 (69.5%), 0.707 (70.7%) and 0.708 (70.8%) respectively while the average EHE for HIGH, MED. and LOW fan speeds were 0.500 (50.0%), 0.477 (47.7%) and 0.515 (51.5%), respectively. Cross-referenced between EHE index with DE index revealed that these efficiency readings were consistent, with an average approximated at 50% in efficiency.

Coefficient of performance (COP) is another expression of energy efficiency associated with the drying system performance. COP reflects the ratio of drying capabilities to the available sensible heat. COP focuses on the performance of the dryer system to perform drying activities with respects to its current operating condition; as indicated by the relationship between the amounts of moisture evaporated (represented by the status of the exhaust air temperature) to the unused heat in the dryer system (represented by the status of the ambient air temperature). According to Dissanayake *et al.* (2016), COP normally started with a small value and gradually increased over the drying period; a statement that is in-line with the findings on all of the experiments. During the early stages of the drying process where the exhaust air temperature was very high (signifying that the current drying status is at its optimum level), the COP index showed a low value; signalling the low capabilities of the dryer to perform drying activities based on its current and ambient air status. As the drying progressed, the exhaust air temperature began to increase and so did the COP index. This showed that the dryer capabilities can be further optimized based on its current drying condition. From the experiments conducted, the average COP for HIGH, MED. and LOW fan speeds were between 29.2 to 30.5%. These COP values were very close to that reported by Kallai (2011) of a mixed-flow paddy dryer where the value was at 31.4% (0.314).

E. Overall Energy Efficiency

The most commonly used performance efficiency index is the overall energy consumption efficiency, the specific energy consumption (SEC) (Jokiniemi and Ahokas, 2016; Fayose and Huan, 2016). SEC refers to the relationship between the supplied energy, mainly fuel and electrical energy and the mass of evaporated water. In general term it is the ratio of the total supplied energy to the mass of evaporated water and it is expressed in kilojoules (kJ) of energy per kilogram (kg) of water evaporated. SEC considers the energy utilization in drying as "black box", as it describes very little about the properties of the process. However, SEC serves a very useful index in energy analysis as well as in comparison of different dryers and dryer types, provided that the properties of the dried material and the ambient conditions remain equal (Jokiniemi, 2016). Results from the experiment indicated that the average SEC value of the mixed-flow LSU type of dryer at *Loji Pemprosesan Benih Padi Sah (A) Telok Chengai* were between 5.677 to 6.896 MJ/kg of water removed to dry paddy seed to 14% moisture content (Figure 7).

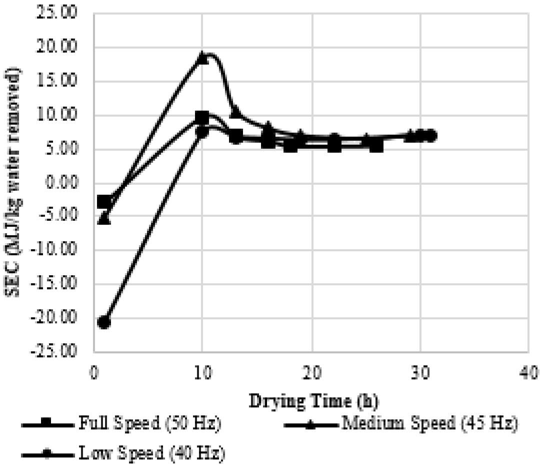


Figure 7. SEC for all three fan speeds

The SEC values vary within the range of a typical commercial dryer between 4.0 and 8.0 MJ per kg of water removed, as reported by Peltola (1985), Nellist (1987) and

Suomi *et al.* (2003). However, the SEC value were recorded to be twice the amount of the same mixed flow grain dryer type as reported by Brinker and Johnson (2010), at 2.577 MJ/kg of water removed. From the analysis, it was also noted that thermal energy represents approximately 90% of the total energy used whilst electrical energy makes up the remaining 10%. During the earlier stages of drying process, negative SEC value was recorded as a result of additional moisture detected particularly in the paddy seeds samples at the upper section of the dryer. This addition of moisture was found in every sample taken from every experiment conducted. It may be attributed by the accumulation of evaporated moisture at the topmost of the dryer and its slow release to the atmosphere. The SEC at this stage were recorded to be 2,834.0, 5,117.0 and 20,573.0 kJ/kg water removed for HIGH, MED. and LOW fan speed respectively. It was observed that after 10h of drying, the SECs began to increase until they reached their maximum values of 9,732.0, 18,479.0 and 7,513.0 kJ/kg water removed for three fan speeds. As drying progressed further - at approximately 13 h of drying, a dip in the SEC was also observed in the three fan speeds. This dip corresponded to the decrease in the rate of moisture evaporation as a result of un-wetted surface condition of the paddy seeds and the lower degree of moisture movement from the interior of the seeds to its outer surface, or commonly known as unsaturated surface drying. It was noted in all three fan speeds experiment that after 16h of drying, a slight reduction in the SEC values were observed. For HIGH fan speed, the SEC value reduced slightly by 9.6% from 6,829.0 to 6,175.0 kJ/kg water removed. For MED. fan speed, the reduction was the most apparent among the three fan speeds; with an approximately 24.1%, reduction from 10,615.0 to 8,053.0 kJ/kg water removed. The lowest in reduction was observed in the LOW fan speed where the SEC value dip by only 3.1%, from 6,787.0 to 6,574.0 kJ/kg water removed - from 13 to 16h of drying. As the drying process progressed, the SEC became relatively stable and attained a more consistent value. Beyond the 16 h of drying, the SECs for the HIGH fan speed ranged between 5,441.0 to 5,677.0 kJ/kg water removed, while SECs values for the MED. and LOW fan speeds ranged from 6,950.0 to 6,896.0 kJ/kg water removed and 6,355.0 to 6,776.0 kJ/kg water removed. It can be inferred that continuing the supply of high energy beyond the 16h of drying process would be a waste as its utilization was more or less stagnant. SEC is the most popular method to measure the performance efficiency of a drying system. Its simplicity in analysis coupled with a comprehensible idea of the energy utilization would give researchers, engineers or mill managers a more explicit understanding on the performance and optimization of the drying system.

IV. CONCLUSION

A comprehensible understanding on the performance of the LSU dryer at *Loji Pemprosesan Benih Padi Sah (A) Telok Chengai*, can be provided by SEC as it provides better characterization in dryer performance for meaningful comparison. Its quantifiable value offers a clearer picture on the state of the dryer performance. However, SEC offers limited information on the types of modification that could be exploited to improve the dryer performance. Nevertheless, one possible design improvement that could be exploited to enhance the energy utilization of the dryer system based on SEC analysis, is the use of alternative heating fuel sources. The simplicity in analysis makes the temperature-based efficiency represented by HUF, EHE and COP practical alternative to millers and plant engineers to assess the performance of a drying system on-site as their analysis involves only temperature measurement, which is easily achievable. From the study, it was found that HUF, EHE and COP yielded an almost consistent efficiency values under the three fan speeds – at 70%, 50% and 30% respectively. Based on the three fan speeds tested, it can be inferred that the optimum drying condition can be achieved during the HIGH fan speed configuration as indicated by three indices (HUF, EHE and COP). The air properties-based efficiency as represented by DE is a more complex approach as compared to others as it analyses the psychrometric conditions of the ambient, heated and exhaust air properties. DE however is the more reliable approach and more preferred choice by the dryer designers because it provides clearer options on the possible design improvements that could be introduced to the dryer system. By monitoring the air properties and analysing them using psychrometric chart, specific design improvements involving modifying drying air conditions and drying equipment can be carried out such as the introduction of intermittent drying technique, combination drying and by recycling the exhaust air could be adopted in the future, singly or in combination.

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