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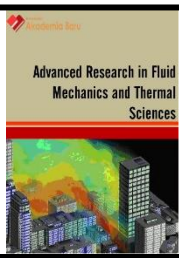

Specific Energy Consumption and Drying Efficiency Analysis of Commercial Mixed-Flow Batch Type Seed Drying System

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ABSTRACT

In Malaysia, numerous extensive researches to gauge the performance and energy requisite of paddy dryers and milling quality of rice were conducted by past researchers. These studies gave valuable insights into paddy drying and its effects under Malaysian climate and promoted further research opportunities, especially in engineering and studies on energy. However, the study of commercial grain dryer's performance for paddy seed drying still lacks in Malaysia. The absence of fundamental information, such as the drying rate, drying efficiency and energy requisite in regard to paddy seeds drying leads to ill-informed judgements and poor decision-making which can be detrimental, especially in regards to the national policy on food security. This study was therefore undertaken to evaluate the performance efficiency of a commercial, mixed-flow, batch type seed dryer at Loji Pemprosesan Benih Padi Sah (A) at Telok Chengai, Kedah. Two types of performance indices were studied, namely drying efficiency (DE) and specific energy consumption (SEC). DE examines the drying process more analytically whilst SEC draws an overall conclusion and provides a better comparison among other commercial dryer performances. It can be inferred that, to analyze the performance of a certain dryer system, it is best to initially use SEC as it gives an overall state of efficiency level. Further analysis by using DE best described the design options available for future modifications. From the obtained results, the overall efficiency of seed dryer showed that SEC was calculated to be 50% lower (5.482 MJ/kg water removed) than the commonly recorded dryer efficiency. Analysis of DE revealed a decreasing trend, following the pattern of seed drying rate curve. The average DE was 0.546.

1. Introduction

Syarikat Perniagaan Peladang MADA Sdn. Bhd. (MADACorp), a subsidiary of the Muda Agricultural Development Authority (MADA) operates a commercial seed processing plant, namely 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. High quality certified paddy seeds which are guaranteed in terms of their physical and genetic

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purity, possess important attributes, such as good germination and vigor, are crucial to increase the production yield by between 5% and 20% [1]. The most effective and economical way of preserving seed quality is through drying. However, lately most of the 13 units of plant batch dryers , which have a total holding capacity of 130 metric tons, showed a decline in their performance efficiency. Being a commercial entity that accounted for approximately 40% of the total annual income of MADACorp., a dip in the overall effeciency 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 structrural integrity must therefore be carried out for immediate improvement.

Drying is defined as the removal of moisture to moisture content (MC) in equilibrium with normal atmospheric air or to such an MC that reduces in activity of molds, enzymatic action and insects [2]. Drying is a highly energy intensive process which involves the simultaneous transfer of both mass and heat. It represents about 55% to 60% of total energy used in the production and processing of rice and other agricultural and food products, followed by harvesting (15%), cultivation (10%), seedling (10%), transportation (6%) and milling (4%) [3,4]. According to USDA, drying accounts approximately 38% of the cost of on-farm production and processing operations, which include drying, fertilizers and chemical applications and harvesting [5]. Kemp suggested that drying accounted between 10% and 20% of total industrial energy use in most developed countries [6].

The performance of a drying system can be represented in many forms. Some are suitable for analyzing the overall energy consumption in drying, while some are used to compare different dryer types, such as the drying capacity and drying rate and others are better suited for analyzing the energy utilization across the drying process [7]. The most common performance efficiency indices are the overall energy consumption efficiency, the specific energy consumption (SEC) [8,9]. SEC refers to the relation between the supplied energy, mainly fuel and electrical, and the mass of evaporated water [7,10]. Expressed in kilojoules (kJ) of energy per kilogram (kg) of water evaporated, SEC is a very useful and practical figure in energy analysis. According to previous studies, inclined bed dryers are more energy efficient as compared to a mixed-flow vertical dryer [11]. Another representation of drying performance is the drying efficiency (DE); a representation. a more “in-depth” analysis of the drying system.

Dryer performance efficiency is a critical step in identifying existing opportunities to improve its performance; and consequently, reduce the energy consumption and ultimately enhance cost savings. This paper forms the first part of the evaluation exercise written solely to establish the performance levels of the dryers by using different commonly used performance indices.

2. Materials and Methods

2.1 Seed Dryer System

The experiments were conducted by using one of the commercial scale Louisiana State University (LSU) batch mixed-flow seed dryer systems (Figure 1), which was available at the Loji Pemprosesan Benih Padi Sah (A) Telok Chengai, Kedah. The seed dryer had a holding capacity of 15 metric tons. The cross-sectional area of the dryer was 3.65 m x 2.55 m and the height of dryer was 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 diesel-fired burner, with a burning capacity of 320,000 BTU or 80,000 kcal.

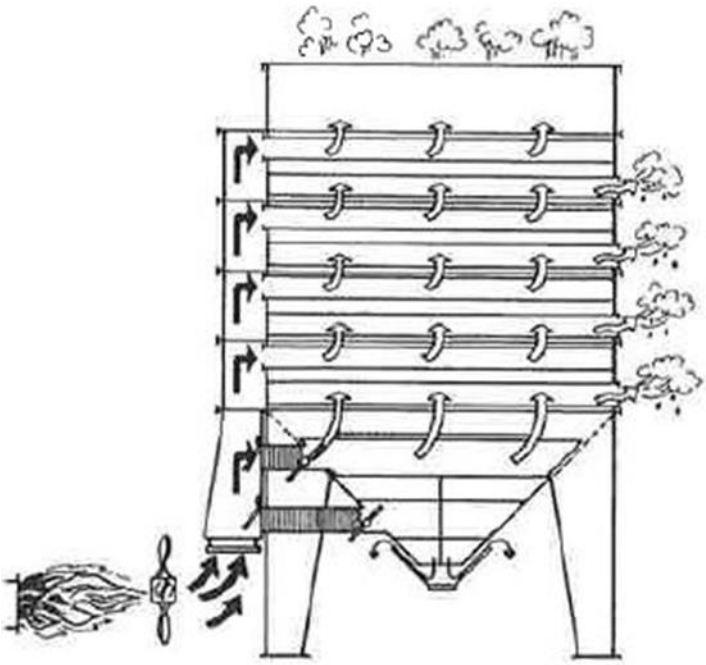

Fig. 1. Schematic Diagram of the LSU Mixed Flow Batch Type dryer at Loji Pemprosesan Benih Padi (A) Telok Chengai

2.2 Preparation of Seed Sample for Drying Trials

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

2.3 Measurement of Temperature and Relative Humidity of Air

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

2.4 Measurement of Air Flow Properties

Air properties, such as its velocity, volumetric flow rate and pressure components were measured by using a pitot tube anemometer/differential manometer (CEM 0001). The measurement was carried out by using log-Tchebycheff for a transverse circular duct method. The readings were recorded at 10 different points and the average value was calculated. These data were collected at the inlet for heated air and outlet for exhausted air and carried out at a specified time interval. The pitot-tube anemometer/differential manometer was calibrated before use.

2.5 Measurement of Electrical Energy and Power

The electrical power consumption was calculated from a direct-read of the average three-phase voltage and current used during a drying experiment for the blower fan. The electrical power consumption for the burner was taken from the motor rated power. The formula used was as recommended by Billiris, Siebenmorgen and Baltz [14].

$$E_{elec.} = E_f + E_b \tag{1}$$

where,
$E_{elec.}$ = total electrical energy
E_f = electrical energy consumed by fan
e_b = electrical energy consumed by burner

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

where,
V = line voltage
I = line current
Cos Ø = power factor
T = operating time (h)

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

where,
P_b = burner rated power
T = operating time (h)

2.6 Measurement of Thermal Energy

The rate of fuel consumption is multiplied with its calorimetric value and the time required for the drying process to complete will give the thermal energy consumption. The calorific or calorimetric value (LHV) for the diesel to be used in this study was 42.6 GJ/metric ton. The formula used was as recommended by Ibrahim *et al.,* [15].

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

where,
E_{th} = total thermal energy
F.C = diesel fuel consumption
C_{diesel} = calorific or calorimetric value of diesel
T = operating time (h)

2.7 Dryer Performance Evaluation

Two types of drying system performance indices were measured in this study, namely DE and SEC. The two indices were evaluated based on the normal operating conditions practised by the seed drying plant. They were calculated at a pre-determined interval and were "mapped-out" throughout the drying process to provide better characterization of the seed dryer performance.

Specific Energy Consumption (SEC) denotes the total energy efficiency in the drying process, which 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 usage through the drying process. The amount of moisture evaporated (m_w) was obtained from the dynamics of moisture content (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 was given by:

$$Specific\ Energy\ Consumption, SEC = \Sigma(E_{th} + E_{elec.})/m_w \tag{5}$$

where,
E_{th} = total thermal energy
E_{elec} = total electrical energy
m_w = amount of water removed

The analysis of DE, on the other hand, involved the utilization of information derived from psychrometric chart to establish the properties of ambient, drying and exhaust air. 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 [12].

$$Drying\ Efficiency = Ed/(Ef + Eh) \tag{6}$$

where,
E_d = drying power output
E_f = input power to fan
E_h = input power to heater (Burner)

$$Drying\ Power\ Output, E_d = 60QL(w_d - w_o)/v_o \tag{7}$$

where,
Q = volumetric air flow rate
L = latent heat of evaporation
w_d = absolute humidity of exhaust air
w_o = absolute humidity of ambient air
v_o = specific volume of air entering fan

$$Input\ Power\ to\ Heater, E_h = 60Q(h_a - h_o)/v_o \tag{8}$$

where,
Q = volumetric air flow rate
h_a = enthalpy of heated air
h_o = enthalpy of ambient air
v_o = specific volume of air entering fan

$$Input\ Power\ to\ Fan, E_f = Q/Q_w \tag{9}$$

where,
Q = volumetric air flow rate
Qw = air flow efficiency

A graph of the drying rate (DR) vs. drying time and its details was presented as an extension of this analysis to provide a further comparison and to establish its close relation with the DE.

$$Drying\ Rate, DR = 60Q(w_d - w_o)/v_o \tag{10}$$

where,
Q = volumetric air flow rate
w_d = absolute humidity of exhaust air
w_o = absolute humidity of ambient air
v_o = specific volume of air entering fan

2.8 Drying Experiment

Temperature and relative humidity (RH) of ambient, drying and exhaust air were taken after 1 h from the start of the drying process, when the drying system was assumed to reach its steady state. The fan characteristics were also taken after 1 h from the start of the drying experiment. The MC of the paddy seed was monitored at two locations, the bottom and the top of the dryer and measured by using a calibrated moisture meter. The drying process was stopped when the average MC of the paddy seeds reached below 14%.

3. Results and Discussion

3.1 Air Properties

Table 1 shows the record and the analysis of the ambient, drying and exhaust air properties, consisting of the temperature (dry and wet bulb), RH, absolute humidity and enthalpy based on the instrument readings and extracted values from the psychrometric chart.

The ambient air condition was quite consistent throughout the drying trial, fluctuating between 27.2 °C to 32.5 °C with an average temperature value of 29.4 °C. The average RH of the ambient air was 58.4% during the course of the drying trial. The drying air was heated by the diesel fired burner to an average value of 38.7 °C or about 9.4 °C above the ambient air temperature, while the average RH of the heated air was 36.3%. The temperature of exhaust air was recorded to be in the range between 27.2 °C and 38.6 °C with an average value of 32.0 °C, while its RH ranged from 91.9%, at the beginning of the drying trial to 38.8%, at the end. The average RH of the exhaust air was 63.5%

Table1
RH, temperature, absolute humidity and enthalpy of the ambient, heated and exhaust air

Frequency of Fan (Hz)	Drying Time (hr)	RH (%)			Temperature (°C)				Absolute Humidity (kg moisture /kg dry air)		Enthalpy (kJ/kg dry air)	
		Amb.	Heated	Exhaust	Amb.	Heated	Exhaust	Dew-Point	Exhaust	Amb.	Heated	Amb.
50 Hz	1	51.5	33.2	91.9	30.6	40.5	27.2	25.5	0.020	0.014	78.0	67.0
Full Speed	4	59.5	34.2	88.1	29.2	39.8	27.8	25.9	0.021	0.015	79.0	68.0
	7	63.7	37.3	74.5	28.9	38.4	29.5	25.9	0.020	0.016	79.0	69.0
	10	60.2	36.3	62.2	27.9	37.6	30.7	24.8	0.018	0.015	74.5	64.0
	13	66.4	42.5	55.7	27.2	35.9	32.1	24.8	0.017	0.015	75.0	66.5
	16	60.8	39.7	51.1	28.5	36.5	33.3	24.9	0.017	0.015	75.0	67.0
	18	55.9	35.5	44.7	30.4	39.7	37.1	25.9	0.017	0.015	79.3	69.5
	22	49.3	31.9	39.8	32.5	41.5	38.6	26.4	0.017	0.016	82.2	72.5
	Avg.	58.4	36.3	63.5	29.4	38.7	32.0	25.5	0.018	0.015	77.8	67.9
	Max	66.4	42.5	91.9	32.5	41.5	38.6	26.4	0.021	0.016	82.2	72.5
	Min	49.3	31.9	39.8	27.2	35.9	27.2	24.8	0.017	0.014	74.5	64.0

Based on the above averages of the recorded ambient, drying and exhaust air conditions, the stages of the air conditions can be mapped on a psychrometric chart. Figure 2 is the typical graphical representation of the three stages of the air conditions superimposed on the chart. Point 1, Point 2 and Point 3 are the three stages of the average air conditions, namely the ambient, heated and exhaust air, measured during the drying process. In a drying process, enough heat or energy must be supplied to evaporate the moisture. This minimum energy is called the latent heat of evaporation and it is approximately 2,257 kJ/kg of water. The optimization of the drying capabilities of the air was achieved during the first 7 h of the drying process, where the exhaust air temperature reached near dew-point temperature (Table 1). As the exhaust air began to exit at higher temperature, the existence of sensible heat became more apparent as compared to the early stages of drying. Such sensible heat build-up is a form of heat loss to the system as the heat is not solely used to evaporate the moisture.

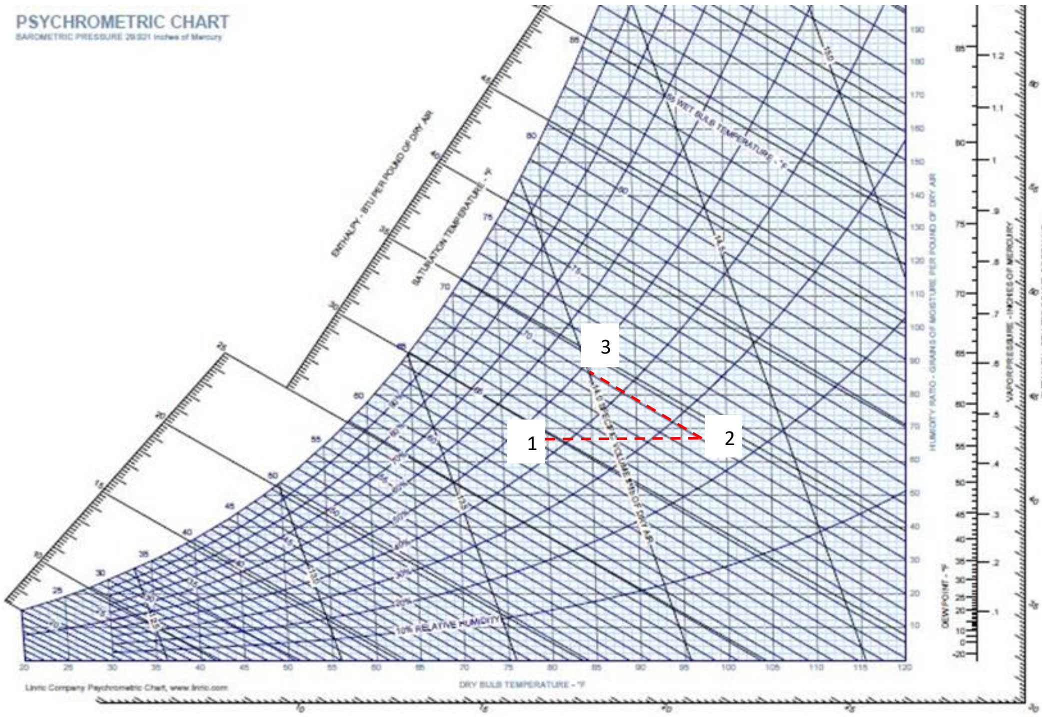

Fig. 2. The three stages of drying air conditions superimposed on psychrometric chart

Figure 3 shows the plot of drying rate (kg moisture removed per h) versus drying time. The trend in the relations typifies the common characteristic of a drying process for paddy, which can be explained as to consist of only one type of period; the falling rate period (FRP). This FRP can be further broken down into two distinct stages; FRP 1 and FRP 2. Based on the MC rate of change pattern of per unit time, it can be deduced that the FRP 1 started from as early as the initial drying until 10 h of drying. This stage registered the highest drying rate of 103.47 kg moisture/h. Beyond 10 h of drying, the drying process indicated that it was in FRP 2. FRP 2 began when the partial pressure of water throughout the material was below the saturation level and moisture transferred was mostly driven by the moisture from the interior of the seed. The drying rate in this period was extremely slow as evidenced by the 16 h of drying completion duration. FRP 2 represented almost 60% of the total drying period. The average drying rate was recorded at 53.5 kg moisture/h.

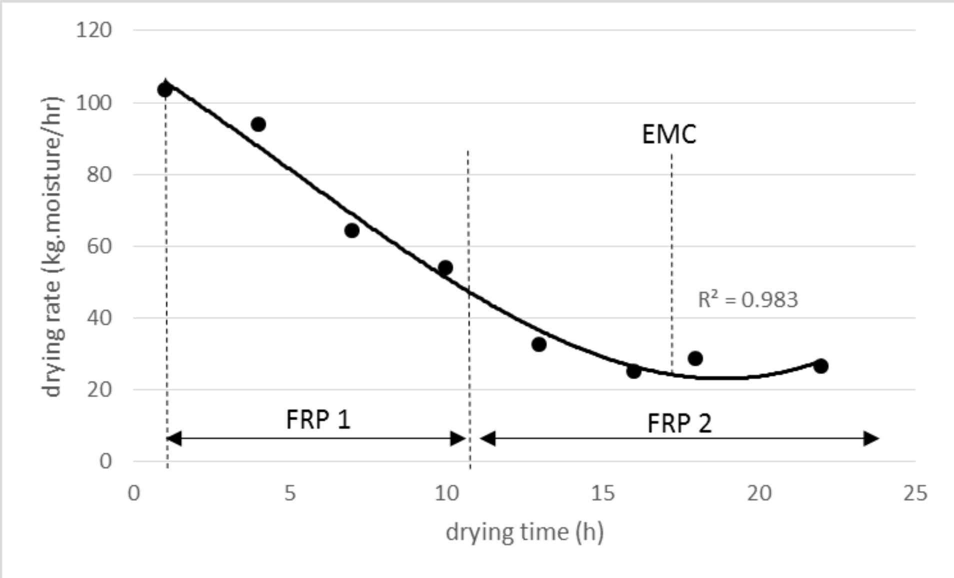

Fig. 3. The relationship between the drying rate and drying time

3.2 Drying Efficiency (DE)

DE 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).

Figure 4 depicts the graphical representation of the dryer system DE across the drying process. From the DE curve, it is evident that its drying process observed the same characteristics of a typical drying rate curve for agricultural products, whereby only the FRPs were present (Figure 3).

After 1h of drying, DE was measured to be at the highest value of 0.994, corresponding to the high utilization of energy that attributed to the presence of high level of humidity in the exhaust air from the evaporation of moisture in the seed. The DE value thereafter decreased gradually until it reached 10 h of drying, before it started to exhibit FRP 2 characteristics, where the rate of decrease was slow.

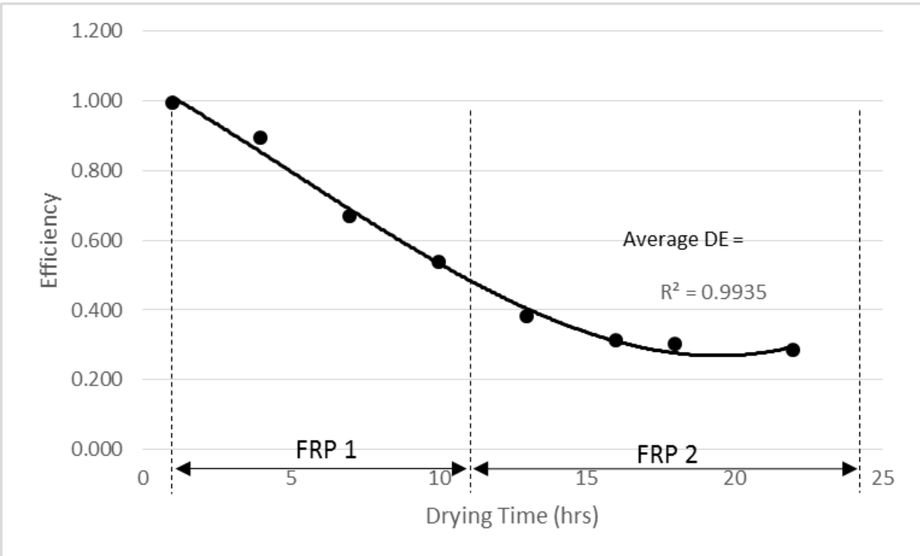

Fig. 4. Drying efficiency (DE) of the seed dryer

The efficiency of the dryer system reached a constant at efficiency level after 16 h of drying with an average DE value of 0.311. This stage was believed to be the EMC point of the paddy seeds. It can be noted that beyond this point, the DE will not be significantly increased though the drying process was not yet completed. It can be inferred that beyond this point, prolonged supply of energy will not translate into an optimum utilization of energy, as evidenced in the DE values at both 18 h and 22 h of drying. A reduction of 2.9% and 5.6% in DE values was observed at both of these points when the DE fell to 0.302 and 0.285 at both 18 h and 22 h of drying time.

As DE is governed by DR, therefore this condition can be traced to the small temperature gradients between the drying air and the paddy seeds that had caused a limitation to the heat flux and had also affected the moisture transfer. At this point though, supplying the same quantity of energy would be a wasted approach. The LSU mixed-flow batch type dryer system at Loji Pemprosesan Benih Padi Sah (A) Telok Chengai registered an average DE value of 0.546.

As DE analysis capitalizes on the psychrometric conditions of the ambient, drying and exhaust air, the performance efficiency of the drying system was more thoroughly represented as compared to SEC. Consistently monitoring these air properties, such as their elevated enthalpy and also their differences in absolute humidity will enhance the efficiency in managing its energy supply and utilization and will improve its economic performance. Based on DE, the scope of future improvements on the dryer will involve the exploitation of these air psychrometric properties. As such, the possible improvements available to enhance the efficiency are namely through the recycling of exhaust air or installing heat recovery or changing operating parameters, dryer feature modification, and improving insulation to reduce heat losses. For instance, insulation of a dryer has shown a three-year energy savings between 16% and 21% as compared to uninsulated dryer [16].

3.3 Specific Energy Consumption (SEC)

Specific energy consumption (SEC) refers to the ratio of the total supplied energy to the mass of evaporated moisture. It serves as a very useful key indicator in energy analysis and in the comparison of different dryers and dryer types, provided that the properties of the dried material and the ambient conditions remain equal [7].

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 was 5.482 MJ/kg of water removed to dry paddy seed to 14% moisture content. The value lied within the range of a typical commercial dryer SEC values of between 4.0 and 8.0 MJ per kg of water removed was reported [17-19]. However, the SEC value was twice the amount of the same mixed flow grain dryer type as reported by Brinker and Johnson, which was at 2.577 MJ/kg of water removed [20].

During the earlier stage of drying process, a negative SEC value was recorded as a result of additional moisture detected in the paddy seeds samples at the upper section of the dryer. This addition of moisture was found in every sample of every experiment conducted. It may be attributed to the accumulation of evaporated moisture at the top most of the dryer and its slow release to the atmosphere. The SEC at this stage was recorded to be 2.834 MJ/kg water removed. As the drying time progressed, the SEC began to increase until it reached its maximum value of 9.732 MJ/kg water removed at approximately 10 h of drying.

As drying progressed further, a dip in the SEC during 13 h of drying was observed, as depicted in Figure 5. The dip corresponded to the transition from the first stage of FRP (FRP 1) to the second stage of the FRP (FRP 2), where the rate of moisture evaporation started to decrease as a result of unwetted surface of the paddy seeds and the lower degree of moisture movement from the inner part of the seeds to their outer surface, or commonly known as the unsaturated surface drying.

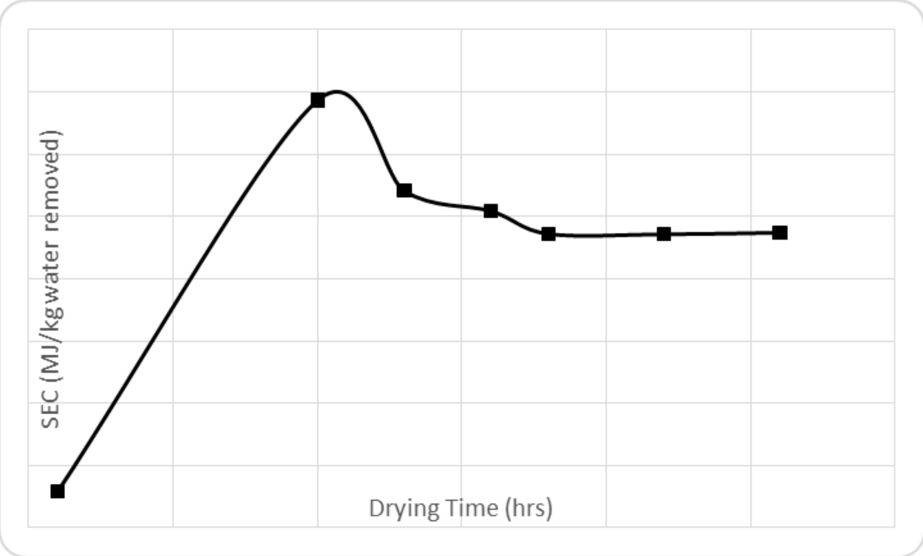

Fig. 5. Specific energy consumption (SEC) of the seed dryer

As the drying progressed, a slight reduction in the SEC value (9.6%) from 6.829 MJ/kg to 6.175 MJ/kg water removed at 16 h of drying was observed. During this period, it can be expected that the EMC point could have been achieved. As the drying progressed beyond this EMC point, the SEC attained a more consistent value, where the values between 18 h to 26 h (end point of drying) ranged between 5.441 MJ/kg and 5.482 MJ/kg water removed. It can be inferred that continuing the supply of high energy beyond the 18 h of drying would be a waste as its utilization was more or less stagnant.

It can be observed that SEC may be easier to monitor as compared to DE, however, it did not give a clear picture on how the drying process occured as compared to DE. However, it can be used as a guideline to compare the overall performance of the dryer, but not on the drying process itself.

4. Conclusion

In terms of providing a comprehensible understanding about the performance of the LSU dryer at Loji Pemprosesan Benih Padi Sah (A) Telok Chengai, SEC provides better characterization in dryer performance 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 aspect that could be exploited to enhance its performance based on SEC is by using different types of fuel to help improve on the energy utilization of the dryer system. On the other hand, DE provides clearer options on the possible design improvements that could be introduced to the dryer than the SEC. By closely monitoring the air properties and analyzing them by using psychrometry, specific design improvements involving modifying drying air conditions and drying equipment can be carried out. To sustain a higher DE level for a longer drying period, 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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References

[1] Nashriyah, Mat, Nai Kin Ho, Sahid Ismail, Ali Ahyaudin, Keng Yeang Lum, and Mansor Mashhor. "Sustainable rice production in Malaysia beyond 2000." (2002).

[2] Henderson, S. M., and R. L. Perry. "Agricultural Process Engineering. The AVI Publ. Co." *Inc, Wesport, Connecticut, USA* (1976).

[3] Wang, Zhenhua, Yingquan Zhang, Bo Zhang, Fuguang Yang, Xiaolei Yu, Bo Zhao, and Yimin Wei. "Analysis on energy consumption of drying process for dried Chinese noodles." *Applied Thermal Engineering* 110 (2017): 941-948.

[4] Kasmaprapruet, Sakaorat, Woranee Paengjuntuek, Phanida Saikhwan, and Harnpon Phungrassami. "Life cycle assessment of milled rice production: case study in Thailand." (2009).

[5] Livezey, J., and L. Foreman. "Characteristics and production costs of US rice farms. Washington: US Department of Agriculture." *Economic Research Service Statistical Bulletin, No.(SB-974-7) p* 34 (2004).

[6] Kemp, Ian C. "Fundamentals of energy analysis of dryers." *Modern drying technology* 4 (2012): 1-46.

[7] Jokiniemi, Tapani. "Energy efficiency in grain preservation." (2016).

[8] Jokiniemi, Heikki T., and Jukka M. Ahokas. "Drying process optimisation in a mixed-flow batch grain dryer." *Biosystems engineering* 121 (2014): 209-220.

[9] Fayose, Folasayo, and Zhongjie Huan. "Heat pump drying of fruits and vegetables: Principles and potentials for Sub-Saharan Africa." *International journal of food science* 2016 (2016).

[10] Firouzi, Saeed, Mohammad Reza Alizadeh, and Didar Haghtalab. "Energy consumption and rice milling quality upon drying paddy with a newly-designed horizontal rotary dryer." *Energy* 119 (2017): 629-636.

[11] Haron, N. S., Zakaria, J. H., & Mohideen Batcha, M. F. "Recent advances in fluidized bed drying." *In IOP Conference Series: Materials Science and Engineering,* vol. 243, Institute of Physics Publishing, 2017.

[12] Bern, C., J., Hurburgh, C., R. "Managing Grain After Harvest". ISU Publication, 2002.

[13] Beigi, Mohsen. "Energy efficiency and moisture diffusivity of apple slices during convective drying." *Food Science and Technology* 36, no. 1 (2016): 145-150.

[14] Billiris, Maria Alejandra, Terry J. Siebenmorgen, and Greg L. Baltz. "Energy Use and Efficiency of Rice-Drying SystemsI. On-Farm Cross-Flow Dryer Measurements." *Applied Engineering in Agriculture* 30, no. 2 (2014): 205-215.

[15] Ibrahim, M. N., M. S. H. Sarker, and P. Mohd Salleh. "Drying Performances and Milling Quality of Rice during Industrial Fluidized Bed Drying of Paddy in Malaysia." *Pertanika Journal of Science & Technology* 23, no. 2 (2015).

[16] Jokiniemi, Heikki Tapani, and Jukka Matias Ahokas. "Effect of heat insulation on the energy consumption of recirculating mixed-flow batch grain dryer." *Agricultural Engineering International: CIGR Journal* 16, no. 3 (2014): 205-213.

[17] Laitinen, A., R. Orava, A. Peltola, O. Salasmaa, and A-L. Yloenen. "Energy saving in grain harvesting." *Publication Series of Work Efficiency Association (Finland)* (1985).

[18] Nellist, M. E. "Modelling the performance of a cross-flow grain drier." *Journal of Agricultural Engineering Research* 37, no. 3-4 (1987): 43-57.

[19] Suomi, P., Lötjonen, T.,Mikkola, H., Kirkkari, A., M., and Palva R. "Harvesting and grain storage in an expanding arable farm." *Agriculture and Food Economy* (2003) p. 31

[20] Brinker, Jennifer L., and Alex Johnson. "Energy Efficiency Study on Two Wisconsin Grain Drying Systems: Mixed Flow and Continuous Cross Flow Grain Dryers." In *2010 Pittsburgh, Pennsylvania, June 20-June 23, 2010*, p. 1. American Society of Agricultural and Biological Engineers, 2010.