Asian Journal of Applied Sciences (ISSN: 2321 – 0893)
Volume 03 – Issue 06, December 2015

Development of a Fully-automated Pilot-scale Model Fluidized Bed Drying System for Complete Drying of Paddy

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ABSTRACT---- ***Fully-automated pilot-scale fluidized bed drying system with 500kg/hr capacity was evaluated using high moisture paddy. Complete drying of paddy with ≥ 28 % (w.b.) initial moisture content was attained after 2 passes of fluidized-bed drying at 2 min exposure to 70 °C drying temperature and 4.9 m/s superficial air velocity, followed by 60 min ambient air tempering period (30 min without ventilation and 30 min with air ventilation) for a total drying time of 2.07 h. Around 82% of normal mechanical drying time was saved at 70 °C drying temperature. The drying cost was calculated to be $0.014 per kilogram of wet paddy. Specific heat energy consumption was only 2.84 MJ/kg of water removed. The Head Rice Yield recovery of the dried paddy passed the Philippine Agricultural Engineering Standards. Sensory evaluation showed that the color and taste of rice samples dried in the fluidized bed dryer were comparable to air dried paddy. The optimum drying parameters of using fluidized bed dryer is 70 ^{o}C drying temperature at 2 min fluidization time, 1493 Pa static pressure, 4.9 m/s superficial air velocity, 10 cm grain depth and 60 min ambient air tempering period.***

Keywords----Paddy, Drying, Fluidized Bed Dryer, Postharvest Machinery

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1. INTRODUCTION

Drying is one way of increasing farmers' income by reducing quantity and quality losses. It expands farmers' opportunities, enabling them to store grains and seek better markets without quality deterioration. In the Philippines, drying could be done in several ways, but the most common methods are by directly exposing the grains to sunlight and by using mechanical dryers. In terms of cost, sun drying is cheaper, but it is time-consuming and not feasible during rainy seasons. Mechanical dryers served the purpose of drying during the wet season. Among the more popular in the Philippines are the flatbed dryers and recirculating batch dryers. These dryers provide good performance though not perfect. The flatbed dryer is simple to operate and maintain however, it is labor intensive and not manageable when multiple units are operating to attain larger capacity. On the other hand, multiple units of recirculating batch dryers can provide larger drying capacity. Such system is easier to manage compared to multiple units of flatbed dryers. However, wet paddy tends to clump together and clog the elevator of the dryer thus, resulting to a long drying time of around 8-10 hours per batch and tedious which is not the ideal for handling very high moisture paddy. This is verified when it contains large amount of impurities. Moreover, high maintenance cost and supervision is needed due to copious moving parts and electric motors using batch-recirculating dryers [1].

Fluidized bed drying system offers better and faster solution when drying high moisture paddy. Paddy is subjected for short duration to a very high air flow resulting to fluidization of the grain bed. The grains are semi-suspended in air and experience vigorous mixing. These eliminate the problem of grain clumping and result to faster and more uniform drying. The grain bed acquires a fluid-like character when fluidized and thus flows more easily [2][3][4][5].

To this date, there is no commercial paddy drying system that entirely uses fluidized bed dryers for both first and second stage drying. Such system could potentially result to a more compact design. The concept has been initially explored [6] but the study was limited to a laboratory scale set-up. A number of more recent experimental research works gave indications that too high drying temperature could result to some physico-chemical changes in rice which may not be acceptable [6].

Based on the studies cited above, complete drying of high moisture paddy using fluidized bed drying system is feasible. Thus, in 2013 the development of fluidized bed drying system for complete drying of paddy was explored at PHilMech through a laboratory-scale set up with 5 kg/batch capacity [7]. Primarily the concept of multi-stage batch drying of paddy under fluidized bed conditions was explored. The project team evaluated the laboratory-scale model and established the drying parameters that best suit the operation of a fluidized bed drying system for complete drying of high moisture paddy.

The results suggested that 70^{o}C drying temperatures with 2 minutes fluidization time were suited for the fluidized bed dryer in drying high moisture paddy. Meanwhile, the drying also involves some technical parameters like static pressure (1,493 *Pa*), grain depth (10 cm), superficial air velocity (4.9 m/s) and 1 hour ambient air tempering period (30 min without air ventilation and 30 min with air ventilation). The quality of the dried product passed the Philippine Agricultural Engineering Standards [8]for Head Rice Yield recovery. Moreover, sensory evaluation showed that the color and taste of rice dried in fluidized bed dryer were acceptable to consumers.

Therefore, there is an incentive of validating the results to a bigger-scale fluidized bed drying system. Thus, prior to the development of a commercial-scale fluidized bed dryer, a pilot-scale fully-automated dryer was developed to validate the viability of drying wet paddy using fluidized bed dryer system. Generally, the aim of the study is to develop a pilot-scale model fluidized bed dryer for high moisture paddy with full-automatic control system. Specifically, it aims to (a) to design and fabricate a pilot-scale (500 kg/h capacity) fully automated fluidized bed dryer for drying high moisture paddy; (b) to validate the technical operating conditions for full drying of high moisture paddy; (c) to evaluate the Head Rice Yield recovery and energy consumption of the developed pilot-scale model fluidized bed dryer system; and (d) to determine the drying cost per kilogram of wet paddy dried to fluidized bed drying system.

2. METHODOLOGY

2.2. Design of the pilot-scale fluidized bed dryer

The pilot-scale fluidized bed dryer set-up was designed for a complete drying of high moisture paddy. The technical parameters (e.g. temperature, air velocity) established in the laboratory-scale set-up were used in designing the pilot-scale model. The pilot.-scale model was a continuous flow fully-automated fluidized bed drying system capable of drying 500 kilogram per hour of high moisture paddy. The pilot-scale model is comprised of automatic control system, heating system assembly, drying chamber assembly, tempering assembly, conveyor system assembly and the dust collector system assembly. The effective volume space occupied by the pilot-scale model dryer was 4.9m x 4.67m x 4.5m. The effective drying area of the fluidized bed dryer was 1.2 m x 0.25 m. The tempering bin assembly has two stages: ambient air without ventilation and with air ventilation. The dimension of each tempering bin was 1.5m x 1.0m. Tempering bin B was provided by 0.75 Hp blower to immediately supply ambient air ventilation effect to the grain during the second stage of tempering. During unloading of the dried paddy, a 1.6 m length screw conveyor powered by a 1 Hp electric motor was installed. The 4 pieces in-line blower (1 Hp each) was coupled by individual variable frequency drive (VFD) to regulate the frequency (Hz) of the motor. Thus, it is easier to set the fluidization pattern of the paddy during drying period. The heat source of the pilot-scale model was an LPG combined with 2 inches diameter torch to easily stabilize the drying temperature during experiment. The centralized control system of the pilot-scale model was fully automatic for easier operation and debugging during troubleshooting.The major parts of the pilot-scale model were shown in Figure 1.

There were two venturi - type conveyor installed in the pilot-scale model, the first one was from the loading bin to the fluidized bed hopper to eliminate grain clogging and choking due to impurities. The second conveyor was from the discharge output of the fluidized bed (drying chamber) to the tempering bin. The conveyor was coupled to a cyclone to control the air velocity that carries the grain. The discharge mechanism from the tempering bin to the loading bin of the fluidized bed dryer was a combination of a 1 HP electric motor and speed reducer. There were shuttering devices present before and after the fluidized bed. This is to regulate the residence time and the thickness of the grains that is entering and discharging from the fluidized bed. All of the electric motors and the VFD were controlled by fully-automated controllers for the safety and easiness during operation.

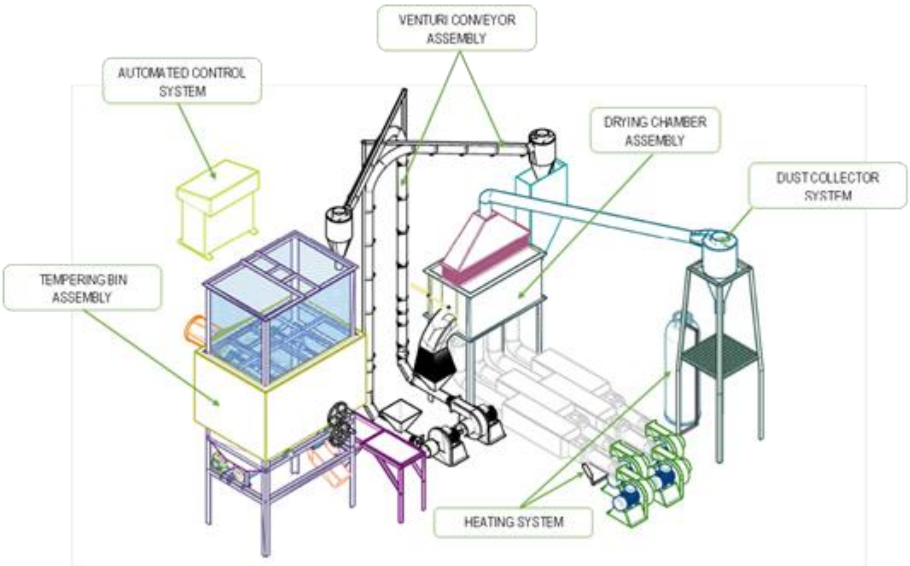

Figure 1. Major components of the pilot-scale model fluidized bed drying system

2.3. Fabrication, installation and debugging

The technical drawing was prepared through the use of autoCAD software at PhilMech. The pilot-scale model was fabricated at Agricultural Machinery Division fabrication shop of PHilMech. Field testing was done in Nueva Vizcaya Alay-Kapwa Multi-Purpose Cooperative Grains Center (NVAKGC), Solano, Nueva Vizcaya. Prior to the conduct of field drying experiments, the dryer was thoroughly debugged and tested at PHilMech to ensure the functional integrity and reliability during operation.

2.4. Conduct of drying experiments

NVAKGC has continuous palay trading operations throughout the year. Thus, samples used in the drying experiments were the daily procurement of the grains center. The variety and initial moisture contents of the paddy used in the drying trials were presented in Table 1. About 500 kg of fresh paddy with initial moisture content of around ≥28% (wet basis) was being used in every trial. A portion of the fresh paddy sample was taken for initial moisture content and purity determination in the laboratory. Also, when the samples are already dried, a 5-kg sample was taken and sealed to polyethylene bag for final moisture content and quality analysis. All laboratory analyses were done at PhilMech.

Table 1. Variety and conditions of the samples used in the drying trials.

Variety	Initial Moisture Content (wet basis)	Grain Length
NSICRC 238 (Tubigan 21)	28 – 35 %	Medium
NSICRC 152 (Tubigan 10)	30 – 34 %	Long
NSICRC 222 (Tubigan 18)	28 – 33%	Long
NSIC RC204H (Mestiso 20)	29 – 30 %	Long
NSIC RC180H (Mestiso 15)	28 – 30 %	Medium

To validate the results generated by previous study[7] from the laboratory-scale experiments, the drying parameters applied in the laboratory were also executed in the pilot-scale model drying experiments. The drying conditions used in this study were presented in Table 2.

Table 2. Technical parameters used during the drying experiments.

Technical Parameters	**Value**	**Unit**
Drying temperature	70, 80, 90, 100	°C
Grain bed depth	10	cm
Static pressure	1,493	Pa
Fluidization time	2, 3	minutes
Tempering time (ambient air without ventilation)	30	minutes
Tempering time (ambient air with ventilation)	30	minutes

The one hour ambient air tempering time (30 min without ventilation and 30 min with ventilation) was used to fully cool down the grains exposed to high velocity and high temperature air at the drying chamber.Initial trials with longer tempering period resulted to a longer drying time while shorter (e.g. < 30 minutes) resulted to large amounts of broken grains during milling due to under dried paddy conditions. On the other hand, drying temperature lower than 70 °C was not considered, because the desired final moisture content of 14% (wet basis) was not attained after the 4^{th} cycle of drying in the laboratory scale fluidized bed dryer [7]. In addition, previous study[9]concluded that in recirculating batch dryers, paddy can be dried up to 70 °C without significant reduction in the head rice recovery. Moreover, temperatures above 100 °C were not considered in view of its negative effects on volatiles and starch properties as reported by previous research [9]. Furthermore, the grain bed depth 10 cm was constant for all of the drying trials since, it was the optimum grain thickness in order that the wet grain to fluidize which was established in the laboratory-scale fluidized bed drying experiments [7].

Prior to every start of experiment, the moisture content of sample was determined by air oven method (three 25 g sub-samples dried at 105 °C for 72 hours) and Kett moisture meter analyzer. The drying temperature and fluidization time were also set. Meanwhile, the pilot-scale dryer was turned on and allowed to stabilize at 30-32°C ambient temperature, 57-60% relative humidity, 1493 *Pa* static pressure and 4.9 m/s superficial air velocity. The material flow diagram of paddy during drying experiments was presented in Figure 2.

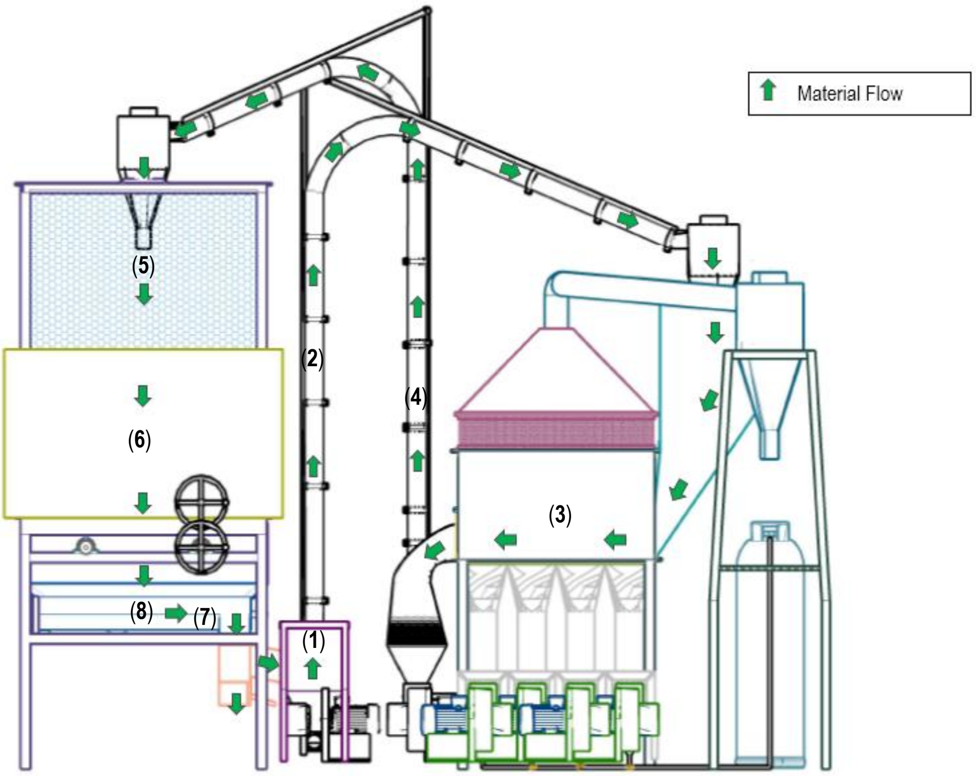

Figure 2. Material flow diagram of the pilot-scale model during dying experiments

The drying process involves loading of a 500 kg high moisture paddy sample (≥28%, wet basis) in the loading bin **(1)** and conveyed through the venturi-type conveyor **(2)** to the hopper of the fluidized dryer. The feeding was continuous at a constant feed rate of 17 kg/min inside the drying chamber **(3)** with hot air for 2 minutes. The sample is then conveyed thru venturi-type conveyor **(4)** into the tempering bin A **(5)** for 30 minutes which allows the sample to temper at ambient air conditions without air ventilation. Then immediately air cooling **(6)** of the samples for 30 minutes followed. Samples were drawn from tempering bin A to tempering bin B by gravitational method. Tempering bin B was provided with a fan for forced air cooling at deep bed cooling (approximately 8 inches grain depth) prior to the next exposure **(7)** to fluidized bed drying chamber. Complete drying was attained after 2 drying passes with specified drying temperatures and fluidization time. Dried product was discharged **(8)** thru the screw conveyor powered by a combination of 1 Hp electric motor and 1:60 ratio speed reducer.

Dried samples were brought to PHilMech for laboratory milling analyses following the PAES standards[8] for milled rice quality evaluation. Likewise selected dried samples with the highest milling recovery were sent to Central Luzon State University-College of Home Science and Industry for the consumer's acceptability tests.

2.5. Conduct of sensory evaluation

Fifty (50) respondents were randomly selected with 50:50 gender distributions and the age ranged from 16 to 50 years old with a skew towards the middle age consumers. Each samplewas steamed at the same degree of heat and level of water. The cooked samples were then served and replicated at 500 grams each with maintained temperature at 65-70^{o}C. Sample that was not consumed within 3 hours after steaming was considered stale and was not used in the evaluation. The respondents evaluated the samples using blind sequential monadic taste test approach. They were given water before tasting the samples to clean their palates and neutralize their taste buds. Data collection was done with structured questionnaire containing both open ended and hedonic scale questions. Using one on one interview, respondents were asked for feedbacks regarding the taste, color, aroma and mouth-feel of the samples.

The analysis for the sensory evaluation results includes key performance indicators (KPI) of the test samples like the overall liking, aroma, taste, color and mouth-feel, a 9 point hedonic scale was used. Duncan Multiple Range Test (DMRT) was used in the comparison among means.

2.6. Drying cost calculation

The drying cost (P/kg) was calculated following the *equation 1*. Direct costs like power, labor and the cost of LPG with respect to time and capacity of the pilot-scale were imputed in the calculations. Investment costs like the shed and the cost of the unit will be considered in future studies of the commercial-scale model.

Drying Cost = (Fixed Cost + Variable Cost)/Capacity *(equation 1)*

where:

FC = Repair cost + Taxes
VC = Salary + Fuel cost + Power cost

2.7. Analysis of data

The analysis of Normalized Moisture Content (NMC) was expressed in dimensionless Moisture Ratio (MR) to get the average moisture content of the paddy during drying and tempering period. The MR was analyzed following the formula:

$$MR = \frac{M - M_e}{M_o - M_e} \qquad \text{(equation 2)}$$

where:
M= Moisture content after drying, %
M_o = Initial moisture content, %

$$M_e = \left[\frac{Ln(1 - RH/100)}{-K(T + C)}\right] \wedge {}^{1}/_{N} \quad \text{as Modified Henderson Equation} \qquad \text{(equation 3)}$$

where:
RH= Relative humidity, %
T = Temperature, ^{o}C
$-K$ = 0.000041276 (long grain)
C = 49.828 (long grain)
N = 2.1191 (long grain)

The Head Rice Yield (HRY) values (*equation 4*) were transformed into dimensionless form so called Head Rice Yield Reduction Ratio (HRYR) values. The highest HRYR value is 1.0 while the lowest is 0.0. An HRYR value near 1 indicates that all the kernels in the samples were broken. An equation of HRYR (*equation 5*) was developed by previous researcher [10] to describe the reduction in head rice yield based on his study on the batch type-bed drying tests.

$$\text{HRY} = \frac{HR}{HR+B} \qquad (\textit{equation 4})$$

where HR is the head rice recovery and B is the broken rice recovery after milling.

$$HRYR = \frac{HRY_0 - HRY}{HRY_o} \qquad (\textit{equation 5})$$

where:

$HRYR$ = head rice yield reduction ratio, dimensionless
HRY_o = head rice yield of control sample, %
HRY = head rice yield of paddy dried to fluidized bed dryer, %

The total energy required to dry the paddy using the fluidized bed dryer was calculated following the equations below:

$$E_H = \frac{Total\ henat\ energy\ consumption\ ,MJ}{Amount\ of\ moisture\ removed\ ,kg} \qquad (\textit{equation 6})$$

$$Total\ heat\ energy\ consumption = \frac{\rho_a AvCt\ (T_a - T_{amb})}{1000\ Eff_b} \qquad (\textit{equation 7})$$

Where:

E_H = specific heat energy consumption, MJ/kg
A = area of the drying bin, m^2
v = specific volume of dry air, m^3/kg d.a.
C = Specific heat of dry air, KJ/kg.^oC
t = fluidization time, s
T = air temperature, ^oC
Eff_b = Efficiency of burner, decimal

The value 1000 converts the energy unit from KJ to MJ. The Eff_b is equal to 0.90.

3. RESULTS AND DISCUSSION

3.1. Optimum drying parameters

The optimum technical drying parameters generated using the pilot-scale model fluidized bed dryer was presented in Table 3. The optimum parameters were quantified based on the merit of the quality of the final product, which was the Head Rice Yield recovery and sensory attributes (e.g. color and taste). Drying temperature of 70^{o}C with 2 minutes fluidization time at 1,493 Pa static pressure, 10 cm grain depth, 4.9 m/s superficial air velocity was the optimum drying parameters that resulted to high Head Rice Yield recovery and acceptable color and taste of the milled product.

Table 3. Technical parameters established for the operation of the fluidized bed dryer

Particulars	Parameters
Drying temperature (^{o}C)	70
Airflow rate (m^3/s)	1.47
Static pressure (Pa)	1,493
Grain depth (cm)	10
Fluidization time (minute)	2
Ambient tempering (minute)	30
Forced air tempering (minute)	30

3.2. Drying rate of paddy on the fluidized bed drying system

Figure 3 shows a typical moisture reduction curve relative to time of paddy dried to pilot-scale model fluidized bed dryer. Wet paddy with 31% (wet basis) initial moisture content (MC) dried with 70 °C drying temperature at 2 min fluidization, 10 cm grain depth, 4.9 m/s air velocity and 60 min tempering period was dried after 2 passes (124 min) in the pilot-scale fluidized bed dryer.

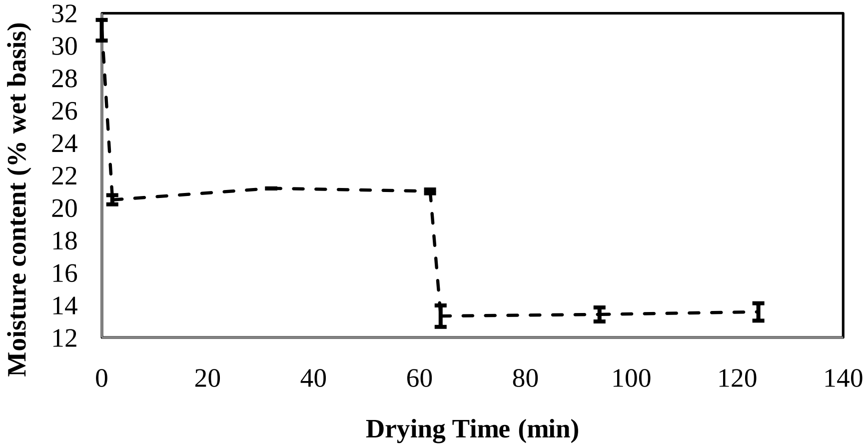

Figure 3. Moisture reduction of paddy dried to fluidized bed dryer at 70°C and 2 min fluidization time with 31% (wet basis) initial MC (error bars ±0.38).

The MC reduction of the wet paddy was a ladder-like plot with a very steep decline during each short fluidization period (2 minutes) and relatively small decrease in MC during tempering period. This indicates that the moisture continues to release from the grain up to 5% (wet basis) during tempering time. This phenomenon is due to the effect of the residual heat content acquired by the grain during the short fluidization stage [11]. It can also be observed that major portion of the grains' moisture was released during fluidization period (1st and 2nd passed) until a pseudo-equilibrium in MC during the last tempering period was observed.

3.3. Effects of drying temperature on the drying rate of paddy

Figure 4 shows the Normalized Moisture Content (NMC) of paddy dried in the fluidized bed dryer with different drying temperatures at 2 minutes fluidization time, 10cm bed depth, 4.9 m/s superficial air velocity and 30% (w.b.) average initial MC of the samples. The NMC was expressed in dimensionless Moisture Ratio (kg d.m./kg sample) which represent the average moisture content of the paddy with time given. The study found that with the increase in drying temperature, the drying rate has been found to be increasing and the equilibrium moisture content to be decreasing as what was also observed by previous authors[12]in the drying behavior of binary mixture of solids in batch fluidized bed dryer.

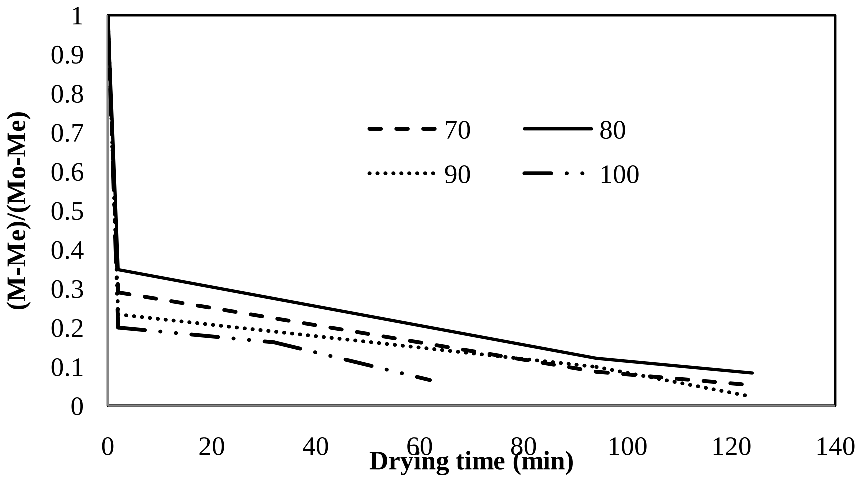

Figure 4. Normalized moisture content of paddy dried to fluidized bed dryer at different drying temperatures with 2 minutes fluidization time.

The increase in temperature also increase heat input to the system and hence increases the rate of evaporation of moisture from the moist surface of the grain. Results also showed that the three drying temperatures (70, 80 and 90^{o}C) used, completely dried (≤14%, wet basis) high moisture paddy (≥28%, wet basis) after 124 minutes (2.067 hours) of drying, while the highest (100^{o}C) dried the wet paddy after one pass (62 min). A progressive significant moisture reduction rates until it reached pseudo-equilibrium moisture content [10]was also plotted towards the final tempering period (2nd pass) in the pilot-scale fluidized bed dryer using the four drying temperatures. Nevertheless, the results validated the NMC of the paddy dried during the study of [7]in the laboratory-scale fluidized bed dryer using the four drying temperatures (70, 80, 90 and 100^{o}C), 2 min fluidization time, 10 cm grain depth, 4.9 m/s superficial air velocity and 60 min tempering period.

The observed variation in the final moisture content of the sample was due to the variety and conditions of the samples used during the trials, nevertheless it was all recorded ≤14% (w.b.). It was also noted during the study that the drying should be stopped sometime earlier than the point when the sample moisture content reaches equilibrium with the drying air condition, because some of the moisture continues to release from the sample due to the effect of residual heat content acquired by the grain. This was observed using 100^{o}C drying temperature. Moreover, the two highest temperatures (90 and 100^{o}C) displayed higher moisture reduction rates during the first stage of fluidization compared to the two lowest (70 and 80^{o}C) drying temperatures. The results confirmed previous study conducted [13]that the moisture reduction is independent of an initial moisture content indicating that the main part of moisture content (>25 %, wet basis), existed only on the exterior surface, thus allowing easier water removal without any interference of disordered void spaces inside grain kernel during drying.

3.4. Effects of the residence period on the drying rate of paddy

The effect of fluidization time on the pilot-scale model batch-type fluidized bed dryer has been studied at two drying temperatures, 10 cm grain bed depth and 4.9 m/s superficial air velocity. Only two fluidization time (2 and 3 minutes) were considered because previous study[7]concluded in the laboratory-scale fluidized bed drying that lower and upper than these two established fluidization time in combination to 70 and 80^{o}C drying temperatures gave truncated quality on the milling recovery of the dried paddy. The variations in the fluidization time have no effect on the drying rates of paddy in drying to the pilot-scale fluidized bed dryer. However, it is important to highlight that using a higher temperature (80^{o}C) and longer exposure time (3 minutes), the moisture reduction in the first cycle of drying is more pronounced until it reached a pseudo-equilibrium moisture content (14%, wet basis). A similar effect was observed by previous study[12]that due to the longer exposure of the material to the drying air convective mass transfer of moisture from solids to air increases resulting to an increase in the drying rate. Moreover, the moisture reduction is independent of initial moisture content that during the first stage of drying the moisture content existed on the exterior surface of the grain is easier to remove without any interference of disordered void spaces inside grain kernel during drying [13].

3.5. Energy Requirement

Fluidizing is very effective way of maximizing the surface area of drying within a small total space. Rapid mixing of the grains results in nearly homogeneous drying and high heat and mass transfer rates between the air and the grains due to the high air velocity [11]. Figure 5 shows the specific heat energy required to dry a kilogram of wet paddy using fluidized bed dryer with 2 min fluidization time at different drying temperatures and variations in the initial moisture contents of the paddy.

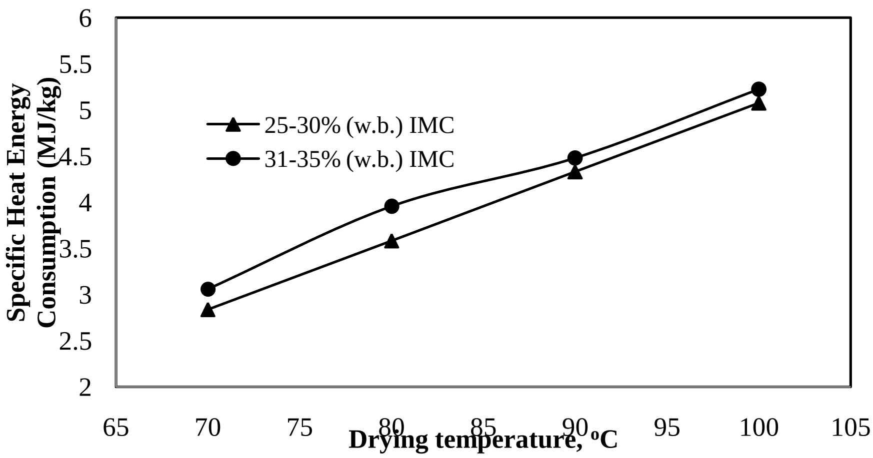

Figure 5. Specific heat energy requirement (MJ/kg) of paddy dried using the pilot-scale fluidized bed dryer at different drying temperatures with 2 min fluidization time and 60 min tempering period.

The analysis of the heat energy requirement only involves the paddy when it is being exposed to hot-air. The paddy was further subjected to two-stages tempering period: tempering period with only surrounding air conditions (without air ventilation) and with air ventilation (cooling stage). Thus, during the first stage of tempering period only thermal effects apply, that is, heat is transferred from the grain to the surrounding air and due to this effect; moisture is released from the grain until the grain residual temperature comes in equilibrium with the surrounding environment. During the second stage of tempering, forced air was supplied to facilitate the release of moisture form the grain until the vapor pressure of grain moisture become equal to the vapor pressure of the surrounding air. Therefore, the two-stages of tempering period facilitate removal of considerable amount of moisture without any energy input.

In this study, the calculated specific heat energy consumption of the pilot scale fluidized bed dryer was only 2.84 MJ/kg. The result supports the earlier findings of [7]on their experiments using the laboratory-scale fluidized bed dryer set-up. Substantially, it is important to highlight the low energy requirement of the developed pilot-scale fluidized bed dryer. Also, the calculated energy requirement was compared to flatbed mechanical dryer, and was found to be comparable [14]. Furthermore, the drying experiments comparing the drying time of the developed pilot-scale fluidized bed dryer and recirculating dryer were presented in Table 4.

Table 4. Drying time comparison of fluidized bed dryer and recirculating dryer.

Particulars	Fluidized bed dryer	Recirculating batch dryer
Initial Moisture Content of the paddy (%, wet basis)	31.5	
Variety	NSICRC 216	
Drying time (h)	2.07	12
Final Moisture Content (%, wet basis)	14.1	14.5

The drying time of paddy in fluidized bed dryer was 2.07 hours while on the recirculating dryer was 12 hours. The long drying time for recirculating batch-type dryer includes the down time (around 2 hours) due to clogging of the wet paddy on the elevator. The results implied 82% reduction on the drying time of wet paddy dried to fluidized bed dryer.

On the other hand, the electric power requirement for the pilot-scale model fluidized bed dryer was 21.5 kW-h/batch (2.07 hours drying time) with 2 min fluidization time at 70^{o}C drying temperature and 1,493 Pa static pressure. With this power requirement, scaling up the pilot-scale into commercial-scale of 1ton per hour capacity would require 25Hp electric motor. However, the high power requirement of the dryer could be compensated by its high capacity. For example, 1ton/h capacity fluidized bed dryer can dry 12 tons of wet paddy for 1 batch (12 hours) of dying operation. Thus, comparing it to flatbed dryer that requires 10Hp electric motor for 1 batch (12 hours) of drying 5 tons of wet paddy [15], fluidized bed drying is an advantage, since 3 flatbed dryers (equivalent to 30Hp) is needed to attain the 12tons capacity per batch of drying (≤ 14%, w.b.) paddy.

Therefore, the versatility of the developed pilot-scale fluidized bed dryer was supported by its low energy requirement connives with the huge reduction on the drying time of wet paddy which can be easily scaled-up for higher drying capacity (1ton/h) for better handling (no grain clumping) of high moisture paddy.

3.6. Drying cost analysis

The drying cost per bag of wet paddy dried in the pilot-scale model fluidized bed dryer was presented in Table 5. The drying cost incurred $0.014 to dry a kilogram of wet paddy in the pilot-scale fluidized bed dryer. The costs include the repair and maintenance, depreciation and taxes as part of the fixed costs while variable costs include the salaries of the operator and laborer (loading and unloading only), fuel cost and electricity cost. The operator is only part-time, since the fluidized dryer has a full-automated-control system. Potentially, the drying cost can be lowered further to $0.007/kg ($0.33/bag) when the heat source of the dryer is replaced by a biomass furnace. Thus, the commercial-scale fluidized bed dryer will be heated by a biomass furnace.

Table 5. Drying cost per bag of using fluidized bed dryer.

Particulars	Value
Fixed Cost/Batch	**430.52**
Repair and Maintenance (P/batch)	133.33
Depreciation cost (P/batch)	215.00
Taxes, licenses, & insurances (P/batch)	82.19
Variable Cost/Batch	**3,329.48**

Salary and wages (P/batch)	500.00
- salary of operator	175.00[a]
- salary of laborer	240.00[b]
Fuel Cost (LPG) (P/batch)	2,799.50
- kg of consumption/batch	50.90
- cost/kg	55.00
Power Cost (P/batch)	214.98
- consumption (kW-hr/batch)	21.50[c]
- cost (P/kW-hr)	10[d]
Total Operating Cost (P/batch)	**3,760.00**
Drying Cost ($/kg)	**0.014[e]**
Drying Cost ($/kg)	**0.007[f]**

[a] Part-time salary wage of Nueva Vizcaya Alay-Kapwa Multi-purpose Cooperative
[b] Payment for the loading and unloading only (1 ton)
[c] Power consumption of the blowers of the fluidized bed dryer and the tempering bin
[d] Based on Nueva Vizcaya Electric Cooperative power rate (2014)
[e] Based on the full capacity of 500kg/hr for 12 hours of operation per batch
[f] Potential drying cost when Biomass Furnace will be used as heat source (@ $0.17/bag of rice hull)
50 kg is equals to 1 bag
$1 = Php 46
1 Batch = 8 hours drying time

3.7. *Head Rice Yield (HRY) of dried paddy*

The Head Rice Yield Reduction Ratio (HRYR) of paddy dried in pilot-scale model fluidized bed dryer with 60 minutes tempering time, 10 cm grain depth, 4.9 m/s superficial air velocity relative to different drying temperatures and fluidization time were compared (Figure 6). The values of HRYR ranged from zero (0) to one (1). The value 0.0 denoted no reduction in HRY while 1.0 denoted that all kernels in the sample were broken.

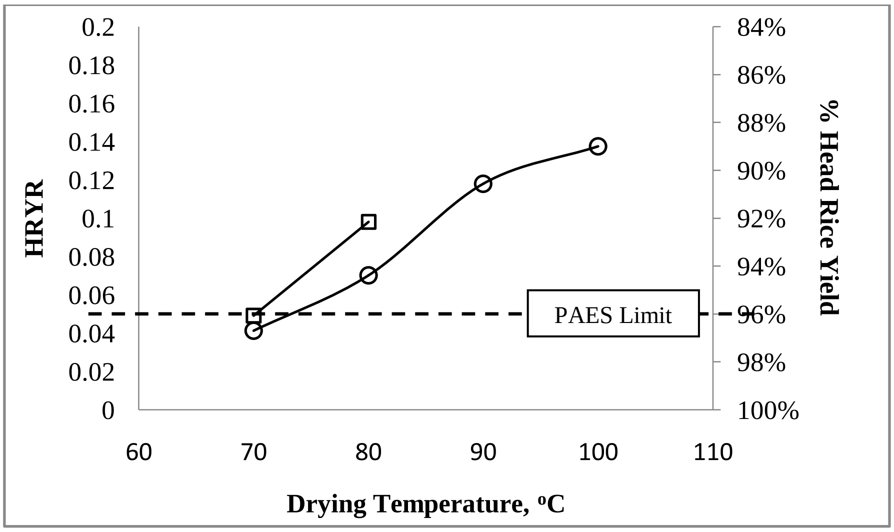

Figure 6. Head rice yield reduction ratio of samples dried in the pilot-scale fluidized bed dryer in relation to the different drying temperatures

It can be seen that an increase in drying temperature and fluidization time resulted an increase in HRYR value (approaching 1), which indicates that more broken kernels were present in the sample. The results suggested that the lowest drying temperature (70°C) with different fluidization time (2 and 3 min) at 10 cm grain depth, 4.9 m/s air velocity and 60 min tempering time has the highest Head Rice Yield Recovery. Nevertheless, although drying temperatures of 90 and 100°C resulted to high moisture reduction rate, there was a decreasing effect on HRY [16]and exceeded the 5% Philippine Agricultural Engineering Standards (PAES) limits for Brokens. Meanwhile, paddy dried at 70°C temperature, 2 min fluidization time, 10 cm grain depth, 4.9 m/s air velocity and 60 min tempering period attained the lowest HRYR and below the PAES limits for Brokens. Thus, samples subjected for sensory evaluation analysis were the samples only dried with 70 °C drying temperature at 2 min fluidization period.

3.8. *Sensory analysis*

Table 6 presents the mean scores of the sensory evaluation analysis of paddy dried to fluidized bed dryer at 70 °C temperature, 2 min fluidization, 10 cm grain depth, 4.9 m/s superficial air velocity and 60 min tempering period compared to air dried (as control). The results shows that there is no significant difference at α = 0.05 between the products dried in the pilot-scale fluidized bed dryer (Product A) and air dried (Product B). This implied that the product A is equally liked in terms of color, aroma, taste and mouth-feel.

Table 6. Mean scores on the color, aroma, taste and mouth-feel of paddy dried in fluidized bed dryer.

Attributes	Product	Mean	Mean Std Error
Over-all liking	A	6.72^{a}	0.19
	B	6.91^{a}	0.18
Color	A	6.98^{a}	0.19
	B	7.34^{a}	0.17
Aroma	A	6.55^{a}	0.17
	B	6.24^{a}	0.28
Taste	A	6.98^{a}	0.19
	B	6.88^{a}	0.24
Mouth-Feel	A	6.22^{a}	0.26
	B	6.42^{ab}	0.24

Note: *Product A= Dried to fluidized bed dryer; Product B= Air dried*; *Mean with the same script is not significantly different at α =0.05*

Considering largely the influence of color and taste in buying preference of consumers to milled rice, the paddy dried to fluidized bed dryer is comparable to air dried.

4.CONCLUSION AND RECOMMENDATION

The developed pilot-scale fully automated fluidized bed dryer system offers better and faster alternative in drying high moisture paddy. The versatility of the developed pilot-scale fluidized bed dryer was supported by its low energy requirement (2.84 MJ/kg), acceptable drying cost ($0.014/kg) connives with substantial reduction on the drying time (82%) that can be easily scaled-up for higher drying capacity (1ton/h) for better handling (no grain clumping) of high moisture paddy. Only the milled product dried to 70°C drying temperature with 2 min fluidization time, 10 cm grain depth, 4.9 m/s superficial air velocity and 60 min tempering period passed the PAES limits for HRY recovery. The major factors that influenced consumer's preferences in buying milled rice like color and taste have no significant differences to air dried paddy.

Furthermore, future work will be optimization of the results in a commercial - scale model with 1 ton/hour input capacity and the validation of $ 0.007/kg ($ 0.33/bag) drying cost with the use of multi-fuel biomass fed furnace as heat source of the fully-automated fluidized bed dryer system.

5. ACKNOWLEDGEMENT

The authors wish to express their sincerest thanks and gratitude to the following institutions that contributes in the successful conduct of this research, namely: (i) Philippine Center for Postharvest Development and Mechanization, Department of Agriculture for funding this research;(ii) Nueva Vizcaya Alay-Kapwa Multi-Purpose Cooperative, Solano, Nueva Vizcaya, Philippines as the project's farmer's cooperator.

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