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Optimum Drying Parameters of Fluidized Bed Dryer Operation for Rice and Corn

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Abstract

This study was carried out to develop a simulation model that can estimate the optimal drying parameters of a fluidized bed dryer such as drying time, moisture reduction rate and provide rough calculation of energy required and fuel consumption to dry a given volume of grains.

Results shows that drying set up of 140^{0}C drying temperature, bed height of 0.04m and an airflow rate of 2.3 m/s for paddy can provide lesser drying time and higher drying rate with a value of 164 minutes and 68.07 kg/hr, respectively. While for corn, a set-up of 170^{0}C drying temperature, bed height of 0.1m and the fixed airflow rate of 2.7 m/s can deliver lesser drying time and higher drying rate with a value of 45 minutes and 369.9 kg/hr, respectively. The simulation results also showed that using a higher temperature, higher airflow and lower bed height gives a lesser drying time which also leads to higher drying rate. In terms of drying energy and fuel consumption, the results showed that the higher the drying temperature, the higher the energy and fuel consumption is required.

Key Words: fluidized bed dryer, corn, paddy, simulator, moisture ratio, drying time, drying rate

Introduction

Drying has always been the most common method of preserving grain. Grains are dried into a certain moisture content (MC) depending to the purpose such as milling and storage to avoid potential quality deterioration problems. [1] In the Philippines, sun drying is the most common and cheapest method to reduce the moisture content of grains. However, sun drying method is a time-consuming, laborious and environmentally dependent. Hence, several mechanical dryers, such as flat-bed dryers and recirculating dryers, were developed to address the drying problems in rainy seasons. These mechanical dryers can dry grains for 8-10 hours per batch of grains. However, these dryers are not ideal in handling large volumes of freshly harvested grains with high moisture content. And the presence of large amount of impurities in freshly harvested grains causes grain clumping and clogging of dryer [2].

Fluidized bed dryers propose a better and faster way in drying large volumes of grains. In the fluidized bed dryer, grains are entrained in very high airflow, causing vigorous mixing of grain and air, and resulting to fluid-like behavior of the grains. These also result to uniform and rapid drying of grains thus reduces drying time of usual 8-10 hours using other mechanical dryers into efficient 3 hours. Moreover, the clumping and clogging of grains are minimized and the impurities are blown away into the cyclones [2]. In terms of head rice yield, studies have shown that high drying temperatures and tempered at the grain temperature can be potentially used to reduce moisture content rapidly without incurring head rice yield reduction [3].

Drying is affected by many factors, such as structure of the dryers, environment, temperature and relative humidity of ambient and drying air, static pressure of drying air, grain temperature, initial moisture content of grain, etc. With these, simulation analysis and models for drying process were developed to understand how the related factors influence drying, for optimizing dryer performance and reducing the time consuming and expensive drying trials [4].

A computer-based simulation model with simple interface was developed to simulate paddy moisture content and temperature based on the input parameters of ambient (temperature and relative humidity) and drying air (temperature and airflow rate), dimensions of the dryers, and input grain properties and weight. Still, this model was designed for conventional and reversible airflow flatbed dryers [4]. An excel-based tool was also developed to allow the users determine the energy consumption and energy efficiency. It has the ability to identify the major sources of dryer inefficiency, and allows energy savings to be calculated for several low- and high-cost measures such as dryer insulation, partial recycling of exhaust air, feed pre-heating, and others. This model calculates the energy use in industrial dryers, evaluate the potential for energy savings, and analyze options for reducing energy consumption [5]. Yet, the application of the excel-based tool requires many values that need to be entered to calculate the data since it was designed for convective dryers and not for a specific mechanical dryer. Another study was conducted to simulate a continuous plug-flow fluidized bed dryer model. The simulation models simulate the drying of shelled corn and study the effects of operating parameters such as gas temperature, gas velocity, particle size, dry solids flow and inlet solid temperature on the moisture content [6]. On the other side, a simulation model for paddy was also presented that predicts about fluidized bed dryer dimensions along safe zone of rough rice moisture content with other parameters [7]. Some of these were purposely developed for engineers, scientist or researchers and not on the level of farmers or drying operators. These simulators are also designed for single grain.

Since the country has two major grains, rice and corn, computer-based simulation or computation application for operation of fluidized bed dryer for these grains would be beneficial to at least improve the knowledge on how to operate the fluidized bed dryer properly. User friendly and less complicated computation application will also be needed to easily understand and appreciate specially by the farmers.

With the aforementioned statements, development of a computer-based simulation model with simple interface for the estimation of energy required, drying time, fuel consumption and other parameters is necessary to easily understand the drying operations that will prevent under-drying or over-drying of grains.

Generally, the objective of the project was to develop a simple and easy-to-use simulation-model for the Fluidized Bed Drying Operation System. Specifically, this aims to develop simulation that can calculate the final weight, and predict the drying time and behavior of moisture reduction rate of a Fluidized Bed Dryer of paddy and shelled corn grains as well as a rough estimation of the energy required and fuel consumption for a certain volume of grains with initial drying conditions based on the formulas and initial conditions of grains.

Materials and Methods

Design and Implementation

The design plan of the project followed the input-process-output approach. The drying and system parameters as well as the initial conditions of the commodity were gathered to use as the input in developing and implementing the proposed project. Modeling and simulation was developed to process the expected output of the project. Results of the testing and evaluation of the program were used to determine the success of the project output.

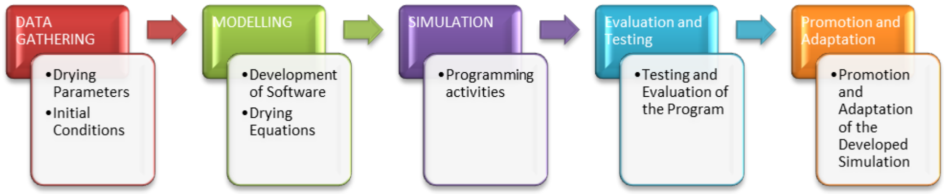

Figure 1. Design Plan of the Project

Data Gathering

Paddy and shelled corn grain were the commodities used for the development of simulation program for fluidized bed drying operation. Tables 1 showed the physical properties of paddy and corn grain and the initial drying conditions which are necessary to develop the simulation program [8 & 10].

Table 1. Properties of Grains and Drying Parameters Conditions used for Fluidized Bed Drying Calculation

Parameters	Paddy	Shelled Corn
Bulk Density, kg/m^3*	579	721
Dryer Air Temperature, C	90 – 140	130 - 175
Mean Residence Time, min	2 - 3	3 - 7
Bed height, m	0.04 - 0.10	0.17 – 0.22
Air Velocity, m/s	1.7 -2.3	2.7

*Reference for: Bulk Density of Corn and Paddy [8], Drying Parameters for Paddy [13], Drying Parameters for Corn [10]

For the program to be executed, drying temperature and input capacity were integrated in the program. Additionally, the user will be needed to input the following parameters:

a) Type of Grain: Paddy or Corn
b) Initial Moisture Content of Grain
c) Desired Final Moisture Content
d) Drying Temp

After the above parameters were inputted, the program was automatically solved the following data:

a) Final Weight, kg
b) Drying Rate, kg/hr
c) Drying time, hr
d) Fuel Consumption, kg

Formulas and Equations

The output data was calculated using the following formulas:

Weight of paddy after drying, kg

$$W2 = \mathrm{W1} - \frac{W1\,(M1-M2)}{100-\mathrm{M2}}$$ *Equation 1* [11]

Where:
W_1 = Weight of undried grain (kg)
W_2 = Weight of dried grain (kg)
M_1 = Moisture content of undried grain (% w.b.)
M_2 = Moisture content of dried grain (% w.b.)

Total Heat Required, (Q_T)

The total heat required by the system was computed by adding the heat load, and heat required to vaporize water while the heat losses on walls, top and bottom covers were added on the power needed since its computed value is already on kW.

$$Q_T = Q_2 + Q_3$$ *Equation 2* [11].

Where,
Q_T = total heat required, kJ
Q_2 = amount of heat needed to vaporize, kJ
Q_3 = heat load needed by the machine, kJ

Fuel Consumption (rice hull needed to generate the heat)

$$FC = (Q_r/HV_{RC}) \times 0.65 \text{ (Furnace Eff)}$$ *Equation 3* [11].

Where,
FC = Fuel Consumption, kg
Q_r = Total heat required, kJ
HV_{RC} = Heating value of rice hull, kJ/kg
Furnace Eff = 65%

Drying Time

For the calculation of drying time, mathematical models (Equation 4 and 5) generated in the previous study of Soponronnarit, et. al, were used to calculate the moisture ratio at set drying conditions to compute the drying time of paddy and corn:

<u>For Paddy</u>

$$MR = \frac{M(t)-Meq}{Min-Meq} = \exp(-xt^y)$$ *Equation 4* [9]

Constants for Paddy

$$x = 0.00163100\,T - 1.16202\,(m_{mix}/hu) + 0.00415300\,(m_{mix}/hu)\,T + 0.147383\,\ln(mmix/hu) + 0.474743$$

$$y = -\,0.00322000\,T - 0.835960\,(m_{mix}/hu) + 0.0203190\,(m_{mix}/hu)\,T - 0.143150\,\ln(m_{mix}/hu) + 0.548493$$

Where

MR = Moisture ratio, dimensionless
M(t) = Moisture content at given time, decimal d.b.

Min = Moisture content initial, decimal d.b.
Meq = Equilibrium moisture content, decimal d.b.
t = Drying time, min
T= Drying Temp, ^0C
Specific Airflow rate (mass flow rate at inlet /hold-up), kg/s/kg dry matter of paddy

For Corn

$$MR = \frac{M(t)-Meq}{Min-Meq} = \exp(-kt) \quad \textit{Equation 5 [11]}$$

Constants for Corn

$$k = 75.93 \exp\left(-\frac{2662.21}{(T+273.16)}\right)-0.087H$$

Where:

MR = Moisture ratio, dimensionless
M(t) = Moisture content at given time, decimal d.b.
Min = Moisture content initial, decimal d.b.
Meq = Equilibrium moisture content, decimal d.b.
t = Drying time, min
T = drying Temp, ^0C
H = Bed depth, m

Drying rate, Dr (kg/hr)

$$Dr = (M_r / D_t) \quad \textit{Equation 6 [11]}$$

Where:
M_r = amount of moisture removed, kg
D_t = computed drying time, hr

Development of Program

The developed simulator was completed through different ways to make the program easily to understand and can be use by anyone. All the relevant data and drying equations were included in the development of program as basis for the computation of output parameters. Shown in Figure 2 is the flow process diagram of the program.

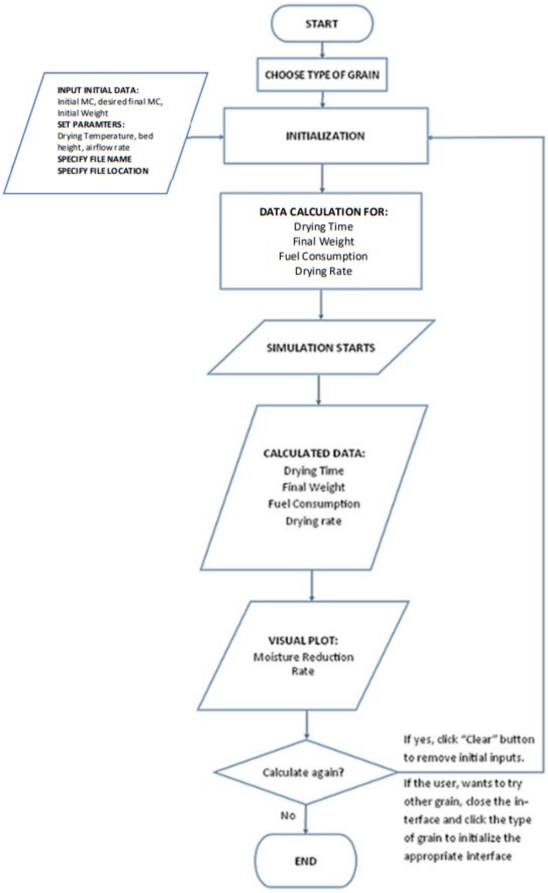

Figure 2 Flow Diagram of the Program

Testing and Evaluation

Series of testing was conducted to determine the performance of the simulation program. To verify if result generated by the program and the computed result from the Microsoft Excel Software was the same, comparison of both results was performed. Threshold value table was generated to use as basis for the evaluation of the result generated or computed by the program. The threshold value result was based on the assumptions, constant data and formulas gathered.

Results and Discussion

A simulator for calculating drying parameters of a Fluidized bed dryer was conceptualized and developed. Data results was generated using the equations and initial conditions of the Fluidized Bed Dryer. Different initial drying conditions was entered in the program for the paddy and corn as can be shown in Table 2 and 3. The program calculated that the dryer can reduced the moisture content from 30-28% to 18-16% (skin dry) in the first pass of drying. Thus, it can be assumed that the Fluidized bed dryer can removed an initial moisture content of 30-28% MC down to 13-14% MC after the second pass on the fluidized dryer. Shown in Figure 3 and 4 are the drying rate in terms of moisture removed over a period of time using different drying temperature. It can be observed in the grapth that it has an abrupt decline during the first fluidization period, and proves that the higher the drying temperature, drying rate increases which was also showed in the study of Pontawe, et. al. in a 500 kg/hr capacity fluidized bed dryer [1].

Table 2 Set-up for Paddy

Parameters	Value	Unit
Input Capacity	1	ton/hr
Bed height	0.04	m
Drying Area	0.6	m^2
Fluidization time	2-3	minutes
Airflow	2.3	m/s
Initial MC	30-28	%
Final MC	13-14	%

Reference: Drying Parameters for Paddy [11]

Table 3 Set-up for Corn

Parameters	Value	Unit
Feed rate	1.6	ton/hr
Bed height	0.17	m
Drying area	1.47	m^2
fluidization time	6-7	minutes
Airflow	2.7	m/s
Drying temperature	130-170	^{0}C
Initial MC	30	%
Final MC	14	%

Reference: Drying Parameters for Corn [12]

Shown in Figure 3 and 4 were the graph generated by the program following the conditions set in Table 3 and 4. Since the set-up for drying of corn has a higher drying temperature and drying area compare to the set parameters in drying paddy, results showed that a freshly harvested corn with initial MC of 30% wet basis can be dried down to 14 % in 85 minutes. Similarly in paddy drying, data generated showed that the higher the temperature, the lower the drying time needed. Same results of simulation was concluded in the study of Soponronnait et., al (1997). The drying temperature affected the drying kinetics of paddy and corn in Fluidized bed dryer.

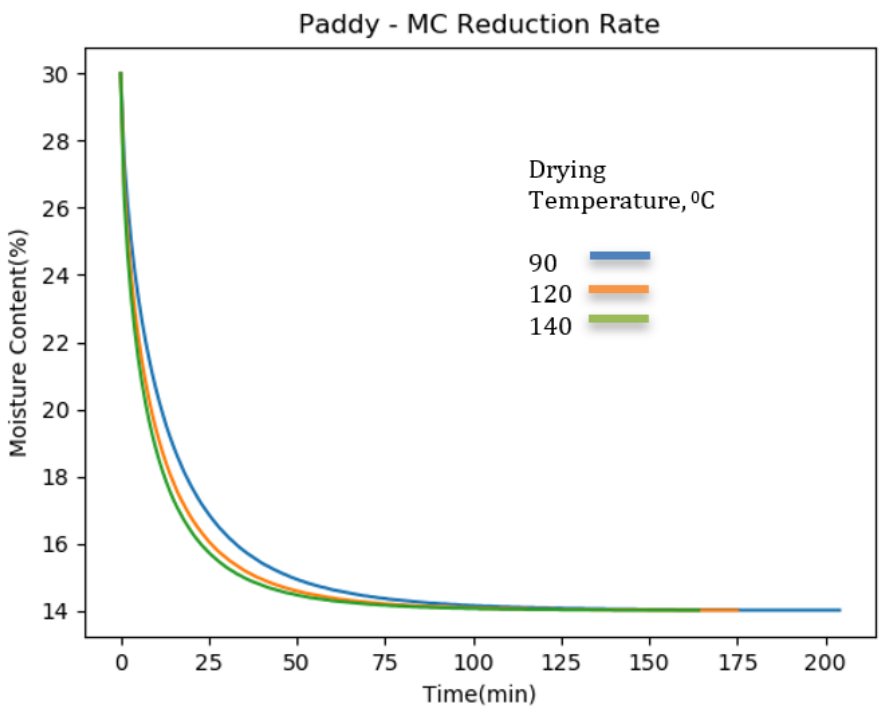

Figure 3. Relation of moisture removal over drying time for paddy condition

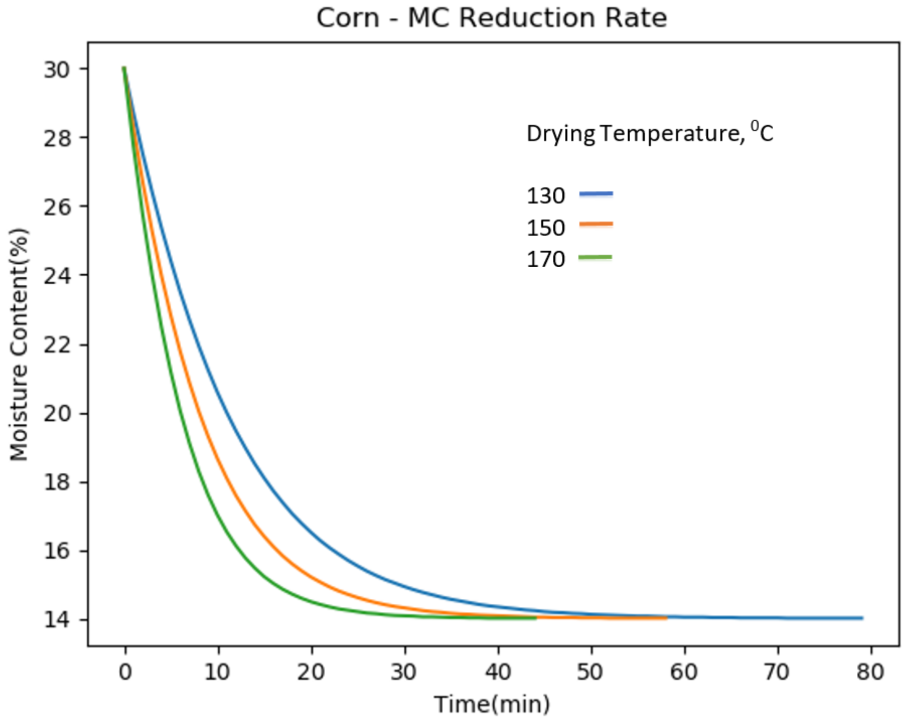

Figure 4. Relation of moisture removal over drying time for corn condition

To determine the effects of other parameters in the drying kinetics of corn and paddy grain, comparison for the different combination of drying temperature, airflow and bed height was also studied.

For paddy, the drying temperature used in the simulation activity were 90, 120 and 140 degree Celsius as illustrated in A1, A2 and A3 respectively, whereas air velocity used were 1.7, 2.0 and 2.3 meter per second connoted as B1, B2 and B3 respectively. While bed height used were 0.04, 0.07 and 0.10 meter indicated as C1, C2 and C3 respectively.

A Drying Temperature
B Air Velocity
C Bed height

Paddy

Table 4 Drying time, min

	B1C1	B1C2	B1C3	B2C1	B2C2	B2C3	B3C1	B3C2	B3C3
A1	212	224	239	209	220	223	204	216	227
A2	204	231	250	191	222	243	175	212	236
A3	208	252	**280****	188	238	271	**164***	222	259

* lowest drying time
**highest drying time

Table 5 Drying Rate, kg/hr

	B1C1	B1C2	B1C3	B2C1	B2C2	B2C3	B3C1	B3C2	B3C3
A1	52.65	49.83	46.71	53.41	50.74	47.91	54.72	51.68	49.18
A2	54.72	48.32	44.65	58.44	50.28	46.2	63.79	52.65	47.3
A3	53.67	44.3	**39.87****	59.38	46.9	41.19	**68.07***	50.28	43.1

*highest drying rate
** lowest drying rate

Table 6. Energy required to removed excess moisture

Drying Temperature	Total Energy Needed, KJ
90 ^{0}C	2,541,544.19
120 ^{0}C	3,579,683.72
140 ^{0}C	4,271,776.74

Table 7. Fuel Consumption, Rice hull for Biomass Furnace with 65% Efficiency

Drying Temperature	Rice Hull, kg
90 ^{0}C	124.68
120 ^{0}C	175.61
140 ^{0}C	**209.56**

Shown in Table 4, 5, 6 and 7 are the calculated data for paddy using different settings. Results showed that a set-up of 140^{0}C drying temperature, bed height of 0.04m and an airflow rate of 2.3 m/s can provide faster drying time and higher drying rate with a value of 164 minutes and 68.07 kg/hr, respectively. While longest drying time and lowest drying rate appear in the combination of 140^{0}C drying temperature, 0.1m bed height and 1.7 m/s. It can also be observed that using a higher temperature requires a higher energy which leads to higher fuel consumption.

For corn set-up, the drying time temperature used in the simulation activity were 90, 120 and 140 degree Celsius as illustrated in A1, A2 and A3 respectively, whereas air velocity used was fixed to 2.7 meter per second as per specified from the older study [10] connoted as B1 respectively. While bed beight used were 0.10, and 0.17 meter indicated as C1 and C2 respectively.

Table 8. Drying time, min.

Drying Temperature	B1C1	B1C2
A1	85	**91****
A2	61	64
A3	**45***	47

* lowest drying time
**highest drying time

Table 9. Drying Rate, kg/hr

Drying Temperature	B1C1	B1C2
A1	210.12	**196.2****
A2	292.79	279.07
A3	**396.9***	380.01

*highest drying rate
** lowest drying rate

Table 10. Energy required to removed excess moisture

Drying Temperature, ^{0}C	Total Energy Needed, KJ
130	6,281,168
150	7,388,517.21
170	8,495,866.05

Table 11. Fuel Consumption, Rice hull for Biomass Furnace with 65% Efficiency

Drying Temperature, ^{0}C	Rice Hull, kg
130	308.13
150	362.46
170	416.78

Shown in Table 8, 9, 10, and 11 are the calculated data for corn with the different drying set-up mentioned. Results showed that a set-up of 170^{0}C drying temperature, bed height of 0.1m and the fixed airflow rate of 2.7 m/s can provide lesser drying time and higher drying rate with a value of 45 minutes and 369.9 kg/hr, respectively. While longest drying time and lowest drying rate appear in the combination of 150^{0}C drying temperature, 0.17m bed height.

In summary, using a higher temperature, higher airflow and lower bed height setting can give a lesser drying time and a higher drying rate. In terms of drying energy and fuel consumption, the higher the drying temperature, the higher the energy and fuel consumption is required.

The developed program provide basic and necessary information in the drying of paddy and corn. It also provided data that was used in generating a visual plot of moisture removal over a period of time. With its easy-to-use graphical interface, this tool can be used by an farmers, engineers or students for the calculation of drying parameters.

Conclusion

A program was developed for calculating the optimum drying parameters of a fluidized bed dryer for corn and paddy grains. Results shows that drying set up of 140^{0}C drying temperature, bed height of 0.04m and an airflow rate of 2.3 m/s for paddy can provide faster drying time and higher drying rate with a value of 164 minutes and 68.07 kg/hr, respectively.While for corn, a set-up of 170^{0}C drying temperature, bed height of 0.1m and the fixed airflow rate of 2.7 m/s can provide faster drying time and higher drying rate with a value of 45 minutes and 369.9 kg/hr, respectively.

Thus, it can also be concluded that using a higher temperature, higher airflow and lower bed height can give a lesser drying time which also leads to higher drying rate. In terms drying energy and fuel consumption, result showed that the higher the drying temperature, the higher the energy and fuel consumption required.

The program was developed to help individuals easily calculate the drying parameters of a fluidized bed dryer applicable for both paddy and shelled corn grains. In addition, it can also be beneficial to engineers and students in designing and modeling of dryers by predicting the energy required by just storing the initial working conditions and parameters.

For future work, it is recommended to further improve the program, exploring and including other factors that may affect the drying performance of a fluidized bed dryer and conduct an experimental study to ensure its workability.

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