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Optimal variables estimation for energy reduction via a remote supervisory control: application to a counter-flow rotary dryer

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Abstract

This research anatomizes an automatic mode control of a counter flow rotary dryer by variable speed drive technology, to control moisture content of product in an organic fertilizer drying process. Effects of rotary dryer cyclone blower and biogas blower were investigated on a fertilizer production by the 3^k factorial experiment technique. Response surface methodology was employed to determine optimum variables. The multiple-response was revealed that the rotary dryer, the cyclone blower, and the biogas blower were 90 %, 48 %, and 92 %, respectively. These values were observed to make the system to consume electricity at the rate of 8.91 kW/h and the product moisture was observed at 18.90 % db. To inspect control system accuracy and accountability, the results obtained from the mathematical model was compared with the data from supervisory control and data acquisition system and with the data from real measurement also. The output responses were the electric power used and the product moisture obtained. The statistical investigation determined the optimization of energy usage.

Keyword: Industrial engineering

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1. Introduction

Effective utilization of energy in a fertilizer factory is a crucial factor for energy conservation. Rotary dryer, which is run on both electricity and gas, is conventionally used in most bio-organic fertilizer industry. Wise management of fuel consumption is crucial for minimizing production cost. Ideally, the operating rate of the devices used in production process should be reduced, energy waste and lose should be kept minimize. However, the reduction of the operational rate of rotary dryer must not result in high moisture products. In this production process, many motors are used to produce high power. Therefore, to reduce the cost of production, it is necessary to reduce the electricity consumption.

Motor power systems are essential for industries in the European Union, with about 70% of electricity used in industry. Extensive use makes motors particularly attractive for improved performance. The use of variable speed drives (VSD) has been identified as the most energy efficient motor technology [1] but VSD need to find the optimum speed to achieve the highest possible energy savings [2, 3] And to make the Pellet Organic Fertilizer has moisture in the specified range.

In this case study, the reduction of the rotary dryer's performing rate could not be conducted directly in the factory that produces bio-organic fertilizer from poultry waste. This was because the factory in the case study was not able to reduce the operating rate of the rotary dryers. Moreover, all the devices relating to fertilizer production were exploited with their maximum capacity. In a study by Ramazanet.all [4] showed that an automation program such as the Programmable Logic Controller (PLC) can be applied to control the water level in water tanks. More specifically, the speed of the water pump was controlled, resulting in a static level of water in the tanks that allows steady and consistent distribution of water. Figueiredo [5] applied the Programmable Logic Controller (PLC) which is a part of the Supervisory Control and Data Collection (SCADA) for the controlling of water distribution in a canal that provides water for farming system, aiming to obtain equal level of water at different phases of the canal to ensure that the nearby farmers receive equal amount of water. Accordingly, the researcher is interested in using automatic controlling system with the factory that is a case study for this research, in order to control the working rates of devices used for the drying of the fertilizer.

The programmable logic controller is an advanced industrial technology that enables high quality products while reducing the risk of performance errors and using less manpower in management. PLC devices are widely accepted in industry since it provides automatic control of a producing process. Example of the application these devices can be seen in the sugar evaporating process, metal stamping machine, and in CNC machine [6]. PLC has many advantages, basically it is known for being

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flexible, accountable, energy saving, and easily expandable [7]. Moreover, the SCADA is a real time information processing machine. It delivers information about the process via graphic patterns which can be transferred via internet. The obtained graphic patterns of the working process are later used for the controlling and monitoring of the industrial process [8, 9] PLC can be connected to SCADA via installing tag to any function blocks of devices, the tag deliver the graphic patterns of the device to the monitor. The SCADA can be used to control the performance of a process, enabling the controller to monitor the work of the machine from a distance [10]. In a study by Kyratsis [11], response surface metrology (RSM) was used to identify the controlled variables that affect the force acting on a driller. The study showed that the rate of input is the factor that has the most effect on the force acting on the driller. Silva et.al [12] applied the RSM to develop a mathematic modeling of a rotary dryer used in the drying process of the superphosphate fertilizer. It was found in Silva's study that the model was able to predict practical suitable working rate for the devices.

Intuitively, the response surface metrology is a significant mathematic and statistic methods that is beneficial for model construction and for analyzing the problems resulted from changing variables. It helps researchers to find values that is suitable for the proper working rate of the devices under interesting [13]. After the observed data from design of experiment is co-analyzed by the Factorial Type 3^k, reliable working rate of the device is yielded [14, 15] The application of Response Surface Metrology for gauging the proper working rate of a device must be done via an experiment that tests the working process of a device. However, such experiment is not possible since it may cause damage to the devices and the production process of a factory.

In a study by Arruda [16], a mathematic model was used to investigate proper working rate of a devices used in the production of the superphosphate fertilizer via a counter current flow dryer. Different variables in the production process were adjusted to predict the influences of the variables on the production process. The variables included in the experiment were material temperature, temperature of the dryer's tube, moisture, rotation speed of the rotary dryer, material flow rate, and air flow rate. In order to obtain better mathematical model, Lobato [17] used a technique called Differential Evolution to obtain numeric figure of the unidentified variables. Abbasfard [18] adopted the mathematical model firstly developed by Arruda to make the former easier for application. Conclusively, mathematical models enhance control parameters adjustment before they will be placed into a real production task. Celso Herrera-Cáceres [19] Have used a mathematical programming model for aiding the decision-making process of olive harvest planning is proposed. The optimization model is flexible, allowing the management of several parameters like the project budget and the risks generated by the climate. E. Santoro [20] proposes a mathematical model to the Route Planning Problem for sugarcane harvesting used mathematical model minimizes the time of maneuvering the harvesting

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machine and, consequently, reduces fuel and labor costs, among others used to produce. Yohann Rousselet [21] confirmed, the model is shown to be able to simulate reliably drying process parameters for a wide range of dryer input conditions and product types. Dryer data obtained in the present study, as well as data found are accurately calculated by the model.

The model leads to a safe piloting experiment to help researchers find an answer to their assumptions about the activities that cannot be placed under a trial since they take up high investment or the concern that the trial might be harmful for lives and process properties.

Specifically in this research, variables relating to remote supervisory controlling via the response surface metrology was investigated via a mathematical model. This modelling is preventive for the damage that might be cause to the device if experiment is conducted directly with the production process. After a proper working rate is obtained from the model, the rate was then applied to the real working process which was controlled by the remote supervisory controlling system and production cost was reduced.

2. Background

Poultry waste that has been fermented and processed into biogas reactors is used for fertilizer making as shown in Fig. 1. The fertilizer making processes takes the following steps. (1) In this process, residues such as stones, or other contaminators are exempted from the poultry waste sediment. The nutritious quality of the fertilizer is attuned to the prescribed standard before the fertilizer is compressed into tiny grains with the sizes of 3–5 mm. The grained fertilizer is transferred via a conveyor

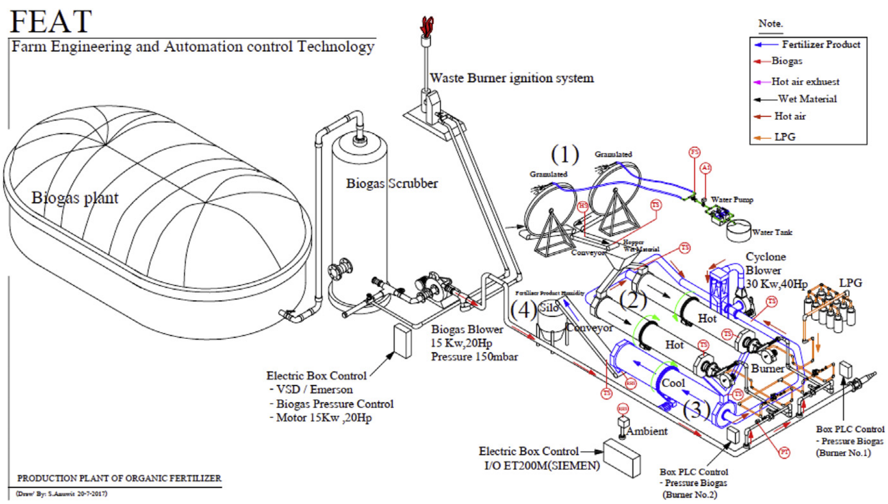

Fig. 1. Processes of poultry waste fertilizer and positions of devices in counter-flow rotary dryer.

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into a rotary drying drum. (2) The rotary drying drum is long cylindrical in shape. Hot air is generated from biogas burners that are attached at the end of the drying tubes. The hot air flows in the opposite direction with the movement of the fertilizer to prevent grain crack and heat damage nutrient avoidance. Along the length of the drying tube, the fertilizer is gradually dried due to its countering exposure to hot air. The tube keeps spinning slowly to shower the fertilizer to the hot air while transferring it to the other end of the tube before it is sent to a storage tube. (3) The below rotary storage tube slowly spins to allow the hot fertilizer to cool down before it is sent to a Silo attached to the opposite edge of the storage tube. (4) In the Silo, the fertilizer is dried to reach the moisture rate of 20 %db before it is sent to packaging and is made ready for selling. The product moisture stated earlier is result of optimal control parameters that they used a pre-calculation technique in this work. In old version of the plant, there were no variable rate controllers for water spray system, rotary drum system, biogas blower, and cyclone blower. And there were less online sensing elements to measure wet solid and hot gas condition. The old plant has online temperature of burners only. Thus, a gap that this work has done consist of 1) changing a discrete plant that its actuators ran on/off mode into a variable rate plant, 2) the product moisture reach to acceptable rate within once round of drying process with our purposed setting (twice round in the old plant) and 3) more sensors were attached to the plant for solid and fluid condition measurement. To sum up at this point, the processes of making fertilizer from poultry waste is monitored by the remote supervisory control system as presented in PI diagram of Fig. 2. This control

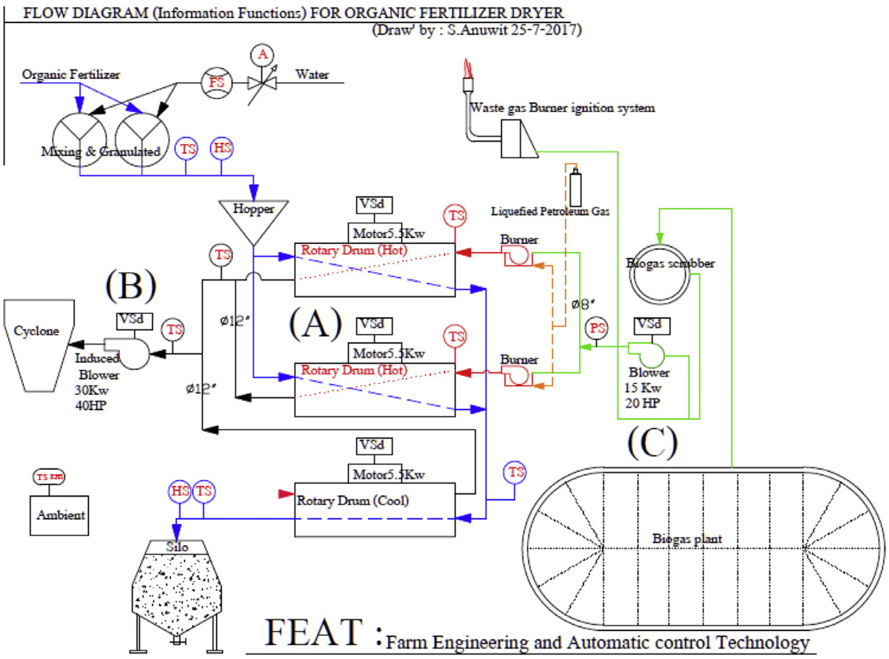

Fig. 2. PI diagram for remote control system.

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system be able to alter the functioning of different variables in the fertilizer making process. More specifically, it can control working rate of the rotary dryer tube, the Cyclone Blower and of Biogas Blower. Consequently, using experimental simulation a set of suitable parameters adjustment is possible.

3. Model

Making mathematical modeling of the whole system is a very complicated task because it involves a lot of unidentified variables. To help ease this complication, only the factors that are most prevailing for eradicating moisture in the fertilizer are selectively used for the mathematical modeling. The location in the production process that is selected for the modeling is the counter-flow rotary dryer (top of the cool rotary drum) as presented in Fig. 3.

The equations used for the mathematical model of the dryer tube are based on Hamed Abbasfard et.al [18] and Lobato et.al, [17]. Note that both models are not time-based model. Because their goal is finding parameters for supervisory control only not for real time control. Like this article, its governing equation system was determined in the distance-based domain while deriving the equation system according to counter flow arrangement as in the work of Lobato et. Al. while relationship of drying rate model of Hamed's work is convenient for our plant and is suit with the experimental data of this work to find other coefficients. However, the time model for feedback automatic control can be done as in work of R. Santivarakorn and T. Radpukdee [22]. By the counter flow characteristic, the total length of the dyer tube is presented in proportion, represented by the letter Z, while Z = 1 is the whole length of the tube (L) as shown in Fig. 3b. To be confident the accuracy of the model, further investigated through experimental validation of the residence time correlation needs to be done [23]. Accordingly, the equations of the mathematical model of the investigated factory are shown as the followings.

Equation for solid moisture (X) at different lengths of the rotary dryer tube is

$$\frac{dX}{dz} = -\frac{R \times M}{S} \tag{1}$$

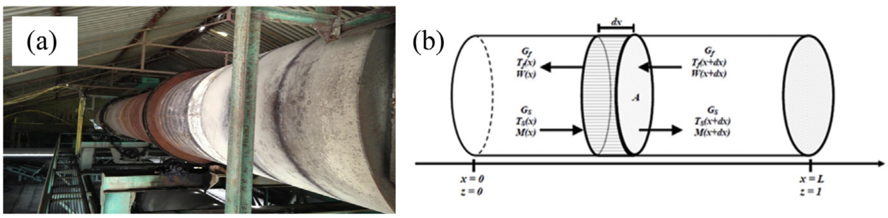

Fig. 3. (a) Counter-Flow Rotary Fertilizer Dryer, (b) control volume of interest.

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For gas moisture (Y) at different lengths of the rotary dryer tube is

$$\frac{dY}{dz} = -\frac{R \times M}{G} \tag{2}$$

While equation for solid temperature (T_s) at different lengths of the rotary dryer tube is

$$\frac{dT_s}{dz} = \frac{+Q - 0.25\lambda RM}{S(C_{pd} + XC_{pv})} \tag{3}$$

And gas temperature (T_g) at different lengths of the rotary dryer tube is

$$\frac{dT_g}{dz} = \frac{Q + C_{pv}RM(T_s - T_g) + Q_p}{G(C_{pg} + YC_{pv})} \tag{4}$$

Energy transfers between solid and gas in a specified volume (Q) is

$$Q = U_{va}V(T_g - T_s) \tag{5}$$

And energy lose on the surface of the rotary dryer tube (Q_p) is

$$Q_p = UpA(T_g - T_{amb}) \tag{6}$$

Which its coefficient of heat transfer (U_{va}) in the total volume and the heat losing coefficient (U_p) of the rotary dryer tube can be described as

$$U_{va} = 0.12(\frac{G}{A})^{0.289}(\frac{S}{A})^{0.541} \tag{7}$$

And

$$U_p = 1.776(\frac{G}{A})^{0.879} \tag{8}$$

the drying rate (R) of the solid substance can be simplified to be

$$R = kX \tag{9}$$

which its fixed rate of drying (k) at a given temperature of solid substance is

$$k = 0.009\exp(\frac{-7.95}{T_g}) \tag{10}$$

while the mass transfer (M) can be determined from Eqs. (11), (12), (13), and (14). The amount of raw material in the rotary drying tube is

$$M = TR \times S \tag{11}$$

And the amount of air-flow (G) in the rotary drying tube is

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$$G = v_{air} \times \rho_{air} \times A \tag{12}$$

Finally, the amount of dried raw material (S) is

$$S = \left(\frac{S_{wet}}{1 + X_0}\right) \tag{13}$$

Initial conditions of the system that using as starting values are

$$X(0) = X_0; Y(1) = Y_0; T_s(0) = T_{s0}; Tg(1) = T_{g0}; \tag{14}$$

The following regressive equations are used for resolving the undefined variables of collected data from the mounted instrument as shown in Fig. 4.

Regressive equation for percentile operation of the dryer performance and the time that the fertilizer remains in the dryer tube (TR), when R-square = 0.9894 and Adjusted R-square = 0.9867 according to the Curve Fitting of real collected data in Fig. 4 is

$$TR = 0.09866\, a^2 - 20.43\, a^1 + 1135 \tag{15}$$

For the cyclone performance and the wind speed (per second) of the dryer tube (v_{air}), a curve fitting is explained by Eq. (16) when R-square = 0.9913 and adjusted R-square = 0.9884. The Curve Fitting of the Eq. (16) is shown in Fig. 5.

$$v_{air} = 0.00027b^2 - 0.02175b + 1.106 \tag{16}$$

Thirdly, the percentile of the Biogas Blower performance and the temperature of the burner (Tg (Z = 1)), when R-square = 0.9999, Adjusted R-square = 0.9998 is described in Eq. (17) (The Curve Fitting of Fig. 6)

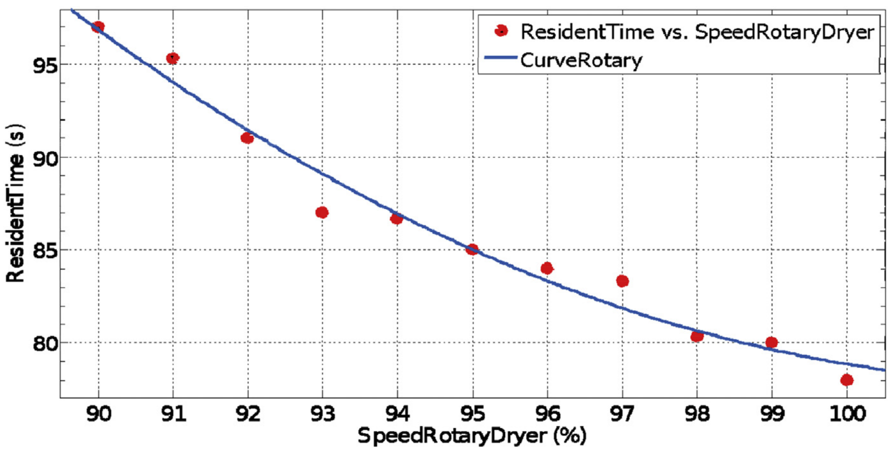

Fig. 4. Schematic illustration of the reciprocating pin-on-flat test apparatus.

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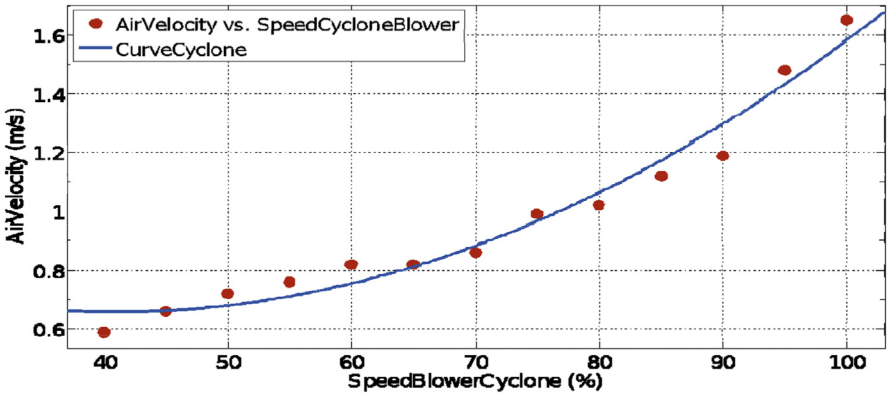

Fig. 5. Schematic illustration of the reciprocating pin-on-flat test apparatus.

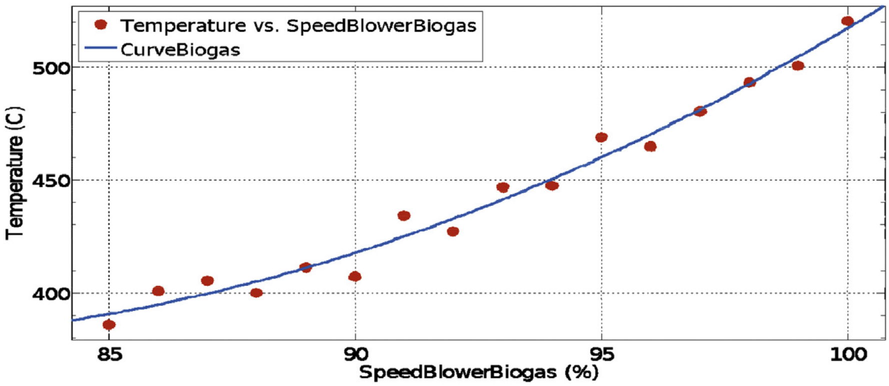

Fig. 6. Schematic illustration of the reciprocating pin-on-flat test apparatus.

$$T_{g0} = 0.3034c^2 - 47.67c + 2251 \quad (17)$$

3.1. Simulation results

A numerical method was applied to obtain the results of the mathematical model due to nonlinearity of the system differential equations. The necessary results were temperature and moisture value that varying along the length of the rotary dryer. The results of the derivatives were obtainable via the exploitation of Runge-Kutta 4th order method. The Runge-Kutta is a modification of the Tayler's method in which its error boundary of higher order term still exists. While there is no need to deal with the higher order derivative of the system. Consequently, the Runge-Kutta 4th order method is more accurate than the lower order method. Parameters and variables as shown in Table 1 which its parameters value came from the instruments collecting data (Fig. 7). The patterns of moisture change at the different lengths of the rotary dryer is presented Fig. 8 illustrated trend of temperature in the dryer tube. The incoming wet solid of 33 °C at the entrance of the drum was flown to the end and its temperature was raised to be 94 °C due to heat transfer from burner (520 °C).

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Table 1. Parameters and variables in calculation.

Symbol	value	value (per unit)
A	Cross-sectional area of the of rotary dryer	1.131 (m^2)
D	Diameter	1.2 (m)
C_{pd}	Specific heat of raw material	3.5 (kJ/kgoC)
C_{pg}	Specific heat of dry air	1.009 (kJ/kgoC)
C_{pv}	Specific heat of vapor	4.1858 (kJ/kgoC)
C_{pw}	Specific heat of water	1.1723 (kJ/kgoC)
L	Length of the tube of rotary dryer	10 (m)
S_{wet}	Flow speed of wet material	0.79 (kg/s)
T_{g0}	Initial temperature of gas	520 (oC)
T_{s0}	Initial Temperature of solid	33 (oC)
T_{amb}	External temperature	35 (oC)
V	Volume of rotary dryer	11.3097 (m^3)
X_0	Initial moisture of the solid	0.46 (kg water/kg dry solid)
Y_0	Initial moisture of the air	0.019 (kg water/kg dry solid)
λ	Volume of latent heat during vaporization	2,502 (kJ/kg)
TR	Average time remaining in the dryer	78 (s)
G	Rate of air flow	1.27 (kg/s)
ρ_{air}	Level of air density	0.675 (kg/m^3)

While hot gas counter flew against the wet solid exiting at the temperature of 88 °C. The pattern of the moisture change at different lengths of the dryer's tube is presented in Fig. 9. Again, the wet solid entered the dryer at its moisture of 0.46 kg water/kg dry solid then transferred mass of water to the hot gas. Due to heat and mass transfer along the length of the drum, the solid moisture was reduced to be 0.22 kg water/kg dry solid while the moisture of hot gas was raised from 0.019 kg water/kg dry air to be 0.104 kg water/kg dry air.

3.2. Testing for accountability of the results of mathematical model with authentic system

The results obtained from the mathematical model was compared with the data from SCADA system and with the data from real measurement in order to inspect its accuracy and accountability. The results of this comparison are portrayed in Table 2.

The deviations of the results from the models and that of their comparative counterparts oriented around the following areas. Temperature deviation in solid substance was 1.79 %, and 4.72 % for hot gas, while the moisture deviation in solid substance was 3.54%. These figures portray that the results of the mathematical model can be used to predict the working system of the rotary dryer.

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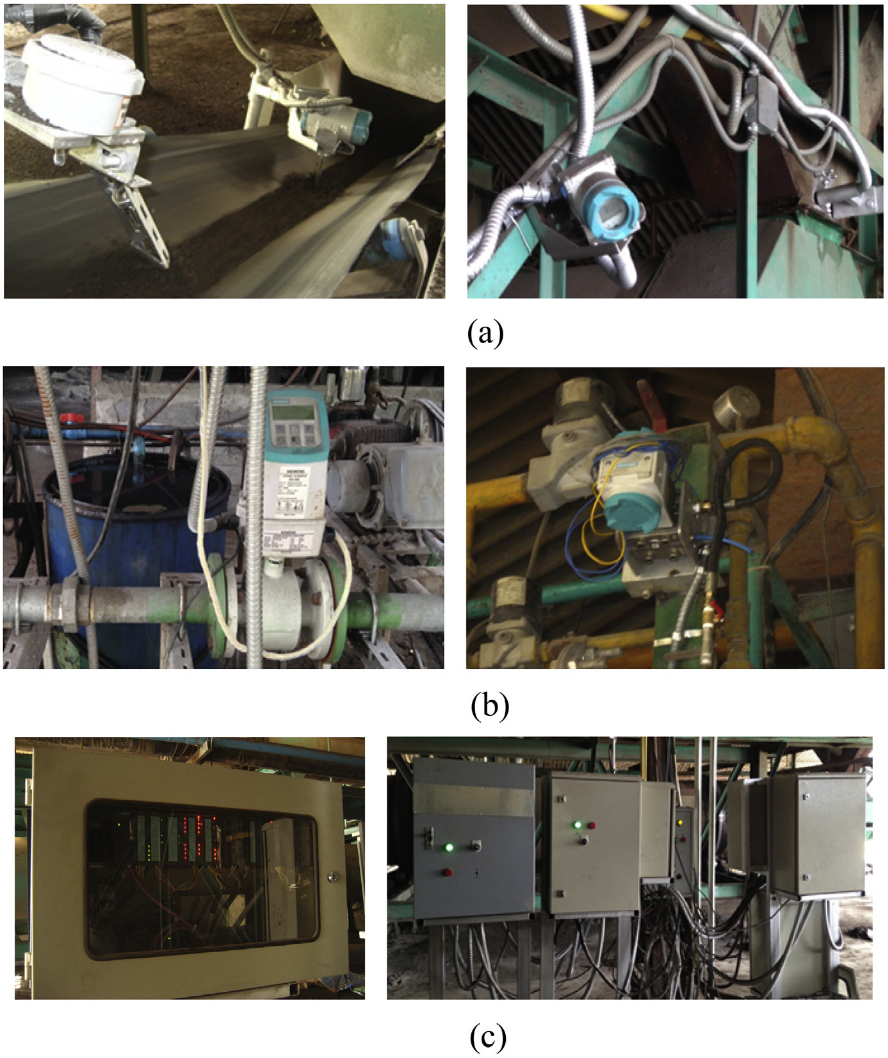

Fig. 7. Illustrate instruments, actuators, and controller; (a) temperature and moisture sensors of wet solid, (b) pressure and flow sensors of biogas and water, (c) rotary drums speed control and main remote I/O.

4. Results

Application of factorial type 3^k for experimental design will be addressed in this section while its results are following. The Factorial Type 3^k focused performances, shown in percentile of the rotary dryer (A), the cyclone blower (B), and the biogas blower (C) to see to what extent do mechanical performances contribute to the consumption of electricity, biogas and level of product moisture. The maximum and the minimum rate of performances for each of the above variables are set as follows. The minimum and the maximum of performance rate of the rotary dryer were set at 90 % and 100 %, respectively. Any performance rate lower than this bottom line can cause fertilizer to stuck in the drying tube. The minimum and the maximum working rates for cyclone blower were at 40 % and 100%, respectively. If the working rate of

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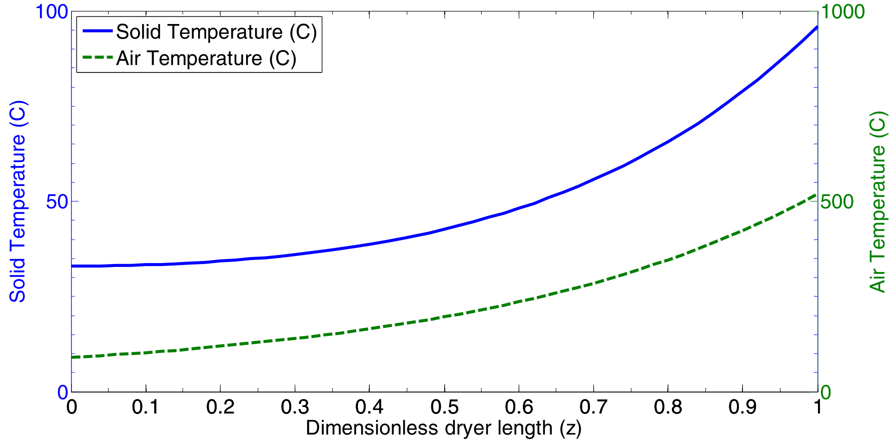

Fig. 8. Tendency of temperature change at different lengths of rotary dryer.

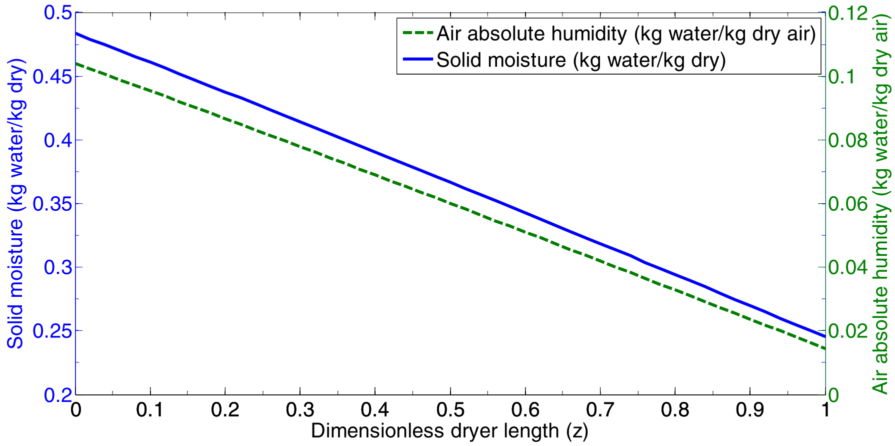

Fig. 9. Tendency of moisture change at different lengths of rotary dryer.

cyclone blower is lower than 40%, the air flow inside the tube is going to be very slow, resulting in the collection of biogas in the tube which can lead to blasting in the tube when the burner is ignited during the turning on process. While the input of burners was set at 85% up to 100% for the performances of the biogas blower, if the performance of the biogas blower is lower than minimum, neither of the burners will be turned on. The data about the consumption of the electricity and the biogas is obtained from the real usage record. The moisture of the product is obtained from the validated model as presented in Table 3.

4.1. Results of the response surface metrology analysis

Data on Table 3 can be analyzed to show statistic figures relating to the use of electricity and biogas, and the volume of moisture by using a program called MINITAB. The results of this analysis are presented in Tables 4, 5, and 6. It is observed statistically that the usage of electricity, the value of moisture and the usage of gas were

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Table 2. Comparison of authentic data collected from the case study site and the data form mathematical modeling.

Run No.	Values of variables prior before drying (authentic measurement)								Values of variables after drying (authentic measurement)			Values of variables (in the model)		
	TR	S_{wet}	G	Tamb	Ts(z = 0)	Tg(z = 1)	X	Y	Ts	Tg	X	Ts	Tg	X
							(z = 0)	(z = 1)	(z = 1)	(z = 0)	(z = 1)	(z = 1)	(z = 0)	(z = 1)
	(s)	(kg/s)	(kg/s)	(°C)	(°C)	(°C)	(%db)	(%db)	(°C)	(°C)	(%db)	(°C)	(°C)	(%db)
1	78.1	0.76	1.5	29.9	30.1	522.2	46.1	2	98.4	98.5	24.2	96.37	89.9	23.81
2	79.23	0.81	1.6	30	30.4	517.2	45.2	2	95.2	94.1	24.4	94.91	89.13	23.21
3	81.33	0.72	1.6	30.2	30.3	521.7	46.3	2	95.3	92.4	23.5	94.89	88.82	22.81
4	82.31	0.76	1.6	30.2	30.6	521.7	43.9	2	92.1	82.7	24.2	94.61	88.7	22.41
5	82.33	0.76	1.7	31.7	31.5	522.6	42.3	1.9	98.7	92.8	21.9	94.33	88.5	22.01
6	84.2	0.74	1.6	31.8	31.6	522.1	48	1.9	95.1	88.6	20.7	94.05	88.3	21.49
7	85.67	0.72	1.6	31.5	31.8	519.6	46.8	1.9	92.7	86.3	21.5	93.77	88.1	21.04
8	88.91	0.71	1.6	32.7	31.4	517.4	46.2	1.9	95.4	92.7	21.6	93.49	87.9	20.57

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Table 3. Percentile of devices' performances and their effects on dependent variables.

No.	Percentile of performance			used electricity	Level of moisture	Used gas
	(A)	(B)	(C)	kW/h	%db	kg/h
1	90	70	100	11.79	0.1959	27.67
2	100	100	92.5	8.95	0.2379	21.32
3	95	70	92.5	8.19	0.2214	21.72
4	90	100	92.5	8.78	0.1921	21.59
5	100	70	92.5	8.1	0.2415	21.43
6	100	100	85	9.03	0.2379	20.33
7	95	40	100	11.58	0.2249	25.88
8	95	100	100	14.39	0.2149	26.11
9	100	40	85	6.33	0.2474	18.25
10	95	70	85	7.65	0.223	20.74
11	95	70	92.5	8.31	0.2214	22.43
12	100	70	100	12.04	0.2395	27.89
13	90	70	92.5	8.11	0.1978	21.35
14	95	100	92.5	8.95	0.2164	23.11
15	100	70	85	7.91	0.2431	18.95
16	95	40	92.5	6.62	0.2266	22.67
17	95	70	100	12.01	0.2194	25.82
18	95	100	85	8.75	0.2182	20.51
19	95	40	85	6.18	0.2279	19.53
20	90	40	92.5	6.56	0.2046	21.42
21	90	40	100	11.87	0.202	25.27
22	90	100	100	14.11	0.19	27.41
23	100	40	100	11.64	0.2435	26.24
24	90	40	85	6.37	0.2067	18.4
25	90	70	85	8.03	0.1997	19.26
26	100	100	100	14.77	0.2361	27.51
27	100	40	92.5	6.04	0.2454	21.92
28	90	100	85	8.94	0.1936	17.89

presented properly in a quadratic model. P-values of each of these factors were found less than 0.05 (p-values for electricity use, moisture and biogas use were 0.0001, 0.0001, 0.0001, respectively). In the Lack-of-Fit Test, the p-value was found higher than 0.05 (p-values for electricity usage, moisture and gas use were 0.1426, -, 0.4049, respectively). However, p-value of moisture was not obtained in the Lack-of-Fit Test since the moisture data was from the mathematical model, it did

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Table 4. Statistic records of electricity use.

model	R^2	$R^2_{pred.}$	lack of fit	p-value model
Quadratic	0.9696	0.9498	0.1426	0.0001

Table 5. Statistic records of moisture value.

model	R2	R2pred.	lack of fit	p-value model
Quadratic	0.9997	0.9994	-	0.0001

Table 6. Statistic records of biogas use.

model	R2	R2pred.	lack of fit	p-value model
Quadratic	0.9171	0.8594	0.4049	0.0001

not make any difference between the predicting results and the result from true measurement, this is evidenced in the values of Adj.R^2 and Pred.R^2 which were presented equally at 0.999. This shows that the patterns of regression as modelled in the experiment is acceptable for predicting and allocating variables that are suitable for application in remote supervisory control system, these factors include the use of electricity, moisture and gas usage. Table 7 shows that in each equation, the coefficient values of both the R^2 and the predicted R^2 are high, closer to 1, representing a pattern of proper regression.

Fig. 10 shows level of electricity use observed from the response surface metrology analysis when the performance rate of the rotary dryer was set at a moderate level. Under this circumstance, the percentiles of work performances of the cyclone blower and of the biogas blower were increased, so the rate of electricity consumption is accordingly high. This is because increment of mechanical load on both blowers due to set point has been increased.

Fig. 11 shows characteristic of response surface metrology and the level of product moisture observed when the working rate of the biogas blower was set at a moderate

Table 7. Equation for the prediction of proper variables to be used in the remote supervisory control system.

properties	Regression	R2adj.
Electricity usage	344.57−0.12A-0.07B-7.48C + 0.04C2	96.96
Moisture rate	-0.69 + 0.02A + 0.04C2	99.97
Gas usage	30.23 + 3.65A-0.04B-3.12C-0.02A2 + 0.02C2	91.71

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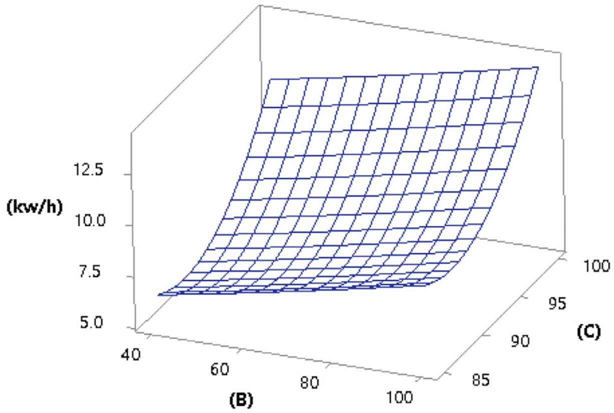

Fig. 10. Characteristics of Response Surface Metrology and electric consumption observed when rotary dryer performance was moderate.

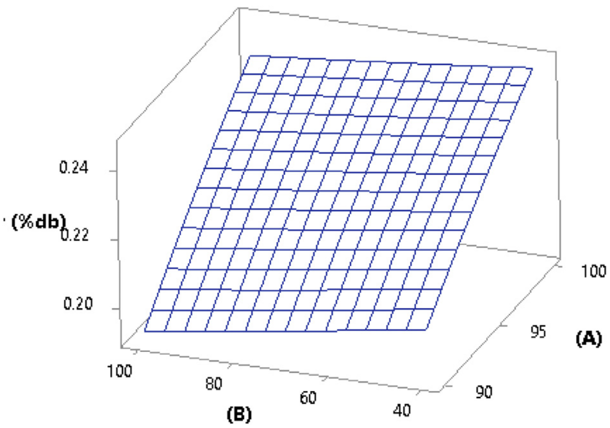

Fig. 11. Response surface metrology of moisture test in biogas blower with moderate performance.

level. It is shown that when the percentile of the working rate of the rotary dryer was lowered, leading to the decreasing of the product moisture because lowering rotary dryer working rate allowed longer residential time in the drum of the wet solid. Additionally, when the working rate of cyclone blower is higher, the level of moisture is lowered due to the humid gas was drawn out of the dryer and the hot dry gas was entered to the system. Therefore, the more drying rate was occurred. It is also observed in this analysis that the percentile of the performance of the rotary dryer has the most effect to level of moisture.

Fig. 12 shows characteristic of the response surface metrology of the gas usage that was observed when working rate of the rotary dryer was set at a moderate level. This picture depicts that working percentile of the biogas blower is the only variable that affects the amount of biogas use in the fertilizer industry. Even though, the cyclone blower may affect increment of the biogas usage. The effect is quite small because the drying process must maintain temperature inside the rotary drum. so the hot gas

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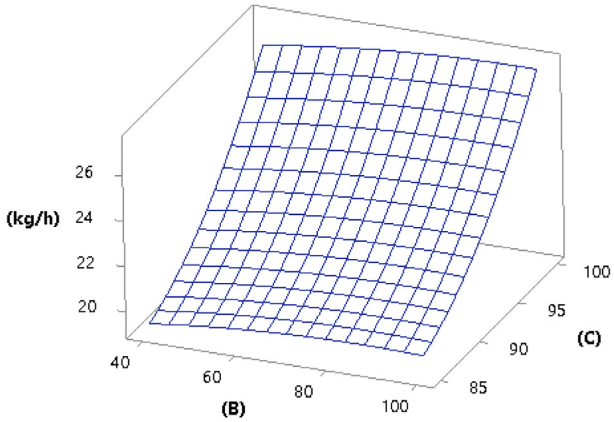

Fig. 12. Characteristic of response surface metrology showing the use of biogas with moderate working percentile of rotary dryer.

Table 8. Identifications of the goals for proper variables in the case study site.

Name	Goal	Lower Limit	Upper Limit
A	range	90	100
B	range	40	100
C	range	85	100
Pow. (kW/h)	minimize	6.04	14.77
Hum. (%db)	minimize	19	24.74
Gas. (kg/h)	minimize	17.89	27.89

can not be induced out improperly. While the biogas usage mainly depends on working condition of a process's burner which proportional to working percentile of the biogas blower directly.

The baseline of satisfactory level for this experiment relies on the extent that the usage of electricity and biogas and the level of humidity are kept optimum values. Table 8 shows acceptable percentiles of the performances of rotary dryer (A), the cyclone blower (B), and the biogas blower (C).

In the satisfactory analysis of the experiment show in Table 9, in order to obtain the effectiveness of the remote supervisory control system, it is important for the percentile of the rotary dryer performance be set at 90%, and the figures were 73.52% and 88.16% for cyclone blower and biogas blower, respectively. The level of satisfaction was gauged at 84.8 %.

4.2. Experimental results

The accountability of the variables derived from the modeling should be reconfirmed to verify if the variables can really be applied with the remote supervisory control

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Table 9. Identifications of the goals for proper variables for the remote supervisory control system.

A (%)	B (%)	C (%)	Pow. (kW/h)	Hum. (%db)	Gas. (kg/h)	Desirability (%)
90	73.52	88.16	7.3	19.84	19.9	84.8
90	61.9	88.74	6.86	20.07	20	84.6
90	99.5	87.48	8.4	19.32	19.63	84.0

system. In the confirmation experiment, the reliability of the variables should be at 95%. In the experiment that was attempted to find the best variables for the remote supervisory control system, it was observed that the proper working percentiles for the rotary dryer, the cyclone blower, and the biogas blower were found at 90%, 73.25%, and 88.16%, respectively. In the confirmation experiment, these variables' values were used with the remote supervisory control system to ascertain whether they can be put into a real work. The working performances of these variables based on their values as mentioned above were recorded every 30 minutes from 8.30 AM to 4.30 PM, leading to 15 set of data. On the data collection day, the humidity of the air was observed at 0.016−0.019 kg water/kg dry air, and the temperature was between 32-37 degree Celsius. The result of the confirmation experiment is shown on Table 10.

When the proper working percentiles for the rotary dryer (90%), the cyclone blower (73.25%), and the biogas blower (88.16%) were placed on the regressive equation as in Table 7, the electricity usage was calculated at 7.30 kW/h, the moisture rate was at 19.84 %db, and the biogas usage was at 19.90 kg/h, the reliability of these figures was observed at 95%. Notice that the collecting responsive results from the real plant quite close to the regressive equations. The comparison of electrical consumption, moisture, and biogas consumption for non-supervisory and supervisory PLC control is illustrated in Table 11.

Table 10. Result of the confirmation experiment conducted with the reliability at 95%.

Responsive results	Reliability at 95%		Average
	Min.	Max.	
Electricity usage (kW/h)	7.42	8.91	7.92
Level of moisture (%db)	19.5	23.1	20.9
Biogas usage (kg/h)	19.91	21.67	20.85

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Table 11. Result of the actual system comparison between non-supervisory and supervisory PLC control.

Parameters of interest	Responsive results		% of resources reduction
	Non-PLC	PLC supervisory	
Electricity usage (kW/h)	14.07	7.92	44%
Level of moisture (%db)	23.8	20.9	12%
Biogas usage (kg/h)	25.98	20.85	20%

5. Conclusion

This research involved using the Factorial Type 3^k in an experiment that attempted to find the proper value of the variables to be used in a remote supervisory control system. Collecting data from the real site during implement the trial working percentiles of the three actuators hasn't been done concerning that the experiment might cause damage to the production system of the targeted factory. Therefore, the mathematical model was used to predict the level of electricity use, level of moisture, and level of biogas usage instead of an on-site data collection during the proper values seeking process. The best performance value of the variables was obtained from the Response Surface Metrology (RSM). They were related to the lowest usage of electricity, the lowest moisture and the lowest usage of biogas.

Satisfactory analysis was also used to test for the proper value of the variables to be used with the remote supervisory control system. Percentiles of the performances of rotary dryer (A), Percentiles of the performances of cyclone blower (B), and Percentiles of the performances of biogas blower (C) were used for telling the level of satisfaction on the variables when they were applied on the remote supervisory control system. These ranges of condition were set on the satisfactory test; $90 < A < 100$, $40 < B < 100$ and $85 < C < 100$. The results show that the proper performance values of the rotary dryer, the cyclone blower, and the biogas blower were 90%, 73.52%, and 88.16%. These values were observed to make the system to consume electricity at the rate of 7.30 kW/h, the moisture was observed at 19.84 %db, and the consumption of biogas was at 19.90 kg/h. The level of satisfaction was gauged at 84.8%.

The confirmatory experiment was also conducted to test the reliability of the variable value to be used in the remote supervisory control system. It was observed in this experiment that the rate of electricity usage, level of moisture and the usage of biogas were found to reach the reliability at the level of 95%. This result apparently ascertains that the variables that were predicted from the mathematical model can be effectively used in the remote supervisory control system of the fertilizer factory. And the implementation results in significant reduction of energy resources with the acceptable product moisture.

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Declarations

Author contribution statement

Anuwit Sonsiri: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Voravee Punyakum: Analyzed and interpreted the data; Wrote the paper.

Thana Radpukdee: Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

[1] A. De Almeida, et al., VSDs for Electric Motor Systems. Final Report, SAVE Programme, European Commission, Brussels, 2001.

[2] R. Saidur, et al., Applications of variable speed drive (VSD) in electrical motors energy savings, Renew. Sustain. Energy Rev. 16 (1) (2012) 543−550.

[3] F. Malrait, A.K. Jebai, K. Ejjabraoui, Power conversion optimization for hydraulic systems controlled by variable speed drives, J. Process Contr. (2017).

[4] R. Bayindir, Y. Cetinceviz, A water pumping control system with a programmable logic controller (PLC) and industrial wireless modules for industrial plants—an experimental setup, ISA Trans. 50 (2) (2011) 321−328.

 https://doi.org/10.1016/j.heliyon.2018.e01087

[5] J. Figueiredo, M.A. Botto, M. Rijo, SCADA system with predictive controller applied to irrigation canals, Contr. Eng. Pract. 21 (6) (2013) 870−886.

[6] W. Bolton, Programmable Logic Controllers, Newnes, 2015.

[7] J.A. Rehg, G.J. Sartori, Programmable Logic Controllers, Prentice-Hall, Inc, 2006.

[8] S.A. Boyer, SCADA: Supervisory Control and Data Acquisition, International Society of Automation, 2009.

[9] D. Peharda, I. Ivanković, N. Jaman, Using data from SCADA for centralized transformer monitoring applications, Proc. Eng. 202 (2017) 65−75.

[10] A. Salihbegovic, et al., Web based multilayered distributed SCADA/HMI system in refinery application, Comput. Stand. Interfac. 31 (3) (2009) 599−612.

[11] P. Kyratsis, N. Bilalis, A. Antoniadis, CAD-based simulations and design of experiments for determining thrust force in drilling operations, Comput. Aided Des. 43 (12) (2011) 1879−1890.

[12] M. Silva, et al., Modelling of fertilizer drying in a rotary dryer: parametric sensitivity analysis, Braz. J. Chem. Eng. 29 (2) (2012) 359−369.

[13] D.C. Montgomery, Design and Analysis of Experiments, John wiley & sons, 2017.

[14] R.H. Myers, et al., Response surface methodology: a retrospective and literature survey, J. Qual. Technol. 36 (1) (2004) 53.

[15] K. Kaharudin, et al., Optimization of process parameter variations on leakage current in SOI vertical double gate MOSFET device, J. Mech. Eng. Sci. 10 (1) (2016) 1895−1907.

[16] E. Arruda, Comparison of the Performance of the Roto-fluidized Dryer and Conventional Rotary Dryer, F ederal University of Uberlândia, Uberlândia-Brazil, 2006.

[17] F. Lobato, et al., Estimation of drying parameters in rotary dryers using differential evolution. Journal of Physics: Conference Series, IOP Publishing, 2008.

[18] H. Abbasfard, et al., Mathematical modeling and simulation of an industrial rotary dryer: a case study of ammonium nitrate plant, Powder Technol. 239 (2013) 499−505.

[19] C. Herrera-Cáceres, et al., Optimization of the harvest planning in the olive oil production: a case study in Chile, Comput. Electron. Agric. 141 (2017) 147−159.

 https://doi.org/10.1016/j.heliyon.2018.e01087

[20] E. Santoro, E. Soler, A. Cherri, Route optimization in mechanized sugarcane harvesting, Comput. Electron. Agric. 141 (2017) 140−146.

[21] Y. Rousselet, V.K. Dhir, Numerical modeling of a co-current cascading rotary dryer, Food Bioprod. Process. 99 (2016) 166−178.

[22] R. Santivarakorn, T. Radpukdee, Multi sliding mode control with residual error estimation for a counter flow rotary dryer, Adv. Sci. Lett. 19 (11) (2013) 3263−3271.

[23] Q. Xu, S. Pang, Mathematical modeling of rotary drying of woody biomass, Dry. Technol. 26 (11) (2008) 1344−1350.

 https://doi.org/10.1016/j.heliyon.2018.e01087