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Comparison of Drying Parameter Optimization of Lemon Grass

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Abstract: The purpose of this study is to determine the optimum condition of humidity contents, drying rate and energy in the experiment of drying of lemon grass in the fluidized bed dryer with presence of inert particles. The studied drying parameters were temperature, air velocity, mass of sand and drying time. The optimization methods used in the studies were Taguchi, Pareto, ANOVA, XLSTAT and Design- Expert. Design of experiment (DOE) used in this study was three levels and three factors (3L3F) where L_{27} orthogonal array was implemented. DOE of three levels and four factors (3L4F) was applied for the optimization to observe the effect of drying time which implemented L_{81} orthogonal array. The temperatures were varied at 40°C, 50°C, 60°C; the air velocities were ranged at 0.61 m/s, 0.73 m/s, 0.85 m/s; mass of sand as an inert particle used in the experiment were 0 g, 50 g and 100g. Lastly, the drying time was conducted at 10 min, 20 min and 30 min. In optimization process, Taguchi and Pareto ANOVA are the most appropriate statistical method to optimize the data due to its simplicity and no ANOVA table involved. For DOE of 3L3F, the optimum value of humidity contents was 0.0658 g/g aq which occurred at temperature of 60°C, air velocity of 0.85 m/s and 100g of sand. The optimum value of drying rate was 0.2497 g/g min which occurred at temperature of 50°C, air velocity of 0.85 m/s and 50 g of sand. Finally the optimum value of energy occurred at temperature of 40°C, air velocity of 0.61 m/s and 100 g of sand.

Key words: Drying · Taguchi · Pareto ANOVA · XLSTAT · Design Expert · Lemon grass · Optimization

INTRODUCTION

Drying is a process of removing the moisture content from a component which is either in the form of solid, half solid, solution or slurry [1, 2]. This process can be said as one of the oldest technology which nowadays becomes very common and important in our life. Drying plays an important role in the field of chemical, agriculture, biotechnology, food, polymer, ceramic, pharmaceutical, paper and wood processing industry [3]. The main purposes of drying are to increase the lifespan of a component (food), reduce the weight of the component (clay soil) for easier delivery and change the form of a component (detergent) so that it can be used and kept easily.

Traditional method of drying by using sun light is not the best drying process as this brings up the problems of sanity and quality of the products. Hence, many dryers have been invented to overcome the problems. One of the commercially used dryer is fluidized bed dryer. Fluidized bed dryer has high thermal efficiency and it is suitable to be used in many fields and sectors [4]. Furthermore, the existence of inert material will increase the fluidization behaviour of the drying products [5]. Inert materials will act as heat carrier and it transfers the heat from the air into the products. Besides that, by drying the products in a fluidized bed dryer and inert material, the quality of the products will be better compared to sun drying. The fluidized bed dryer is the suitable equipment for the drying process since the drying is gently and direct heating is avoided.

Scientific name for lemon grass is *cymbopogon ciatrus*. Recently, many researched have been done on lemon grass to study about its potential usage in our daily life. Lemon grass is not only being used in cooking purpose, but it contains some important component such as citronellal, linalool and citronellol which might be useful in preserving food [6], replacing petrochemical for

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synthesizing of other chemical substances [7], medicine like leukemia [8] as well as insecticide [9]. Hence, this study will carry out the drying of lemon grass in fluidized bed dryer with the presence of inert materials. This objective is achieved by doing the comparison study at different optimization methods (Taguchi, Pareto, ANOVA, XLSTAT and Design- Expert) and the optimum drying conditions.

MATERIALS AND METHODS

Fluidized Bed Dryer: Lemon grass applies in this drying experiment must were cut off and sliced in same size and kept in a container. Lemon grass average size applies in this experiment were cut into 3 mm x 5 mm in shape and kept in the refrigerator before the experiment was carried out. The weight of leaves used for each run is 50 g. Sand as the inert particles used has size of 109 µm and density of 1968.14 kg/m^3. Sand applies in this experiment is sand from Geldart group particle, A.

Equipment: Fluidized bed bin quick dryer (Model TG 100, Retsch GmbH & Co., Germany) as shown in Fig. 1 was used for the experiment. This fluidized bed is cylindrical in shape, approximately 18 cm in diameter and 22 cm high, with a voltage of 230 V 50 Hz. Chrome Meter CR-400 is used for the colorimetric testing on the leaves.

Before starting the experiment, the dryer will be turned on for 10 minutes to warm it up. The experiment will be carried out at different temperature, air velocity, mass of sand and drying time. After every 2 minutes of drying, the leaves are weighed and the run is repeated until a nearly steady reading is achieved. The leaves will be sieved out and separated from the sand by using sieve when the weight of the leaves is taken. This is to prevent the sand from disturbing the result since a small portion of sand loses to the environment during the run. Moisture content lost will be calculated using formula that has been stated in calculation method. Table 1 shows the operating parameters for lemongrass.

Optimization Methods

Design of Experiment (DOE): In the optimization process, appropriate selection on DOE is important before the analysis. For three levels and three factors, a standard L_{27} orthogonal array is chosen. This orthogonal array is chosen due to its minimum number of experiment trials. The experiment trial is represented by each row in the matrix. Meanwhile for three levels and four factors, a standard of L_{81} orthogonal array is chosen.

Fig. 1: Fluidized bed bin quick dryer

Table 1: Operation Parameter for lemongrass

Experiment set	Temperature, oC	Air velocity, m/s	Mass ratio, 1:X	Drying time (min)
A1	40	0.61	None	30
A2	40	0.61	1	30
A3	40	0.61	2	30
A4	40	0.73	None	30
A5	40	0.73	1	30
A6	40	0.73	2	30
A7	40	0.85	None	30
A8	40	0.85	1	30
A9	40	0.85	2	30
A10	50	0.61	None	30
A11	50	0.61	1	30
A12	50	0.61	2	30
A13	50	0.73	None	30
A14	50	0.73	1	30
A15	50	0.73	2	30
A16	50	0.85	None	30
A17	50	0.85	1	30
A18	50	0.85	2	30
A19	60	0.61	None	30
A20	60	0.61	1	30
A21	60	0.61	2	30
A22	60	0.73	None	30
A23	60	0.73	1	30
A24	60	0.73	2	30
A25	60	0.85	None	30
A26	60	0.85	1	30
A27	60	0.85	2	30

Taguchi Method: Only ‘the smaller the better’ and ‘the bigger the better’ are applicable in optimization of humidity contents and drying rate respectively. This is the simple method which is no ANOVA table and F-test. Table 2 shows the optimizations method for lemongrass.

Table 2: Moisture content for drying of Lemongrass

Experiment set	Temperature, oC	Air velocity, m/s	Mass ratio, 1:X	Drying time (min)	Moisture content, X (g/g ak)
A1	40	0.61	None	30	1.2162
A2	40	0.61	1	30	0.3050
A3	40	0.61	2	30	0.1430
A4	40	0.73	None	30	0.8142
A5	40	0.73	1	30	0.3158
A6	40	0.73	2	30	0.1696
A7	40	0.85	None	30	0.4122
A8	40	0.85	1	30	0.3266
A9	40	0.85	2	30	0.1962
A10	50	0.61	None	30	0.8875
A11	50	0.61	1	30	0.2343
A12	50	0.61	2	30	0.1189
A13	50	0.73	None	30	0.6075
A14	50	0.73	1	30	0.2590
A15	50	0.73	2	30	0.1249
A16	50	0.85	None	30	0.3274
A17	50	0.85	1	30	0.2838
A18	50	0.85	2	30	0.1310
A19	60	0.61	None	30	0.5588
A20	60	0.61	1	30	0.1635
A21	60	0.61	2	30	0.0947
A22	60	0.73	None	30	0.4007
A23	60	0.73	1	30	0.2023
A24	60	0.73	2	30	0.0803
A25	60	0.85	None	30	0.2426
A26	60	0.85	1	30	0.2410
A27	60	0.85	2	30	0.0658

For criterion of 'the smaller the better', the formula used to calculate Signal-Noise (SN) ratio to minimize humidity contents and energy is shown below [10]:

$$S/N = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

where y_i is the independent variable and n is the number of replicates. Meanwhile, 'the bigger the better' criterion used to calculate SN ratio to maximize drying rate is depicted below [11]:

$$S/N = -10\log_{10}\frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

In the plot of Taguchi, the level which gives the highest value of sum of SN ratio is the optimum value for that factor.

Pareto ANOVA: Pareto ANOVA analysis is actually prolonged from Taguchi method where it uses the previously calculated of sum of SN ratio for all factors at each level. The next step in this method is to calculate the value of squares of difference (S) for each factor. For instance, the formula of sum of squares of difference for factor A (S_A) is depicted below [12].

$$S_A = (A_0 - A_1)^2 + (A_0 - A_2)^2 + (A_1 - A_2)^2 \quad (3)$$

After obtaining values of sum of squares of difference for all factors, contribution ratio for al factors can be determined by using the formula below [13].

$$\text{Contribution Ratio (\%)} = \frac{S_A}{S_T} \times 100\% \quad (4)$$

By using the calculated values of contribution ratio for all factors, the pareto diagram can be constructed in order to observe the major significant effect contributor on the dependent variables such as humidity contents, drying rate and energy. Therefore, final conclusion can be made from this analysis and it validates the result of optimum condition obtained from Taguchi.

Regression Analysis by XLSTAT: Before performing regression analysis by XLSTAT, the type of model of equation which fits on the experimental data need to be determined. Second-order polynomial model is used as prediction model as shown below [12].

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{\substack{i=1 \\ i<j}}^{k-1} \sum_{j=2}^{k} \beta_{ij} x_i x_j \quad (5)$$

where Y is response (humidity contents, drying rate and energy) and X_i is independent variables, *i*, influencing the responses Y. X_j is independent variables, *j*, influencing the responses Y. β_0 is regression coefficient of variables for intercept while β_i is regression coefficient of variables for linear. β_{ii} is regression coefficient of variables for quadratic and β_{ij} is regression coefficient of variables for interaction meanwhile k is number of variables.

Also before performing regression by XLSTAT, the model terms in second-order polynomial model have to be calculated first. For DOE of three levels and three factors, model terms such as 'AB', 'AC', 'BC', 'A^2', 'B^2' and 'C^2' need to be calculated where the model terms of 'A', 'B' and 'C' are temperature, air velocity and mass of sand respectively. Whereas for DOE of three levels and four factors, model terms of 'AB', 'AC', 'AD', 'BC', 'BD', 'CD', 'A^2', 'B^2', 'C^2' and 'D^2' need to be calculated where 'D' is drying time.

The result of regression from XLSTAT show R^2, analysis of variance (ANOVA), lower and upper bound of 95% confidence interval, model of equation, predicted value of dependent variable with the residuals and plots of 95% confidence interval and actual versus predicted. The lowest predicted value of humidity contents and the highest predicted value of drying rate is optimum value.

Response Surface Method by Design-Expert: Design Expert is software that provides powerful statistical tools which can be used for optimization such as two-level factorial screening designs which identify the important factors that affect the process etc. The outcome from Response Surface Method (RSM) give easily view of response surfaces from all angles with rotatable 3D plots, interactive 2D graphs and point prediction to find the optimum condition.

RESULTS AND DISCUSSION

The fractional factorial designs used L_{27} orthogonal array for three levels and three factors and L81 orthogonal array for three levels and four factors. Levels for each factor in the matrix were represented by '0', '1' and '2' where '0' is the minimum value and '2' is the maximum value. Table 3 shows three levels and three factors and Table 4 shows three factors and four levels used in this experiment.

Taguchi Method: Taguchi method is one of common optimization tools practiced by industrial engineers and chemists to maximize yield of product at optimum conditions. This method involves in calculation of SN ratio where it has different criteria which are 'the smaller the better', 'the bigger the better' and 'nominal is the best'. In Taguchi, the analysis is simple due to analysis of means and graphing the effects which identify the significant factors without using ANOVA.

Humidity Contents: The values of SN ratio for 'the smaller the better' from L_{27} were plotted in Figure 2 to identify the optimum condition at each factor. Based on relative stiffness, mass of sand has the greatest effect on humidity contents of drying of lemon grass and followed by temperature and air velocity. It is obviously observe that the optimum condition of humidity for three levels and three factors is at A2 (temperature at 60°C), B2 (air velocity at 0.85 m/s) and C2 (mass of sand at 100 g).

Table 3: Three levels and three factors in the experiment

Factor/Level	0	1	2
A – Temperature (?C)	40	50	60
B – Air velocity (m/s)	0.61	0.73	0.85
C – Mass of sand (g)	0	50	100

Drying time is constant at 30 minutes

Table 4: Three levels and four factors in the experiment

Factor/Level	0	1	2
A – Temperature (?C)	40	50	60
B – Air velocity (m/s)	0.61	0.73	0.85
C – Mass of sand (g)	0	50	100
D – Drying time (min)	10	20	30

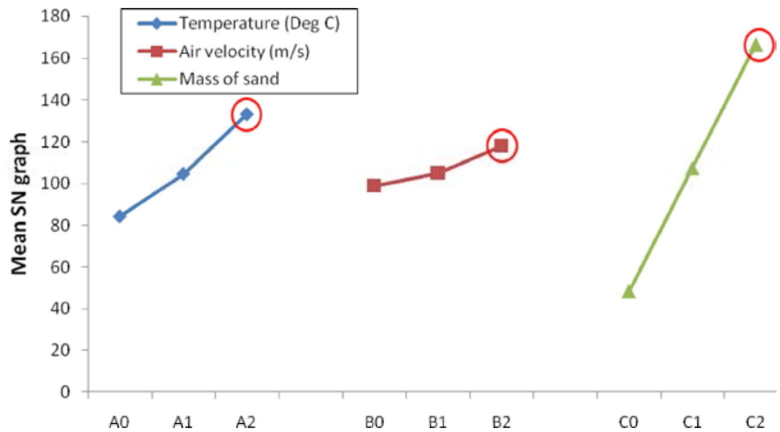


Fig. 2: Plots of SN Ratio for each drying parameter in determining optimum condition of humidity contents (three levels and three factors).

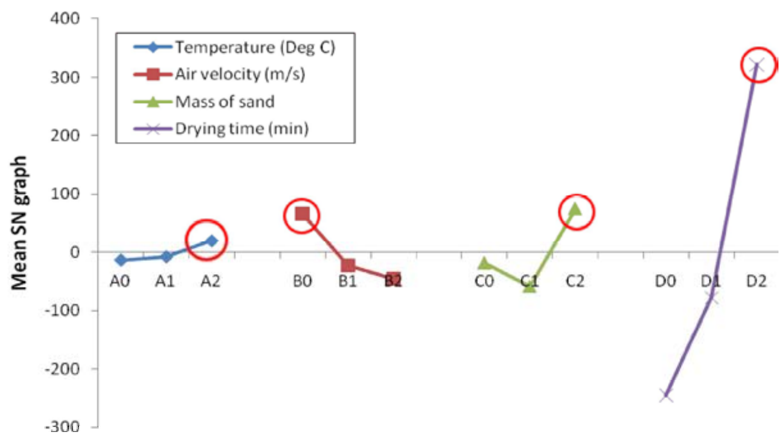


Fig. 3: Plots of SN Ratio for each drying parameter in determining optimum condition of humidity contents (three levels and four factors)

The value of humidity contents at these conditions is 0.0658 g/g aq. Thus, Taguchi method suggests that the fluidized bed dryer is recommended to run under these conditions in order to obtain low humidity contents.

For three levels and four factors, the plots of SN ratio of drying parameters are shown in Figure 3. The optimum condition is at A2 (temperature at 60°C), B0 (air velocity at 0.61 m/s), C2 (mass of sand at 100g) and D2 (drying time of 30 min). Therefore, the value of humidity contents at these conditions is 0.947 g/g aq.

Drying Rate: The values of SN ratio for ‘the bigger the better’ from L_{27} were plotted in Figure 4 to identify the optimum condition at each factor. Relative stiffness indicates that air velocity has the greatest effect on drying rate of drying of lemon grass and followed by mass of sand and temperature. The optimum condition is at A1 (temperature at 50°C), B2 (air velocity at 0.85 m/s) and C1 (mass of sand at 50g). The value of drying rate at these conditions is 0.2479 g/g min. Therefore, Taguchi method suggests that the fluidized bed dryer is recommended to run under these conditions in order to obtain the highest drying rate.

For three levels and four factors, the plots of SN ratio of drying parameters are shown in Figure 5. The optimum condition is at A2 (temperature at 60°C), B2 (air velocity at 0.85m/s), C1 (mass of sand at 50g) and D0 (drying time of 10 min). The value of drying rate at these conditions is 0.7924 g/g min.

Pareto ANOVA: Park (1966) states that another statistical tool to optimize parameters is Pareto ANOVA. The unique of this method is due to not involve an ANOVA table in analyzing data which means that no F-test is used [14]. Moreover, Pareto diagram is included in this method to show the contribution ratio for all factors. Finally, the significant factor level is shown for the optimum condition.

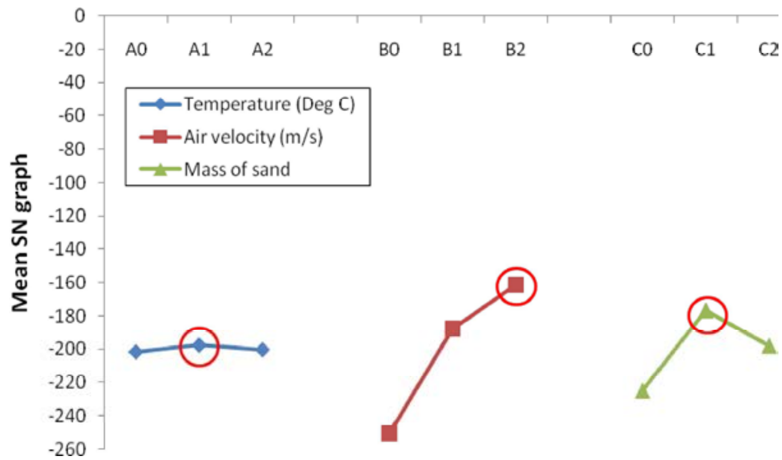


Fig. 4: Plots of SN Ratio for each drying parameter in determining optimum condition of drying rate (three levels and three factors).

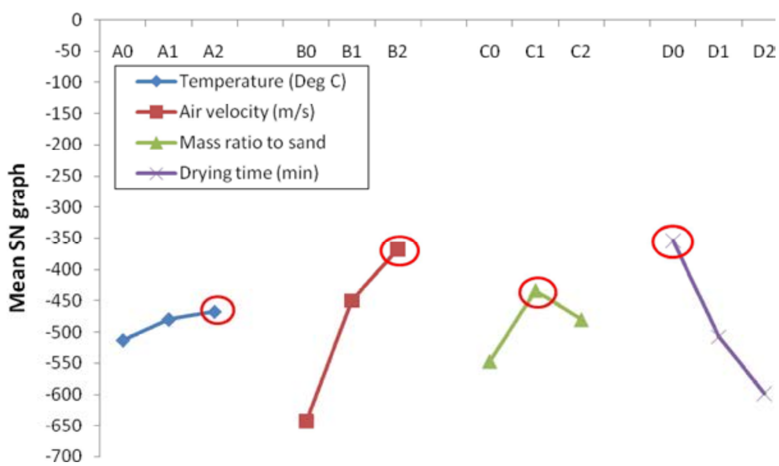


Fig. 5: Plots of SN Ratio for each drying parameter in determining optimum condition of drying rate (three levels and four factors)

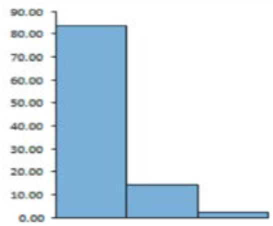
Humidity Contents: Pareto ANOVA analysis of humidity contents for three levels and three factors is displayed in Table 5 and shows that mass of sand give the most significant effects where it contributes 83.33% and followed by temperature and air velocity which contribute 14.38% and 2.29% respectively. The optimum condition of A2B2C2 (temperature of 60°C, air velocity of 0.85 m/s and mass of sand at 100g) is revealed from Pareto ANOVA analysis was validated experimentally where the humidity contents was equal to 0.0658 g/g aq.

For three levels and four factors, Pareto ANOVA analysis of humidity contents shows that drying time gives the most significant effect where it contributes 91.01% and followed by mass of sand, air velocity and temperature which contribute 4.98%, 3.68% and 0.33% respectively as shown in Table 6. The optimum condition of A2B0C2D2 (temperature of 60°C, air velocity 0.61 m/s, mass ratio to sand 1:2 and drying time at 30min) is revealed from Pareto ANOVA analysis was validated experimentally where the humidity contents was equal to 0.0947 g/g aq.

Drying Rate: Pareto ANOVA analysis of drying rate for three levels and three factors displayed in Table 7 shows that air velocity gives the most significant effects where it contributes 78.13% and 0.16% respectively. The optimum condition of A1B2C1 (temperature of 50°C, air velocity of 0.85 m/s and mass ration to sand 1:1) is analyzed from Pareto ANOVA analysis was validated experimentally where the drying rate was equal to 0.2497 g/g min.

Table 5: Pareto ANOVA analysis of humidity contents for three levels and three factors DOE.

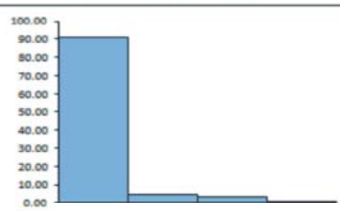
Factors and interaction		A	B	C	Total
Sum at factor level	0	84.28	98.90	48.15	Sum of 0, 1
	1	104.56	105.07	107.29	& 2 levels:
	2	133.28	118.15	166.68	322.12
Sum of squares of differences (S)		3637.12	579.72	21074.07	25290.91
Contribution ratio (%)		14.38	2.29	83.33	100.00



Factor and interaction	C	A	B
Cumulative contri-bution ratio (%)	83.33	97.71	100.00
Optimum combination of significant factor levels	A2B2C2		
Remarks on optimum conditions	The significant factors are choosen from the left-hand side in the above pareto diagram which contribute about 90%		
Overall optimum condition for all factors	A2: Temperature at 60 deg C B2: Air velocity at 0.85 m/s C2: Mass ratio of sand is 100 g		

Table 6: Pareto ANOVA analysis of humidity contents for three levels and four factors DOE

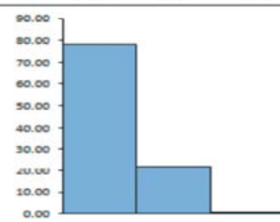
Factors and interaction		A	B	C	D	Total
Sum at factor level	0	-13.03	66.13	-17.62	-244.94	Sum of 0, 1:
	1	-7.39	-22.11	-58.07	-77.92	& 2 levels
	2	19.68	-44.76	74.95	322.13	-0.74
Sum of squares of differences (S)		1835	20596	27900	509504	559834
Contribution ratio (%)		0.33	3.68	4.98	91.01	100.00



Factor and interaction	D	C	B	A
Cumulative contri-bution ratio (%)	91.01	95.99	99.67	100.00
Optimum combination of significant factor levels	A2B0C2D2			
Remarks on optimum conditions	The significant factors are choosen from the left-hand side in the above pareto diagram which contribute about 90%			
Overall optimum condition for all factors	A2: Temperature at 60 deg C B0: Air velocity at 0.61 m/s C2: Mass ratio to sand is 1:2 D2: Drying time is 30 min			

Table 7: Pareto ANOVA analysis of drying rate for three levels and three factors DOE

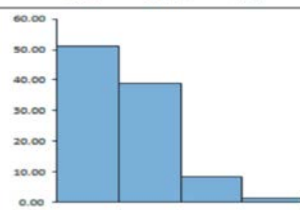
Factors and interaction		A	B	C	Total
Sum at factor level	0	-201.47	-250.48	-224.78	Sum of 0, 1 & 2
	1	-197.44	-187.36	-176.52	levels:
	2	-200.15	-161.23	-197.76	-599.06
Sum of squares of differences (S)		25.33	12632.47	3510.25	16168.05
Contribution ratio (%)		0.16	78.13	21.71	100.00



Factor and interaction	B	C	A
Cumulative contri-bution ratio (%)	78.13	99.84	100.00
Optimum combination of significant factor levels	A1B2C1		
Remarks on optimum conditions	The significant factors are choosen from the left-hand side in the above pareto diagram which contribute about 90%		
Overall optimum condition for all factors	A1: Temperature at 50 deg C B2: Air velocity at 0.85 m/s C1: Mass ratio to sand is 1:1		

Table 8: Pareto ANOVA analysis of drying rate for three levels and four factors DOE

Factors and interaction		A	B	C	D	Total
Sum at factor level	0	-513.53	-643.79	-547.54	-354.39	Sum of 0, 1 & 2
	1	-480.09	-449.66	-433.46	-508.01	levels:
	2	-467.85	-368.02	-480.47	-599.07	-1461.47
Sum of squares of differences (S)		3354.71	120400.64	19722.57	91759.33	235237.25
Contribution ratio (%)		1.43	51.18	8.38	39.01	100.00



Factor and interaction	B	D	C	A
Cumulative contri-bution ratio (%)	51.18	90.19	98.57	100.00
Optimum combination of significant factor levels	A2B2C1D0			
Remarks on optimum conditions	The significant factors are choosen from the left-hand side in the above pareto diagram which contribute about 90%			
Overall optimum condition for all factors	A2: Temperature at 60 deg C B2: Air velocity at 0.85 m/s C1: Mass ratio to sand is 1:1 D0: Drying time is 10 min			

For three levels and four factors, Pareto ANOVA analysis of drying rate presented in Table 8 shows that air velocity gives the most significant effect where it contributes 51.18% and followed by drying time, mass of sand and temperature which contribute 39.01%, 8.38% and 1.43% respectively. The optimum condition of A2B2C1D0 (temperature of 60°C, air velocity of 0.85 m/s, mass ratio to sand 1:1 and drying time of 10 min) is revealed from Pareto ANOVA analysis was proven experimentally where the drying rate was equal to 0.7924 g/g min.

Regression Analysis by XLSTAT: XLSTAT is a software package which is a part of add-on in EXCEL. In order to predict a model of equation, regression analysis can be performed by XLSTAT using experimental data [15]. Prior to regression analysis, it is essential to determine the type of model of equation which fits on the experimental data. The second order polynomial model is used in this case.

Humidity Contents: In Table 9, for 3L3F the degree of freedom is 17 and high coefficient of determination (R^2) of 0.914 shows that the predicted values were well adapted with the experimental data [16]. Both F-test value of 19.949 and value of Pr>F which is less than 0.0050 depict that the model is significant.

Values of Pr>|t| less than 0.0050 shows model terms are significant. In Table 10, model terms such as 'C','AC','BC' and 'C^2' show value of Pr>|t| less than 0.0050. This depicts that those model terms are significant. Whereas the other model terms such as 'A','B','AB','A^2' and 'B^2' indicate values of Pr>|t| more than 0.1000 which are insignificant model terms. Therefore it can be concluded that mass of sand gives significant effect for 3L3F DOE.

The model equation of humidity contents generated from XLSTAT for 3L3F is shown below:

$$\text{Humidity contents} = 4.0716 - 0.0418A - 3.4866B - (3.4621E-02)C + (3.2056E-02)AB + (1.6208E-04)AC + (2.3823E-02)BC - (5.5556E-08)A^2 - (3.8580E-04)B^2$$

From the model of equation, the predicted values of humidity contents can be calculated and shown in Table 11. In row of Observation 12 which is highlighted with grey shows the smallest value of adjusted predicted humidity contents (0.037 g/g aq). Therefore, the optimum condition occurs at A1B0C2 which is at temperature of 50°C, air velocity of 0.61 m/s and mass of sand of 100g.

For 3L4F is shown in Table 12 where the degree of freedom is 66 and coefficient of determination (R^2) of 0.715 shows that the predicted values are fairly well adapted

Table 9: Goodness of fit statistics and ANOVA

Goodness of fit statistics:	
Observations	27.000
Sum of weights	27.000
DF	17.000
R^2	0.914
Adjusted R^2	0.868

Analysis of variance (ANOVA): ...

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	9	1.773	0.197	19.949	< 0.0001
Error	17	0.168	0.010		
Corrected Total	26	1.941			

Computed against model Y=Mean(Y)

Table 10: Standardized coefficients for the model terms with t and Pr>|t| values

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
A	-1.272	1.350	-0.943	0.359	-4.120	1.575
B	-1.274	1.569	-0.812	0.428	-4.585	2.037
C	-5.272	0.734	-7.178	< 0.0001	-6.821	-3.722
AB	0.927	0.692	1.341	0.198	-0.532	2.387
AC	1.274	0.451	2.825	0.012	0.323	2.226
BC	2.709	0.543	4.987	0.000	1.563	3.856
A^2	0.000	1.238	0.000	1.000	-2.611	2.611
B^2	0.000	1.505	0.000	1.000	-3.175	3.175
C^2	0.679	0.257	2.641	0.017	0.137	1.222

Table 11: Actual humidity contents, predicted value and adjusted predicted value with residual and 95% confidence interval

Observation	Humidity contents	Pred (Humidity contents)	Residual	Std. residual	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)	Adjusted Pred.
Obs1	1.216	1.056	0.160	1.614	0.122	0.798	1.313	0.889
Obs2	0.305	0.483	-0.178	-1.794	0.115	0.240	0.726	0.576
Obs3	0.143	0.125	0.018	0.180	0.122	-0.132	0.383	0.107
Obs4	0.814	0.791	0.023	0.231	0.115	0.548	1.034	0.779
Obs5	0.316	0.362	-0.046	-0.463	0.112	0.126	0.597	0.378
Obs6	0.170	0.147	0.023	0.231	0.115	-0.096	0.390	0.135
Obs7	0.412	0.527	-0.114	-1.151	0.122	0.269	0.784	0.645
Obs8	0.327	0.240	0.086	0.869	0.115	-0.003	0.483	0.195
Obs9	0.196	0.168	0.028	0.282	0.122	-0.089	0.426	0.139
Obs10	0.888	0.834	0.054	0.543	0.115	0.591	1.077	0.805
Obs11	0.234	0.342	-0.108	-1.085	0.112	0.107	0.577	0.380
Obs12	0.119	0.065	0.054	0.543	0.115	-0.178	0.308	0.037
Obs13	0.608	0.607	0.000	0.000	0.112	0.372	0.843	0.607
Obs14	0.259	0.259	0.000	0.000	0.112	0.024	0.494	0.259
Obs15	0.125	0.125	0.000	0.000	0.112	-0.110	0.360	0.125
Obs16	0.327	0.381	-0.054	-0.543	0.115	0.138	0.624	0.409
Obs17	0.284	0.176	0.108	1.085	0.112	-0.059	0.411	0.138
Obs18	0.131	0.185	-0.054	-0.543	0.115	-0.058	0.428	0.213
Obs19	0.559	0.611	-0.053	-0.529	0.122	0.354	0.869	0.666
Obs20	0.164	0.201	-0.037	-0.376	0.115	-0.042	0.444	0.220
Obs21	0.095	0.005	0.090	0.905	0.122	-0.253	0.262	-0.089
Obs22	0.401	0.424	-0.023	-0.231	0.115	0.181	0.667	0.436
Obs23	0.202	0.156	0.046	0.463	0.112	-0.079	0.392	0.140
Obs24	0.080	0.103	-0.023	-0.231	0.115	-0.140	0.346	0.115
Obs25	0.243	0.236	0.007	0.066	0.122	-0.022	0.494	0.229
Obs26	0.241	0.112	0.129	1.301	0.115	-0.131	0.355	0.044
Obs27	0.066	0.202	-0.136	-1.368	0.122	-0.056	0.459	0.343

Table 12: Goodness of fit statistics and ANOVA

Goodness of fit statistics:	
Observations	81.000
Sum of weights	81.000
DF	66.000
R^2	0.715
Adjusted R^2	0.654

Analysis of variance (ANOVA):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	14	244.739	17.481	11.814	< 0.0001
Error	66	97.664	1.480		
Corrected Total	80	342.403			

Computed against model Y=Mean(Y)

with the experimental data. Both F-test value of 11.814 and value of Pr>F which is less than 0.0050 indicate that the model is significant. Table 13 model term such as 'D','BC','BD' and 'C^2' depicts that those model terms are significant. On the other hands, other model such 'A','B','C','AD','CD','A^2','B^2' and 'D^2' are insignificant. Therefore, it can be concluded that drying time and interactions of 'mass of sand', 'air velocity and mass of sand' and 'air velocity and drying time' give significant effect for 3L4F DOE.

The model equation of humidity contents generated from XLSTAT for 3L4F is shown below:

$$\text{Humidity contents} = -6.4021 - (2.356E-02)A - 12.2118B - (1.3209E-02)C + 0.4362D$$
$$-(9.2593E-08)A^2 - (6.4300E-04)B^2 - (5.1446E-04)C^2 + (2.1260E-03)D^2 +$$
$$(8.7032E-02)AB + (3.2282E-04)AC - (2.2402E-03)AD + (8.8227E-02)BC - 0.7309BD$$
$$-(6.9081E-04)CD$$

Table 13: Standardized Coefficients for the model terms with t and Pr>|t| values

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
A	-0.094	1.254	-0.075	0.941	-2.598	2.411
B	0.582	1.455	0.400	0.691	-2.324	3.488
C	-0.262	0.696	-0.377	0.707	-1.651	1.127
D	1.732	0.788	2.200	0.031	0.160	3.305
A^2	0.000	1.141	0.000	1.000	-2.277	2.277
B^2	0.000	1.387	0.000	1.000	-2.769	2.769
C^2	-1.063	0.237	-4.486	< 0.0001	-1.536	-0.590
D^2	0.341	0.460	0.741	0.461	-0.578	1.260
AB	0.328	0.637	0.515	0.608	-0.944	1.601
AC	0.331	0.416	0.796	0.429	-0.499	1.161
AD	-0.485	0.439	-1.105	0.273	-1.360	0.391
BC	1.307	0.501	2.611	0.011	0.308	2.307
BD	-2.249	0.520	-4.326	< 0.0001	-3.286	-1.211
CD	-0.327	0.192	-1.704	0.093	-0.709	0.056

Table 14: Actual humidity contents, predicted value and adjusted predicted value with residual and 95% confidence interval

Obs46	1.848	3.740	-1.892	-1.555	1.329	1.086	6.394	4.197
Obs47	0.820	1.407	-0.587	-0.483	1.298	-1.185	3.999	1.502
Obs48	0.327	-0.500	0.828	0.680	1.329	-3.155	2.154	-0.700
Obs49	9.027	6.005	3.023	2.485	1.298	3.413	8.597	5.517
Obs50	4.397	3.326	1.070	0.880	1.282	0.766	5.887	3.193
Obs51	0.284	1.074	-0.790	-0.649	1.298	-1.518	3.665	1.201
Obs52	4.660	5.697	-1.037	-0.852	1.329	3.043	8.351	5.947
Obs53	2.003	2.673	-0.671	-0.551	1.298	0.082	5.265	2.782
Obs54	0.131	0.075	0.056	0.046	1.329	-2.579	2.730	0.062
Obs55	1.812	1.590	0.222	0.182	1.375	-1.155	4.336	1.505
Obs56	0.913	0.788	0.125	0.103	1.329	-1.867	3.442	0.757
Obs57	0.559	0.410	0.149	0.122	1.375	-2.335	3.156	0.353
Obs58	1.887	2.958	-1.071	-0.880	1.329	0.303	5.612	3.216
Obs59	1.037	1.810	-0.772	-0.635	1.298	-0.782	4.401	1.934
Obs60	0.164	1.087	-0.923	-0.759	1.329	-1.568	3.741	1.310
Obs61	2.347	1.753	0.595	0.489	1.375	-0.993	4.498	1.524

Table 15: Goodness of fit statistics and ANOVA

Goodness of fit statistics:	
Observations	27.000
Sum of weights	27.000
DF	17.000
R²	0.737
Adjusted R²	0.598

Analysis of variance (ANOVA):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	9	0.098	0.011	5.300	0.002
Error	17	0.035	0.002		
Corrected Total	26	0.133			

Computed against model Y=Mean(Y)

From the model of equation, the predicted values of humidity contents can be calculated and shown in Table 14. In row of Observation 54 which is highlighted with grey shows the highest value of adjusted predicted humidity contents (0.062g/g aq). Therefore, the optimum condition occurs at A1B2C2D2 which is at temperature of 50°C, air velocity of 0.85 m/s, mass of sand of 100g and drying time 0f 30 min.

Drying Rate: In Table 15, for 3L3F the degree of freedom is 17 and coefficient of determination (R^2) of 0.737 shows that the predicted values were fairly well adapted with the experimental data. Both F-test value of 5.300 and value of Pr>F which is less than 0.0020 which is less than 0.0050 indicate that the model is significant. In Table 16 model terms such as 'BC' and 'C^2' depicts that those model terms are significant while model terms such as

Table 16: Standardized coefficients for the model terms with t and Pr>|t| values

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
A	-0.142	2.352	-0.060	0.953	-5.105	4.821
B	0.246	2.735	0.090	0.929	-5.525	6.017
C	-0.957	1.280	-0.747	0.465	-3.657	1.744
AB	0.095	1.205	0.078	0.938	-2.449	2.638
AC	0.646	0.786	0.822	0.423	-1.013	2.305
BC	2.096	0.947	2.214	0.041	0.099	4.094
A^2	-0.001	2.157	0.000	1.000	-4.552	4.550
B^2	0.000	2.623	0.000	1.000	-5.534	5.534
C^2	-1.566	0.448	-3.494	0.003	-2.512	-0.620

Table 17: Actual drying rate predicted value and adjusted predicted value with residual and 95% confidence interval

Observation	Drying rate	Pred (Drying rate)	Residual	Std. residual	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)	Adjusted Pred.
Obs1	0.072	0.040	0.033	0.722	0.056	-0.078	0.157	0.006
Obs2	0.028	0.083	-0.055	-1.212	0.052	-0.028	0.194	0.111
Obs3	0.019	-0.003	0.022	0.490	0.056	-0.120	0.114	-0.026
Obs4	0.078	0.065	0.013	0.286	0.052	-0.046	0.175	0.058
Obs5	0.111	0.137	-0.026	-0.572	0.051	0.030	0.244	0.146
Obs6	0.093	0.080	0.013	0.286	0.052	-0.030	0.191	0.073
Obs7	0.083	0.090	-0.007	-0.150	0.056	-0.027	0.207	0.097
Obs8	0.194	0.191	0.003	0.068	0.052	0.080	0.302	0.189
Obs9	0.167	0.163	0.004	0.082	0.056	0.046	0.280	0.159
Obs10	0.059	0.032	0.026	0.584	0.052	-0.078	0.143	0.019
Obs11	0.034	0.087	-0.053	-1.168	0.051	-0.021	0.194	0.105
Obs12	0.038	0.012	0.026	0.585	0.052	-0.099	0.122	-0.002
Obs13	0.059	0.059	0.000	0.000	0.051	-0.048	0.166	0.059
Obs14	0.142	0.142	0.000	0.000	0.051	0.035	0.249	0.142
Obs15	0.096	0.096	0.000	0.000	0.051	-0.012	0.203	0.096
Obs16	0.059	0.085	-0.026	-0.583	0.052	-0.026	0.196	0.099
Obs17	0.250	0.197	0.053	1.168	0.051	0.090	0.304	0.178
Obs18	0.153	0.180	-0.026	-0.585	0.052	0.069	0.290	0.193
Obs19	0.046	0.025	0.020	0.446	0.056	-0.092	0.143	0.004
Obs20	0.039	0.090	-0.051	-1.123	0.052	-0.020	0.201	0.117
Obs21	0.057	0.026	0.031	0.677	0.056	-0.091	0.143	-0.006
Obs22	0.040	0.053	-0.013	-0.286	0.052	-0.058	0.163	0.059
Obs23	0.172	0.146	0.026	0.572	0.051	0.039	0.254	0.137
Obs24	0.098	0.111	-0.013	-0.286	0.052	0.000	0.222	0.118
Obs25	0.034	0.080	-0.046	-1.018	0.056	-0.037	0.197	0.128
Obs26	0.305	0.203	0.103	2.268	0.052	0.092	0.313	0.149
Obs27	0.140	0.196	-0.057	-1.249	0.056	0.079	0.313	0.255

Table 18: Goodness of fit statistics and ANOVA

Goodness of fit statistics:	
Observations	81.000
Sum of weights	81.000
DF	66.000
R^2	0.818
Adjusted R^2	0.779

Analysis of variance (ANOVA):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	14	1.442	0.103	21.166	<0.0001
Error	66	0.321	0.005		
Corrected Total	80	1.763			

Computed against model Y=Mean(Y)

Table 19: Standardized coefficients for the model terms with t and Pr>|t| values

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
A	0.086	1.002	0.086	0.932	-1.915	2.087
B	0.953	1.163	0.819	0.416	-1.369	3.275
C	-0.732	0.556	-1.316	0.193	-1.842	0.378
D	0.601	0.629	0.956	0.343	-0.655	1.858
A^2	-0.001	0.911	-0.001	0.999	-1.820	1.819
B^2	0.000	1.108	0.000	1.000	-2.213	2.213
C^2	-1.019	0.189	-5.378	< 0.0001	-1.397	-0.641
D^2	1.195	0.368	3.249	0.002	0.460	1.929
AB	-0.018	0.509	-0.034	0.973	-1.035	0.999
AC	0.488	0.332	1.468	0.147	-0.176	1.151
AD	-0.227	0.350	-0.648	0.519	-0.927	0.472
BC	1.594	0.400	3.983	0.000	0.795	2.392
BD	-2.129	0.415	-5.125	< 0.0001	-2.958	-1.299
CD	-0.180	0.153	-1.177	0.243	-0.486	0.126

‘A’,’B’,’C’,’AB’,’AC’,’A^2’ and ‘B^2’ are insignificant. Therefore, it can be concluded that interactions of ‘mass of sand’ and ‘air velocity and mass of sand’ give significant effect 3L3F DOE. The model equation of drying rate generated from XLSTAT for 3L4F is shown below:

$$\text{Drying Rate} = --0.0397-(1.218E-03)A-0.1757B-(1.6415E-03)C+(8.541E-04)AB$$
$$+(2.1475E-05)AC+(4.8208E-02)BC-(8.3333E-08)A^2-(2.5823E-04)C^2$$

From the model of equation, the predicted values of drying rate can be calculated and shown in Table 17. In row of Observation 27 which is highlighted with grey shows the highest value of adjusted predicted drying rate (0.255 g/g min). Therefore, the optimum condition occurs at A2B2C2 which is at temperature of 60°C, air velocity of 0.85 m/s and mass of sand of 100g.

For 3L4F is shown in Table 18 where the degree of freedom is 66 and coefficient of determination (R^2) of 0.818 shows that the predicted values were well adapted with the experimental data. Both F-test value of 21.166 and value of Pr>F which is less than 0.0050 indicate that the model is significant. Table 19 model term such as ’BC’,’BD’,’D^2’ and ‘C^2’ depicts that those model terms are significant. On the other hands, other model such ‘A’,’B’,’C’,’D’,’AB’,’AC’,’AD’,’CD’,’A^2’ and ’B^2’ are insignificant. Therefore, it can be concluded that interactions between ‘air velocity and mass of sand’, ‘air velocity and drying time’, ‘mass of sand’ and ‘drying time’ give significant effect for 3L4F DOE.

The model equation of humidity contents generated from XLSTAT for 3L4F is shown below:

$$\text{Drying Rate} = -0.6662-(1.5496E-03)A-1.4348B-(2.6442E-03)C+(1.0867E-02)D$$
$$-(1.1111E-07)A^2-(3.858E-04)B^2-(3.5369E-05)C^2+(5.2411E-04)D^2+$$
$$(3.3333E-04)AB+(3.4133E-05)AC-(7.5389E-05)AD+(7.7167E-03)BC$$
$$-(4.9650E-02)BD-(2.7367E-05)CD$$

From the model of equation, the predicted values of drying rate can be calculated and shown in Table 20. In row of Observation 79 which is highlighted with grey shows the highest value of adjusted predicted drying rate (0.578). Therefore, the optimum condition occurs at A2B2C2D0 which is at temperature of 60°C, air velocity of 0.85 m/s, mass of sand of 100g and drying time 0f 10 min.

Response Surface by Design-Expert: Design-Expert is one of the advanced optimization software owned by Stat-Ease Inc. In Minneapolis, USA . Design-Expert help the user to analyze the data by providing the outcomes such as a model, graph correlation, ANOVA, diagnostic plots and point prediction of optimization [17].

Table 20: Actual drying rate predicted value and adjusted predicted value with residual and 95% confidence interval

Obs62	0.108	0.027	0.081	1.160	0.076	-0.125	0.179	0.007
Obs63	0.057	0.027	0.030	0.425	0.079	-0.130	0.184	0.016
Obs64	0.154	0.213	-0.060	-0.854	0.076	0.061	0.366	0.228
Obs65	0.082	0.075	0.008	0.109	0.074	-0.074	0.223	0.073
Obs66	0.040	0.043	-0.003	-0.042	0.076	-0.110	0.195	0.043
Obs67	0.449	0.363	0.086	1.237	0.074	0.214	0.512	0.349
Obs68	0.227	0.211	0.016	0.234	0.074	0.064	0.357	0.209
Obs69	0.172	0.165	0.007	0.104	0.074	0.016	0.314	0.164
Obs70	0.301	0.336	-0.035	-0.498	0.076	0.184	0.488	0.344
Obs71	0.162	0.170	-0.008	-0.111	0.074	0.021	0.318	0.171
Obs72	0.098	0.111	-0.012	-0.178	0.076	-0.042	0.263	0.114
Obs73	0.183	0.324	-0.141	-2.019	0.079	0.166	0.481	0.378
Obs74	0.077	0.125	-0.048	-0.692	0.076	-0.027	0.277	0.137
Obs75	0.034	0.034	0.000	0.003	0.079	-0.124	0.191	0.034
Obs76	0.792	0.520	0.273	3.912	0.076	0.367	0.672	0.454
Obs77	0.374	0.308	0.066	0.949	0.074	0.159	0.456	0.297
Obs78	0.305	0.202	0.103	1.476	0.076	0.050	0.354	0.177
Obs79	0.437	0.539	-0.102	-1.466	0.079	0.381	0.696	0.578
Obs80	0.217	0.313	-0.096	-1.382	0.076	0.161	0.465	0.336
Obs81	0.140	0.194	-0.055	-0.781	0.079	0.037	0.352	0.215

Humidity Contents: Based on Figure 6 to Figure 8 for 3L3F, 3D plots indicate that the optimum humidity contents occurs at mass of sand of 100g, air velocity of 0.85 m/s and temperature of 60°C. This result is according to the optimum analyzed by Taguchi and Pareto ANOVA. The predicted value of humidity contents was optimized by using 'Prediction Point' in Design Expert. The optimum value occurs at mass of sand of 100g, air velocity of 0.61 m/s and temperature of 60°C which the value is 0.03572 g/g aq.

For 3L4F, 3D plots indicate that the optimum of humidity contents occurs at drying time of 30 min, mass sand of 50g, air velocity of 0.61 m/s and temperature of 60 °C as shown in Figure 9 to 12. However the result is different with the optimum analyzed by Taguchi and Pareto ANOVA. By using 'Prediction Point', the optimum condition occur at drying time of 30 min, mass of sand of 0g, air velocity of 0.85 m/s and temperature of 60°C which the value is 0.0005185 g/g aq.

Drying Rate: Based on Figure 13 to Figure 15 for 3L3F, 3D plots indicate that the optimum drying rate occurs at mass of sand of 50g, air velocity of 0.85 m/s and temperature of 60°C. This result is however contradict with the optimum analyzed by Taguchi and Pareto ANOVA. The predicted value of drying rate was optimized by using 'Prediction Point' in Design Expert. The optimum value occurs at mass of sand of 50g, air velocity of 0.85 m/s and temperature of 60°C which the value is 0.2813 g/g min.

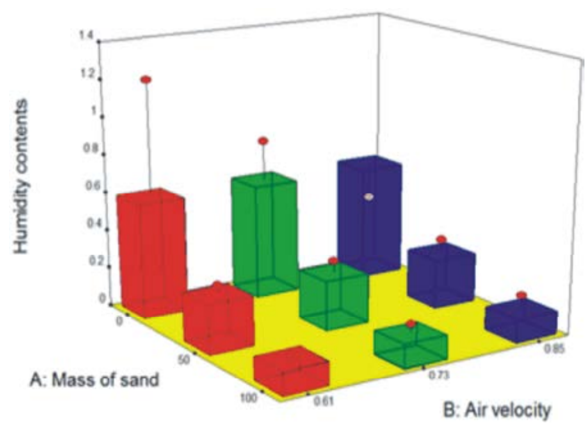


Fig. 6: 3D plot of mass of sand, air velocity and humidity contents for 3L3F

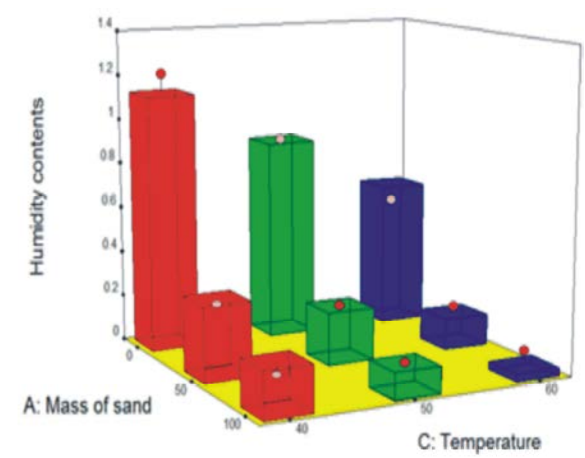


Fig. 7: Plot of mass of sand, temperature and humidity contents for 3L3F

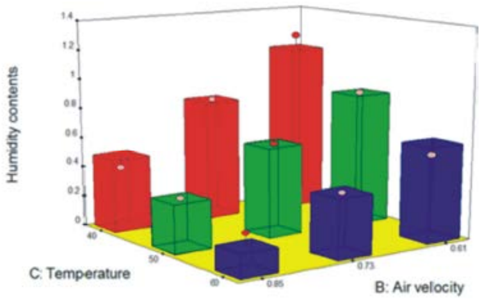


Fig. 8: 3D plot of temperature, air velocity and humidity contents for 3L3F

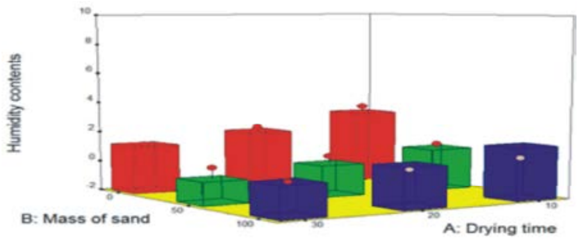


Fig. 9: 3D plot mass of sand, drying time and humidity contents for 3L4F

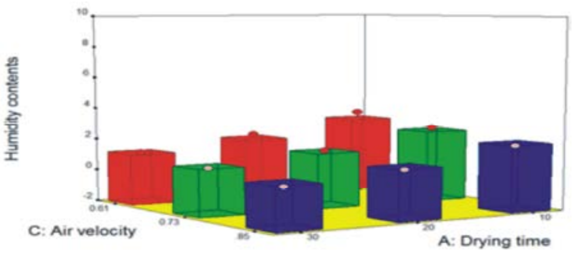


Fig. 10: 3D plot mass of drying time, air velocity and humidity contents for 3L4F

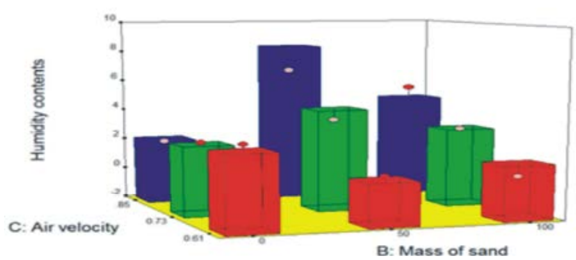


Fig. 11: 3D plot mass of mass of sand, air velocity and humidity contents for 3L4F

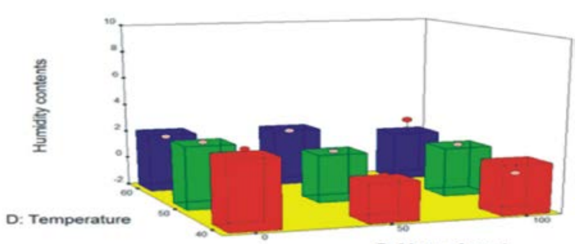


Fig. 12: 3D plot of temperature, mass of sand and humidity contents for 3L4

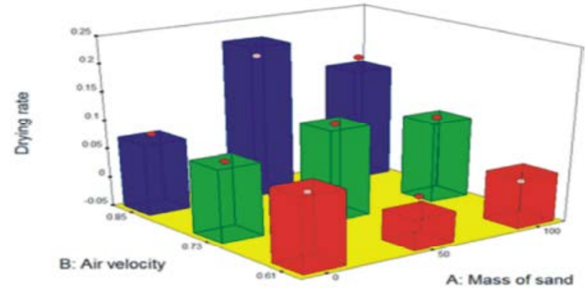


Fig. 13: 3D plot of mass of sand, air velocity and drying rate for 3L3F

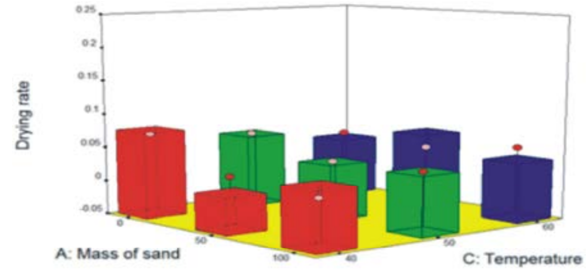


Fig. 14: 3D plot of mass of sand, temperature and drying rate for 3L3F

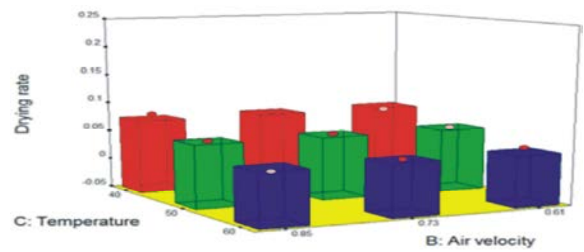


Fig. 15: 3D plot of temperature, air velocity and drying rate for 3L3F

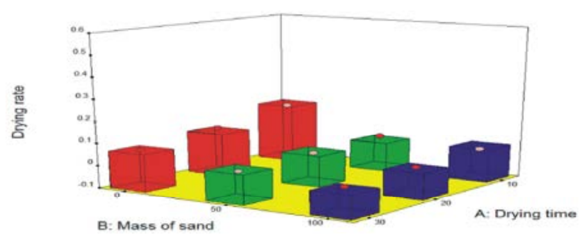


Fig. 16: 3D plot of drying time, mass of sand and drying rate for 3L4F

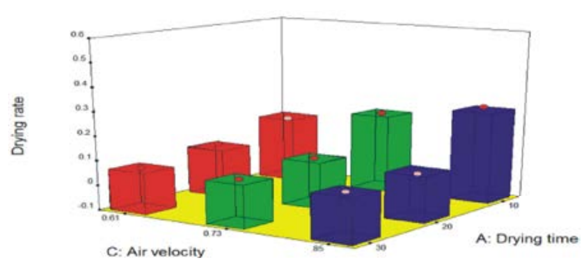


Fig. 17: 3D plot of dying time, air velocity and drying rate for 3L4F

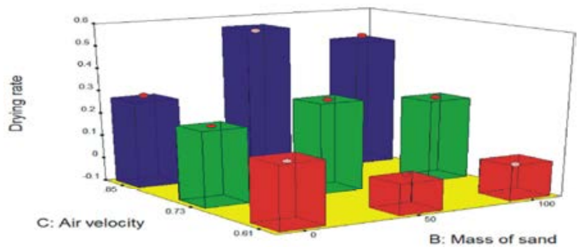


Fig. 18: 3D plot of mass of sand, air velocity and drying rate for 3L4F

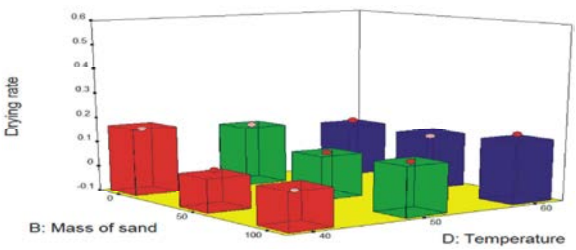


Fig. 19: 3D plot of mass of sand, temperature and drying rate for 3L4F

For 3L4F, 3D plots indicate that the optimum of drying rate occurs at drying time of 10 min, mass sand of 50g, air velocity of 0.85 m/s and temperature of 60°C as shown in Figure 16 to 19. The result is similar with the optimum analyzed by Taguchi and Pareto ANOVA. By using 'Prediction Point', the optimum condition occur at drying time of 10 min, mass of sand of 50g, air velocity of 0.85 m/s and temperature of 60°C which the value is 0.7770 g/g min.

CONCLUSION

The optimization analysis on humidity contents, drying rate and energy for both DOE of 3L3F and 3L4F by using Taguchi, Pareto ANOVA, XLSTAT and Design-Expert gave different results of optimum condition. Both conceptual optimization methods which are Taguchi and Pareto ANOVA lead to an equal conclusion. However, results of optimization analyzed by XLSTAT and Design-Expert do not agree with the conclusion draw by Taguchi and Pareto ANOVA. The difference of optimization results between conceptual statistical methods (Taguchi and Pareto ANOVA) and statistical software (XLSTAT and Design Expert) is due to the selection of data for optimization process. In Taguchi and Pareto ANOVA, experimental data was used which was then converted to SN ratio values. On the other hands, XLSTAT and Design-Expert developed adjusted predicted values from generated model in determining optimum condition instead of using experimental data.

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