The Optimal Milling Condition of the Quartz Rice Polishing Cylinder Using Response Surface Methodology

Surapong Bangphan, Phiraphan Bangphan, Sukangkana Lee, Sermkiat Jomjunyong and Suwattanarwong phanphet

***Abstract*— The purpose of this research is to develop the small rice milling machine in order to support the agricultural communities in Chiang Mai province and Ubon Ratchathani province using design of experiment technique.**

The experiment was designed by Response Surface Methodology (RSM) based on Central Composite Design (CCD). Type of rice: Thai Hom Mali rice 105 was chosen as testing rice. The two major factors including revolution per minute (RPM) and clearance between rubber and polishing cylinder were studied their effect on the percentage of broken rice after milling. In addition, the inverter system is also implemented in order to control the operation of the small rice milling.

The level of factor was determined to evaluate the factor's effect that optimized the yield and to verify the optimal conditions. Based on the statistical significance with α level of 0.05, the optimal conditions are as follows. The revolution per minute and clearance between rubber and rice polishing cylinder to yield 15.29 % broken rice were 1560 rpm and 1.71 mm, respectively. After milling, the percentages of broken rice were calculated and analyzed using Regression analysis and Analysis of Variance (ANOVA). At a significant level α = 0.05, the values of Regression coefficient, $R^2_{(adj)}$were 98.42 %.

***Keywords*—Response surface methodology, Rice Polishing Cylinder, Abrasive, Design of Experiment**

I. INTRODUCTION

The quality of milled rice are depends on many factors such as rice strain, the rate of feeding, clearance between a rubber and abrasive cylinder, paddy moisture content which usually are controlled not to be exceed 14% et. But the most important factor is the type of the abrasives [1]-[2]. Furthermore, one of the major problems encountered is the wear of the polishing stone i.e. stones come off or chip from the cylinder and mix in the milled rice. This seems to be the common problem but for the farmer, wear of stone reduces the cylinder life and can increase milling cost. Also, the polishing cylinders are locally made and the qualities of the cylinder are often not consistent. Furthermore, the mixture of the abrasive cylinder is varied [2]. The major rice polishing technique in Thailand is the abrasive type. The major mixture of polishing cylinder consists of emery, silicon carbide, calcined mangnesite and magnesium chloride solution. The Emery stone is a major abrasive medium containing about 50 wt%. The Emery stones used in Thailand are imported from Europe are dark brown to black in color and have high hardness. However, it was found that the quality of this imported product is descending i.e. hardness values up on the pureness. In addition, good quality Emery stone is becoming rare resulting in progressively cost increasing. After forming the polishing cylinder, the emery stone cannot be able to recycle. It was reported that the imported emery stone were more than 1.25 million US dollar per annual [1]. Therefore, it is important to utilize the usage of the emery.

One of the statically method that can be used to obtain the optimization is by response surface methodology. The response surface method, was originally proposed [14] as a statistical tool, to find the operating conditions of a chemical process at which some response was optimized [4]. Techniques used in the empirical study of relationships between one or more responses and a group of variable [10]. Although it is usually referred to as the process of identifying and fitting an appropriate response surface model from experimental data, it can be applied to numerical modeling studies, where each run can be regarded as an experiment. RSM comprises of three techniques or methods [9]:

(1) Statistical experimental design, in particular, two-level factorial or fractional factorial design

(2) Regression modeling techniques

(3) Optimization methods [5].

The Response Surface Methodology (RSM) and others developed it for designing experiments and subsequent analysis of experimental data [14]. The method uses Design of Experiments techniques or DOE [11]. such as Two-level Full and Fractional Factorial Designs, as well as regression

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analysis methods where DOE techniques are employed before, during, and after the regression analysis to evaluate the accuracy of the model [5].

I. EXPERIMENTAL PROCEDURE

A. Materials Preparation

Quartz is a natural mineral found in many areas in the Western and the Northern region of Thailand. The chemical formula of Quartz is SiO_2. Quartz contains 46.7 wt%of Si and 53.6 wt% of O. The Mohr scale hardness of quartz is equivalent to 7. Quartz used in this experiment has white color. Samples were collected from Wiang Pa Pao district in Chiangrai province. Imported silicon carbide was replaced by reused silicon carbide obtained from the Alumina-Silicon carbide plate. Reused silicon carbide contains 50.0 wt %Si and 21.0 wt% C. All replaced materials were mechanically crushed and meshed to sizes. The binder paste or magnesium oxychloride cement was a mixture of Calcined magnesite 250 mesh with the magnesium chloride solution 30 Baume [3].

B. Theoretical analysis

The experimental design was created to determine the conditions when varying the composition of the materials according to a two factor designate the possibility of improving the performances of materials mixtures prepared by the selective quartzes with the binder fraction of the rice polishing cylinder [4]. Response surface methodology (RSM) is concerned with the modeling of one or more responses to the settings of several explanatory variables. The nature of the function relating the responses to the variables is assumed to be unknown and the function or surface is modeled empirically using a first- or a second-order polynomial model [6]. RSM is generally conducted in three phases [9]. Response surface techniques are eminently suitable to such situations but this area of application has only recently attracted attention in the RSM literature [7]. The second order model is

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

The second order polynomial response function is given in Equation (2)

$$y = 24.9783 + 3.1282 x_1 - 10.7496 x_2 + 0.1421 x_1^2 + 5.1171 x_2^2 - 4.7167 x_1 x_2 \quad (2)$$

where y is the studied response (percentage of Broken Rice (BR)), β_{ij} are the regression parameters and x_1 *and* x_2 are the factors of between rubber with rice polishing cylinder clearance and revolution per minute respectively. This full quadratic can be used for obtaining the response surface to be analyzed in which y represents the response variable; β_0 represents an overall average term; β_1, and β_2 represent regression coefficients of the two factor interaction terms (i.e., β_{12} represents the interaction coefficient between factors x_1, and x_2) and ε represents the error term.

These components are measured by their proportion (usually by weight, in this paper use materials and binder ratio,) and the response variables depend only on the component proportions that are present, not their absolute amounts [9]-[12]. Response surface methodology was used to study the simultaneous effect of the influent variables (factors) [3]-[4].

C. Statistical Methods and Software

The analysis and results of the experimental design were studied and interpreted by MINITAB RELEASE 14.00 (PA, USA licensed to Department of Industrial Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani, Thailand) statistical software to estimate the response of the dependent variable. The response curves and contour plots are also generated. After milling, the percentage of good rice and the wear rate of polishing cylinder were calculated and analyzed using Regression analysis and Analysis of Variance (ANOVA) [3]. And this research is the percentage of broken rice.

RESULTS AND DISCUSSION

D. Results

The results of variance are presented in Table I, II, III and IV. The application of response surface methodology in this experiment was complicated and time consuming. Since all of the coefficients have to be interpreted under the restriction that a two factor is varied at the same time as the two which are actively used, the only significant contributions are from the product of x_1 and from the product of x_2.

E. Discussion

The RSM paradigm can be used to good effect in a traditional agricultural setting and this point is further underscored by the work [8].

The estimate of the variance due to pure error was possible. Hence, the adequacy of the fitted model could be corrected by comparing the error component due to the model to that one due to experimental error. The test statistic was the *F*-ratio given by the estimate of the variance due to lack of fit (MS_{LOF}) and the estimate of the variance due to pure error (MS_{PE}). In general, lack of fit of the model is suspected when the computed value of *F* is significant. As shown in Tables IV, The parameters of the combined model in Equation (2) were estimated by fitting the 6-term quadratic to the experimental data here reported. For the two variable responses, the estimated residual variance was MS_E = 0.13 for y_1. Using the three replicates, the experimental error variance was estimated such as 41 *df* for y_1, Having obtained the estimation of the variance due to lack of fit ($MS_{LOF} = MS_E - MS_{PE}$), based on the LOF test for response y_2, the combined model shown in Equation (2) was augmented with four terms of the special-cubic polynomial. In fact, the value of the *F*-statistic, for testing the presence of lack of fit of model in Equation (2) was F = 1.36 with a *P*-value of 0.000 for y_1, this model was maintained. From the analysis of variance table, the R^2 statistics for the two combined models were computed and their values were R^2=0.99 and with an $R^2(adj)$ = 0.984, The coefficient of determination corrected for the number of terms in the equation should be always preferred to R^2 as it gives a more stable measure to the model adequacy.

The final model was chosen selecting only those coefficients. This lead to the elimination of the x_1,x_2, x_1^2 , x_2^2 *and* x_1x_2 terms from the model. Equations (2) are the coefficient of the broken rice. Then another important issue is the determination of factor levels that are related to the physical and economical conditions of the system. Allowable minimum and maximum levels of the factors are shown in Table I and Table II shown The RSM combined with a 2^2 full factorial experimental design is used to show the relationship between response function that represent system output and factors that represent system inputs in which a response of interest is influenced by factors and the aim is to optimize this response [13]. Table III and Table IV contains the results and summarize of regression of ANOVA and coefficients for the percentage of broken rice. The regression coefficients from multiple regression analysis showed that component proportions had significant ($P \leq 0.05$) full quadratic model. graphed the normal probability of residuals for response is broken as shown in Figure 1 To study the effects of two factors, 14 = 42 runs are required. Due to space limitations, the treatments, factor values, and the corresponding responses are not shown. Analysis of variance method (ANOVA) is used to find factors with significant effects. Effects A, B, AA, BB, and AB are found to be significant. the residuals plot approximately along a straight line, In this research , the residuals can be judged as normally probability, and Figure 2 Residuals versus the Fitted Values is Broken rice(percentage) this graph was diffused between upper and lower limited.

TABLE I
FACTOR LEVELS AND CODES FOR DESIGN OF EXPERIMENT

Factor	min	max	Min code	Max code
Revolution (x_1)	1200	1500	-1	1
Clearance(x_2)	1	2	-1	1

TABLE II
2^2 FACTORIAL DESIGN (CENTRAL COMPOSITE DESIGN)

A	*B*	*AA*	*BB*	*AB*	*Yield*
0	0	0	0	0	25.50
-1	1	1	1	-1	21.30
0	0	0	0	0	25.10
1	-1	1	1	-1	49.50
0	0	0	0	0	25.80
1	1	1	1	1	18.70
-1	-1	1	1	1	33.10
0	0	0	0	0	25.05
1	1	1	1	1	18.50
1	1	1	1	1	17.90
1	-1	1	1	-1	48.70
1	-1	1	1	-1	49.00
0	0	0	0	0	25.20
-1	1	1	1	-1	21.80
0	0	0	0	0	25.20
-1	-1	1	1	1	33.20
-1	-1	1	1	1	33.80
0	0	0	0	0	25.60
0	0	0	0	0	25.30
-1	1	1	1	-1	21.50
0	0	0	0	0	25.80
0	1.4	0	2	0	19.10
-1.4	0	2	0	0	20.20
0	-1.4	0	2	0	50.10
0	0	0	0	0	24.50
0	0	0	0	0	24.70
1.4	0	2	0	0	29.50
0	1.4	0	2	0	19.60
0	0	0	0	0	24.30
0	0	0	0	0	24.80
0	1.4	0	2	0	19.80
-1.4	0	2	0	0	20.80
1.4	0	2	0	0	29.20
0	0	0	0	0	24.20
0	0	0	0	0	24.46
0	-1.4	0	2	0	50.50
0	0	0	0	0	24.50
-1.4	0	2	0	0	20.50
0	0	0	0	0	25.10

TABLE III
ESTIMATED REGRESSION COEFFICIENTS FOR BROKEN

Term	Coef	SE Coef	T	P
Constant	24.9783	0.07254	344.351	0.000
revolution	3.1282	0.06282	49.797	0.000
clearance	-10.7496	0.06282	-171.119	0.000
revolution*revolution	0.1421	0.06538	2.173	0.037
clearance*clearance	5.1171	0.06538	78.262	0.000
revolution*clearance	-4.7167	0.08884	-53.092	0.000

S = 0.3078 R-Sq = 99.9% R-Sq(adj) = 98.42 %

TABLE IV
ANOVA RESULTS FOR THE SECOND –ORDER MODLE

Analysis of Variance for Broken

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	3856.61	3856.61	771.32	8144.01	0.000
Linear	2	3008.15	3008.15	1504.07	15880.78	0.000
Square	2	581.50	581.50	290.75	3069.88	0.000
Interaction	1	266.96	266.96	266.96	2818.73	0.000
Residual Error	35	3.31	3.31	0.09		
Lack-of-Fit	3	0.38	0.38	0.13	1.36	0.271
Pure Error	32	2.94	2.94	0.09		
Total	41	3865.86				

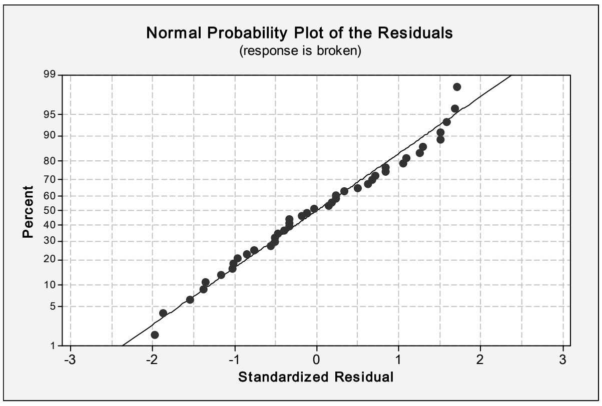

Fig. 1 Normal Probability Plot of the Residuals Response is broken

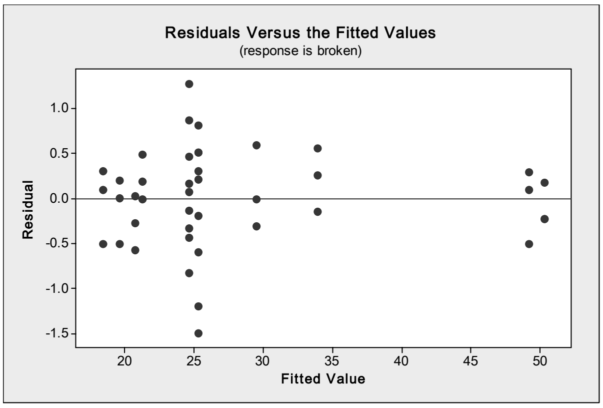

Fig.2 Residuals versus the Fitted Values Response is Broken

Since the response surface is explained by the second-order model, it is necessary to analyze the optimum setting. The graphical visualization is very helpful in understanding the second-order response surface. This graphed the contour plot of broken rice (*Yield)* as is shown in Figure 3.

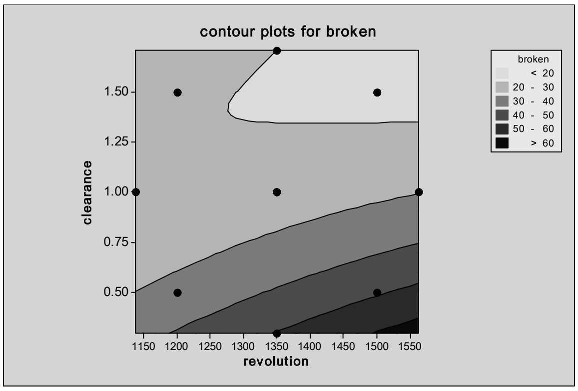

Fig.3 Contour Plot for Broken between clearance and revolution

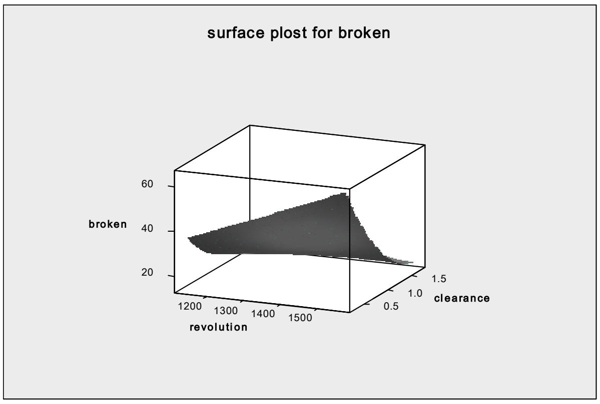

Fig.4 Response Surface plots of broken rice as function of the number of revolution (x_1), the number of clearance (x_2).

Figure 4 presents a graphical representation of one of the response surfaces generated through RSM using a full quadratic model of revolution and clearance to predict the percentage of broken rice . The predicted mean value of each response and the associated standard error of prediction at several points in the triangle. To assess the magnitude of prediction error, and also computed 95% confidence limits on the mean response, Table V show the response optimization of global solution. It is shown that the predicted response of 15.29 and composite desirability of 0.489 respectively.

TABLE V
RESPONSE OPTIMIZATION

Parameters	Goal	Lower	Target	Upper	Weight	Import
% Broken	Minimum	5	5	25	1.0	1.0
Global Solution						
	Revolution		= 1562			
	Clearance		= 1.71			
Predicted Responses						
	%Broken		= 15.29 , desirability = 0.489			
Composite Desirability			= 0.489			

II. Conclusion

The response surface methodology in the study of the effects of the components on some physical properties of a rice polishing cylinder formulation. Under optimal values of process parameters. This research clearly showed that response surface methodology was one of the suitable methods to optimize the best operating conditions to maximize the abrasive removing. Graphical response surface and contour plot were used to locate the optimum point. The statistical fitted models and the contour plot of responses can be used to predict values of responses at any point inside the experimental space. It also can be successfully used to optimize the rice polishing cylinder mixture.

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