Brown Rice Peeling Machine Production Process Optimization Using $(2)^3$ Factorial Design : Part I

S. Bangphan, P. Bangphan, P. kettim, P. Maliwan, T. Boonkang ., and W. Insorn

***Abstract*— The phenomenon of husker of rice grains during peeling operations was analysed using factorial experimental designs as well as a response surface regression method. The factors chosen were peeling husker operation, temperature, moisture and volume. To conduct the tests using the factorial approach, two levels were chosen for each factor. After obtaining the data (GR), the significant factors were determined by an analysis of variance (ANOVA). Then, the level of significant factors tests were carried out using factorial design. ANOVA was applied again and, finally, the initial response surface regression model was produced considering the significant factors. After verifying the validity of the initial models, the Design of Experiment was implemented until the models achieved validity.**

***Keywords*— Brown rice peeling machine, Process, Response surface regression, factorial design**

I. INTRODUCTION

The quality of peeled rice are depends on many factors such as rice strain, the rate of feeding, clearance between a rubber to rubber cylinder, paddy moisture content which usually are controlled not to be exceed 14% ect. But the most important factor is the type of the abrasives [1]-[2]. Nutritional Implications of Rice Milling: In rice milling, the bran layers and germ removed during polishing are high in fiber, vitamins and minerals as well as protein. Their removal results in loss of nutrients, especially in substantial losses of B vitamins. Polishing rice reduces the thiamin content of rice by over 80%. Parboiling results in substantial losses of B vitamins. Polishing rice reduces the thiamin content of rice by over 80%. Parboiling results in gelatinization of the starch and disintegration of the protein in the endosperm resulting in inward shift of water-soluble vitamins to the endosperm. Parboiled rice is therefore higher in B vitamins [3] and see Table 1. Brown Rice Is Superior to Polished Rice: Brown rice has high dietary fiber (a gentle laxative, prevents gastro-intestinal diseases and good for diabetes sufferers); rich in B vitamins and minerals (prevents beriberi); and high in fat (energy source). Also it has been reported that brown rice contains high phytic acid (antioxidant, anti-cancer); it decreases serum cholesterol (prevents cardio-vascular diseases); and it is considered a low glycemic index food (low starch, high complex carbohydrates which decreases risk to type 2 diabetes). The enhancement of rice supply is another advantage of brown rice relative to polished or white rice. Post harvest researchers say that the milling recovery in brown rice is 10% higher than polished rice [4]. It follows that the milling time is also shortened; labor is less; and the cost of equipment (if the mill is dedicated to brown rice) is much lower because the miller doesn't have to install polishers and whiteners. The enhancement in output volume and the economy in milling constitute the business opportunity in brown rice. [5].

TABLE I
NUTRIENT CONTENT OF RICE [3]

mg/10g	Brown rice	Polished rice
Thiamine	0.34	0.07
Riboflavin	0.05	0.03
Niacin	4.7	1.6
Iron	1.9	0.5
Magnesium	187.0	13.0

Milling affects the nutritional quality of the rice. Milling strips off the bran layer, leaving a core comprised of mostly carbohydrates. Fiber is dramatically lower in white rice, as are the oils, most of the B vitamins and important minerals. Unknown to many, the bran layer contains very important nutrient such as thiamine, an important component in mother's milk [6]. Brown rice (hulled rice) is composed of surface bran (6–7% by weight), endosperm (E90%) and embryo (2–3%) [7] White rice is referred to as milled,

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Fig. 1 Brown Rice

polished or whitened rice when 8–10% of mass (mainly bran) has been removed from brown rice [8]. During milling, brown rice is subjected to abrasive or friction pressure to remove bran layers resulting in high, medium or low degrees of milling depending on the amount of bran removed [7,9]. As most cereals, rice does not show a homogeneous structure from its outer (surface) to inner (central) [10]. As a consequence, information on the distribution of nutrients will greatly help in understanding the effect of milling and aid in improving sensory properties of rice while retaining its [11].

This study is going to follow the framework set with some modifications to brown rice peels, so that we can investigate the possibility of using Factorial Design to improve our broking results by only varying the period of selection temperature, moisture and volume respectively.

II. EXPERIMENTAL PROCEDURE

A. *Materials and Method*

Paddy (rough rice) must be milled after harvesting and drying. In milling process uneatable hulls and bran are removed from paddy and brown rice is produced. In general, rice peeling process consists of three main operations combination:

When paddy comes to the milling system it may contain some foreign materials such as stones, stalk, dust, soil particles, and weed seeds; therefore, it is necessary to pass the paddy though a cleaning system. This cleaning system can be a simple sieve or a progressive system.

The most outer rough shell of paddy is removed. Rubber roll sheller (Fig. 2) is the most common machine that is used for paddy shelling, however friction type browner is sometimes used as a sheller. Paddy goes between two rubber rollers that are rotating in opposite direction with different velocities. There is a small clearance between the rollers so that when paddy passes through, it is subjected to some shear forces and husk is removed from it.

B. *Methods*

In almost all the fields of inquiry, experiments are carried out in order to discover some findings about the processes or systems. An experiment can be defined as a test or series of tests in which purposeful changes were made to the input factors of a process or a system, so that the reason for the changes were observed and identified. The design concept of the experiments has been in use since Fisher's work in agricultural experimentation. Fisher successfully designed experiments to determine the optimum treatments for the land to achieve a maximum yield [12].

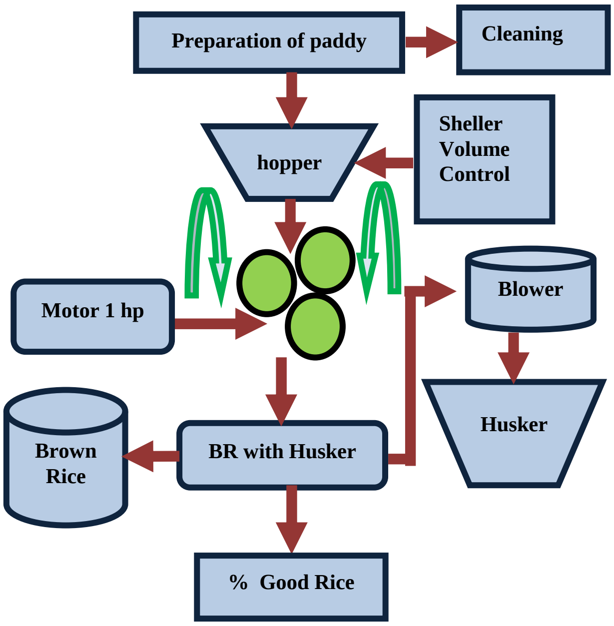

Fig.2. Diagram of brown rice peeling machine

The first step in designing any experiment is recognizing the problem. This is followed by the determination of the effective factors with their levels and specifying a response variable. Then, based on the objectives, one must select a suitable experimental design and carry out the experiments accordingly. The obtained data would be studied using the analysis of variance (ANOVA) method, leading to the determination of the factors with a significant effect on a response variable. Finally, a model can be worked out which represents the response variable as a function of the already determined significant factors. The choice of the experimental design depends on the type of problem, the number of factors, as well as their levels [13]. the full factorial design considers all possible combinations of a given set of factors. Since most of the industrial experiments usually involve a significant number of factors, a full factorial design results in a large number of experiments [14]. The response surface methodology, a collection of mathematical and statistical techniques, is useful for the modeling and analysis of problems in which a response of interest is influenced by several factors. If the response is modeled by a linear function of the independent factors, then the approximating function is the first order model Equation (1).

$$y_k = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + .. \beta_k x_k + \varepsilon \qquad (1)$$

Where ε represents the noise or error observed in the response y. In this model, the regression coefficient, β_i, is a measure of the change in the response y due to a change in the input variable x_i. If there is curvature in the system, then a polynomial of a higher degree, such as a second order model Equation (2), must be used [14]:

$$y_k = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1}\sum_{j=1}^{n-1} \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

III. IMPLEMENTATION AND RESULTS

A. Implementation

The DOE simulation was accomplished with three parameters: temperature, moisture and volume. It was performed according (see Table II and III), and brown rice peeling machine in Fig 2. A model fitting was accomplished for the first 2^3 Factorial Design in Table III. The independent (TEMP, MOIS, and VOL.) and the dependent variables were fitted to the second-order model equation and examined in terms of the goodness of fit. The analysis of variance (ANOVA) was used to evaluate the adequacy of the fitted model. The R-square value (determination coefficient) provided a measure of how much of the variability in the observed response values could be explained by the experiment factors and their interactions.

DOE order defines the sequence that variables should be introduced in response surface analysis. See Table III shows the results according to simulated analysis performed in MINITAB Release 15.00 used for simultaneous optimization of the multiple responses. The desired goals for each variable and response were chosen. All the independent variables were kept within range while the responses were either maximized or minimized. The significant terms in different models were found by analysis of variance (ANOVA) for each response. Significance was judged by determining the probability level that the F-statistic calculated from the data is less than 5%. The model adequacies were checked by R^2, adjusted-R^2 (adj-R^2).The coefficient of determination, R^2, is defined as the ratio of the explained variation to the total variation according to its magnitude. It is also the proportion of the variation in the response variable attributed to the model and was suggested that for a good fitting model, R^2 should not be more than 75 %. A good model should have a large R^2, adj-R^2. Response surface plots were generated with MINITAB Release 15.00.

B. Factorial Design and results

Response surfaces equations were obtained from design of experiments. Using all values (tests 1 to 40) to the system analysis, the following polynomial equations were generated: The Estimated Regression Coefficients for GOOD RICE using data in uncoded units:

TABLE II
DOE PARAMETERS

Parameter	Variable	Lower Limit	Upper Limit
Temperature (TEMP)	x_1	25.00	35.00
Moisture (MOIS)	x_2	10.00	14.00
Volume (VOL)	x_3	50.00	100.00

Remarks : TEMP = degree Celsius, MOIS = percentage , VOL = grams

$$\begin{aligned} y &= (300.220x_0) + (-8.08800x_1) + (-9.63500x_2) + (-3.95210x_3) \\ &\quad + (0.397000x_1x_2) + (0.132820x_1x_3) + (0.242650x_2x_3) \\ &\quad + (-0.0086900x_1x_2x_3) \qquad (3) \end{aligned}$$

Equation (3) is generate the graphic shown in Fig. 3 shows optimal solutions considering TEMP, MOIS and VOL. Main solutions are positioned at 25 and 35 degree Celsius distance and there is a range between 10 and 14 percentages of moisture and volume equal 50 with 100 grams respectively where it is allowable to use other distances (see Table II. DOE parameter). Result of the analysis of variance is given in Table IV. The test statistic F_0= 1568.41 is bigger than the critical $F_{.05,3,32}$ =2.8895 value. There is significant evidence of lack of fit at a = 0.05. Therefore, this study can conclude that the true response surface is explained by the linear model. To study the effects of three factors, 2^3 = 10 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 X_1, X_2,X_3 X_1X_2, X_1X_3,X_2X_3, $X_1X_2X_3$ and DF are found to be significant ,that is the most significant effect, has significant interactions with all other factors. Alternatively, these results can be obtained visually from the residual versus fits probability plot of effects method shown in Fig.3 plot the range of the residuals looks essentially constant across the levels of the predictor variable, TEMP, MOIS, and VOL. The scatter in the residuals at TEMP between 25 and 35 degree Celsius with MOIS at between 10 and 14 percentages and VOL equal 50 and 100 grams that the standard deviation of the random errors is the same for the responses observed at each TEMP, MOIS and VOL respectively.

The response taken from Table IV revealed that the square coefficients of temperature (X_1), moisture (X_2)and volume (X_3), have a remarkable effect on the GOOD RICE yield. Moreover, all the linear and interaction terms of three factor presented in significant effects on the GOOD RICE yield at 5% probability level. Since all coefficients of the above equation (3) are all negative, the response surface is suggested suggested have a maximum point in Fig 4.

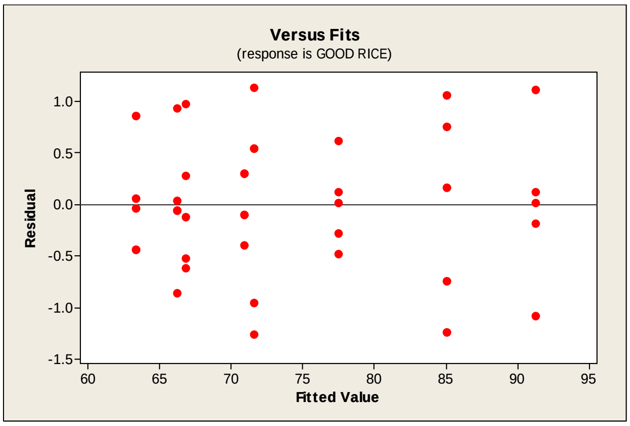

Fig.3 Residual of Response is GOOD RICE

A significantly brown rice peel was observed as temperature, moisture and volume addition increased (P <

0.05, Fig. 4). In Fig.4 presents a graphical representation of one of the response surfaces generated through FACTORIAL DESIGN using a full quadratic model of temperature (X_1), moisture (X_2) and volume (X_3) to predict the GOOD RICE. As depicted, the normalized search direction to minimize the brown rice is (-low , + high). And Table V Predicted Response for New Design Points Using Model for GOOD RICE.

TABLE IV
ANALYSIS OF VARIANCE FOR GOOD RICE (CODE UNITS)

Source	DF	SS	MS	F	P
Main Effects	3	2383.78	794.595	1568.41	0.000
2-Way Interactions	3	801.25	267.084	527.18	0.000
3-Way Interactions	1	188.79	188.790	372.64	0.000
Residual Error	32	16.21	0.507		
Pure Error	32	16.21	0.507		
Total	39	3390.04			

TABLE V
PREDICTED RESPONSE FOR NEW DESIGN POINTS UNSING MODEL FOR GOOD RICE

Point	Fit	SE Fit	95 % CI	95 % PI
1	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
2	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
3	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
4	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
5	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
6	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
7	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
8	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
9	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
10	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
11	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
12	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
13	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
14	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
15	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
16	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
17	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
18	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
19	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
20	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
21	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
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27	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
28	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
29	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
30	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
31	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
32	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
33	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
34	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
35	92.5981	11.4868	(69.2002, 115.9960)	(69.1553, 116.0409)
36	15.4952	21.2994	(-27.8902, 58.8806)	(-27.9144, 58.9048)
37	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
38	32.9725	20.1623	(-8.0968, 74.0418)	(-8.1224, 74.0674)
39	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)
40	84.4792	12.1346	(59.7618, 109.1966)	(59.7193, 109.2391)

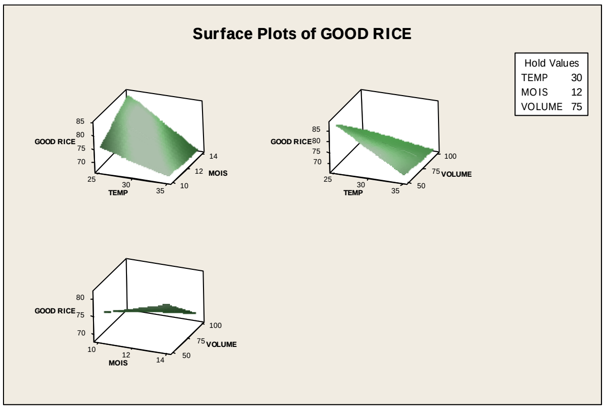

Fig.4 Response surfaces for the TEMP of 25 degree Celsius, MOIS of 14 percentage, and VOL of 50 grams

IV. CONCLUSIONS

The results of factorial design with three factors, parameter (two levels) are given in Table II and Forty runs in Table V were carried out to cover all possible combination of the three factors. When productions into the formulation, the optimized levels of R-Squire $_{\text{(adjust)}}$ was 99.42 % and standard deviation was 0.711776 yielded good quality peeling. This study clearly showed that FACTORIAL DESIGN was one of the suitable methods to optimize the best operating conditions to maximize the peel 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 and can be successfully used to optimize the brown rice peeling machine. Also, the size and amount of this surface degradation was noticeably increased as a function of exposure time. The factorial design was used. The optimal composition of the brown rice established (run order 40) was: TEMP = 25 degree Celsius with MOIS =14 percentage and VOL = 50 grams. The optimal values for the brown rice peeling parameters were good rice of 91.28 %.

ACKNOWLEDGMENT

Financial support from Department of Science in Technical Education, Faculty of Engineering, RMUTL: Rajamangala University of Technology Lanna Chiangmai, Campus is gratefully acknowledged

REFERENCES

[1] S. Bangphan, S. Lee, “Modeling Material Mixtures to Replace of Rice Polishing Cylinder,”Proceeding of the Conference of Industrial Engineering, IE NETWORK CONFERENCE, 17-19 December 2006.
[2] S. Bangphan, S. Lee and S. Jomjunyong, “Development of the Alternative Composite Material for Rice Polishing Cylinder,” APIEMS & CIIE 2007.,Dec.2007, Proceeding 8th Conference. Industrial Engineeris Taiwan, 2007,p.146.
[3] Oh, C.H. and S.H. Oh, “Effects of germinated brown rice extracts with enhanced levels of GABA on cancer cell proliferation and apoptosis”. Journal of Medical Food, 7(1).2004.
[4] Garrow, J.S. *et al*., “Human Nutrition and Dietetics”, Harcourt Publishers, London,2000.
[5] Rogelio V. Cuyno, “The National Campaign to Combat Hidden Hunger through Brown Rice Paper presented during Consultative Meeting on Nutritional Aspect of Brown Rice”, at Food & Nutrition Research Institute, Manila Philippines,2003.
[6] Wood, Rebecca., “The Whole Foods Encyclopedia”. New York, NY: Prentice-Hall Press; 1988.

[7] Chen, H., Siebenmorgen, T.J., “Effect of rice thickness in degree of milling and associated optical measurements”. Cereal Chemistry 74, 821–825,1997.

[8] Chen, H., Siebenmorgen, T.J., Griffin, K., “Quality characteristics of long-grain rice milled in two commercial systems”. Cereal Chemistry 75, 560–565,1998.

[9] Kennedy, G., Burlingame, B., Nguyen, N., “Nutrient impact assessment of rice in major rice-consuming countries”. International Rice Commission Newsletter 51, 33–41,2002.

[10] Itani, T., Tamaki, M., Arai, E., Horino, T., “Distribution of amylose, nitrogen, and minerals in rice kernels with various characters”. Journal of Agricultural and Food Chemistry 50, 5326–5332,2002.

[11] Jianfen Liang et al., “Milling characteristics and distribution of phytic acid and zinc in long-,medium- and short-grain rice” Journal of Cereal Science 48 (2008) 83–91.

[12] Montgomery, D. C., *Design and analysis of experiments*, John Wiely & Sons Inc., New jersey, 2000.

[13] Roy, R., Design of experiments using Taguchi approach, John Wiley, New York, 2001.

[14] Montgomery, D.C., Introduction to linear Regression Analysis, John Wiley & Sons Inc., New Jersey, 1991.

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