Advances in Biological Sciences Research, volume 19
Proceedings of the 2nd International Conference on Smart and Innovative Agriculture (ICoSIA 2021)

Multiobjective Optimization of Vibro-Pneumatic Separator Using Full Factorial Design

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ABSTRACT
Vibro-pneumatic separator has been applied widely in grain cleaning industries for separating light impurity, gravel and various types of contaminant from grain products. Pneumatic section is utilized as the suction part to separate the light impurity contaminant from the basic product based on the distinction of aerodynamic properties between basic product and impurities contaminants. A multilayer sieves equipped with vibration motor is utilized to separate the grain product from foreign materials other than grains such as sands and pieces of rocks based on the size. To improve the separation efficiency and productivity, several parameters need to be adjusted including the air velocity, vibration frequency and sieve angle. This study attempts to optimize the process parameter of a vibro-pneumatic separator based on the separation efficiency and productivity. An experimental design based on full factorial design was used to adequately adjust the process parameter of a vibro-pneumatic separator including air velocity, sieve angle and vibration frequency on cleaning paddy seeds from different types of contaminants. The effect of factors on each response are analyzed to study the effect of each factor on the desired responses. Multiobjective optimization using a response optimizer is functioned to obtain the optimal setup parameters of a vibro-pneumatic separator based on separation efficiency and productivity. The experiments revealed that vibration frequency was found to be significant for both separation efficiency and separation productivity, while air velocity and sieve angle factors were found to be insignificant for both separation efficiency and separation productivity. An increase in vibration frequency increased the separation efficiency and separation productivity. The statistical results confirmed that R2 of the regression models were 0.78 and 0.89 for the separation efficiency and separation productivity, respectively. According to the multiobjective response optimizer, the optimum setup was at 8 m/s of air velocity, 7 degree of sieve angle, and 20 m/s of vibration frequency. This appraoch enable us to determine the setup of separation machine based on more than one machining parameter using multiobjective approach.

Keywords: *Grain Cleaning Process; Vibro-Pneumatic Separator; Multiobjective Optimization; Full Factorial Design; Separator Machine*

1. INTRODUCTION

After the harvesting stage of paddy, the grain seeds still contain some undesired materials other than grain (MOG) such as debris, sand, stone pebbles, chaff, and straw which reduce the quality of the crops. Cleaning and separating process therefore required to remove MOG in terms of upgrading the grain quality. This pre-cleaning process is required after the paddy harvesting stage before drying or storing process, and it is one of the important postharvest paddy processing. According to the current cleaning technology [1], the existing tools according to its technological aspect: efficiency, productivity, and reliability did not fit to the requirements of grain processing in the field environment conditions. There is still possibility to increase the efficiency of the current grain cleaning product by using vibration separators that are practically exhausted [2].

A number of researches have been proposed to clean a grain product using pneumatic separation machine [3-6]. Afolabi, et al. [7] proposed a pneumatic based separator to separate a maize grain material from impurities. They identified the effect of factors including air velocity and feed gate opening on separation efficiency and losses. Panasiewicz, et al. [8] found that an increase in the moisture content of crushed lupine seeds significantly decreased the separation effectiveness, while an increase in air velocity increased the separation effectiveness. Choszcz, et al. [9] identified the effect of factors such as air velocity, moisture and grain type on the separation efficiency of the pneumatic conical separator. In order to increase the test weight and reduce impurities from types of grain product, Crepon and Duyme [10] tested the efficiency of three different types of grain cleaner machine using different grain flow and aspiration rate. They found that the highest test weight increase is obtained with low grain flow rate while an increase in aspiration rate has no major impact on the test weight gain.

There were a significant number of researches on grain vibrative separation processes [11], focusing on the increasing grain separation efficiency. However, there is still the possibility to increase the grain separators effectiveness technologically [12] which was not intensified enough yet. An improvement approach in the grain separator machine based on vibrative separation to increase the productivity [13], while maintaining the quality of the operation [14]. For this objective, it is important to enhance the sifting system throughout the grain layer sieves vibration. This paper proposed to study the effect of technological aspects of vibro-pneumatic separator namely air velocity, sieve angle, and vibration frequency to optimize both Separation efficiency and separation productivity.

A number of researches have been executed based on the theory of vibration, as well as the mechanical background. The equation that developed on vibration displacement was based on an analytical approach using computer technologies. Experimental approaches have been proposed on grain separator based on statistical processing of experimental data [15]. The research study was proposed to identify parameters of numerical models according to its fitness to check the theoretical background and establish the efficiency of separation process depending on the machining parameters in a range of variables [16]. The experimental installations of sieve vibration separators have been coducted. A physical based simulation [17], focusing on geometric analogy of the structural variable as well as the similarity of the tides of air and grain material.

2. MATERIAL AND METHOD

2.1. Vibro-Pneumatic Separator

Figure 1 showed the design of the vibro-pneumatic separation machine proposed in this study to pre-clean paddy seeds. The machine was designed with a modified suction channel to suck the light impurities contaminant from the mixture grain product. The air velocity in the suction channel was regulated using an inverter tool on the 3 phase electrical motor to set the voltage frequency from 0 - 50 Hz. The slope of the sieve was adjusted according to the desired and required angle (7o and 10o Angle). The vibration frequency of the sieve was also adjustable by changing the ballast pendulum on the motor vibrator with two ballast for a larger vibration and with one ballast for low vibration frequency. This separator machine was operated under two electric motors, namely the suction fan motor and the sieve vibration motor. It was also equipped with two different screen size sieves and one tight board at the base. To clean the grain product, the grain material to be cleaned is placed on the hooper then the feed rate is set based on the desired value through the opening gate sheet. Then, the material will drop due to gravity while light impurities will be sucked in by the suction fan and being collected in suction channel output, while the rest of materials will then fall down to the vibrated sieve. The first layer of the sieve will hold a large size of contaminants while the basic product and small size of contaminants will go down to the second layer of the screen sieve. At the second layer of the sieve the basic product will be detained as the basic product output while the rest (smaller size of contaminants) will go to the third layer of the sieve as the contaminants. This enabled the vibro-pneumatic separator machine to efficiently clean the grain product from various types of contaminants.

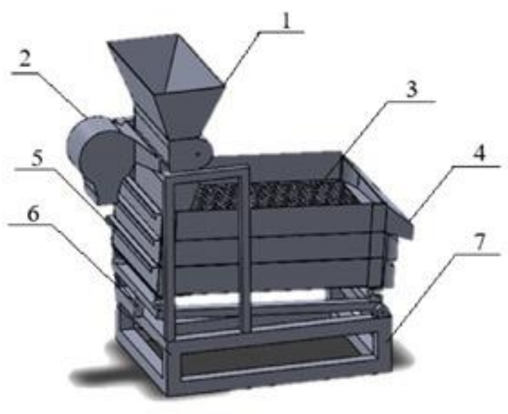


Figure 1. Scheme of grain separator **:** 1 - hooper, 2 - pneumatic suction, 3 – sieve, 4 – output, 5 – sieve substitute, 6 – height adjuster, 7 – machine frame.

2.2. Sample Preparation

The material used in this study was a Situ Bagendit variety of paddy seed from Department of Agricultural Service, Yogyakarta Province that has been pre-cleaned in advance from contaminants. The paddy seed has a moisture content of 10% wb, then it was mixed with contaminants in the form of rice bran, dried leaves, and broken rice. The grain weight is 4500 grams, while contaminants are 200 g of broken rice, 200 g of rice bran, and 30 g of dried leaves, where the total number of the mixture was 4930 g.

2.3. Design of Experiment

This research was based on experimental study to analyze the influence of the factors on the separation efficiency and productivity and also to determine the optimum setup parameters of the separator machine. The selected factors and its level can be found at table 1. The experiment was conducted based on full factorial design with 3 factors, 2 levels of each factor and 3 replications. Separation efficiency of the vibro-pneumatic separator machine was calculated using the following equation:

Separation Efficiency (%)

$$=\left(\frac{\left(\frac{M_1-M_2}{M_1}\right)+\left(\frac{M_3-M_4}{M_3}\right)+\left(\frac{M_5-M_6}{M_5}\right)}{3}\right)\times 100\% \quad (1)$$

Where, M_1 is the weight of broken rice contaminant before separation (200 g), M_2 weight of broken rice contaminant after separation. M_3 is the weight of rice bran contaminant before separation (200 g), M_4 is the weight of rice bran contaminant after separation. M_5 is the weight of dried leaves contaminant before separation (30 g), M_6 is the weight of dried leaves contaminant after separation.

While separation productivity is measured through the follwing equation:

Separation Productivity (kg/min)

$$= \frac{W_s}{t} \times 100\% \quad (2)$$

Where, W_s is the weight of mixture product (kg) and *t* is the separating time calculated from the gate opening at the hopper is released untuil the last product exit the output gate. The time was calculated from the opening gate sheet is removed from the hopper until the last grain exit the output channel.

Table 1. Selected factors and levels.

Selected Factors	Low Level	High Level
Air Velocity (m/s)	5	8
Sieve Angle (degree)	7	10
Vibration Frequency (m/s)	10	20

3. RESULTS AND DISCUSSION

3.1. Experimental results

Table 2 showed the results of this experiment for both separation effieciency (SE) and separation productivity. Minitab software was used to create the full factorial design and analyze the results. The effect of each factor on both responses therefore analyzed using Analysis of Varians (ANOVA) and plot for each response. Then, the regression model was presented to show the effect and trend of each factor on each response. Multiobjective optimization using responses optimizer then proposed to give best setup of the vibro-pneumatic according to both responses namely separation efficiency and productivity. This approach therefore can be an alternative to adequately adjust the machining parameter for different types of response.

Table 2. Experimental results.

Air Velocity (m/s)	Vibration Angle (degree)	Vibration Frequency (m/s)	SE (%)	Productivity (%)
5	7	20	97%	6.01
5	7	20	98%	7.05
8	15	10	92%	2.24
8	7	20	98%	7.11
8	15	20	98%	6.19
5	15	20	98%	6.52
5	15	10	94%	2.44
8	7	20	98%	7.17

5	7	10	95%	2.35
5	15	20	98%	7.00
5	15	10	93%	2.11
5	7	20	97%	5.35
5	7	10	92%	3.33
8	7	20	98%	7.41
8	15	10	96%	2.11
8	15	20	97%	5.16
5	7	10	93%	2.51
8	7	10	95%	2.21
5	15	10	93%	3.08
5	15	20	98%	5.12
8	7	10	95%	2.22
8	15	10	94%	1.44
8	15	20	97%	4.51
8	7	10	96%	2.54

3.2. Factor Analysis

Table 3 showed the effect of the independent factors on the separation efficiency. It showed that the air velocity and sieve angle factor give insignificant effect on the separation efficiency, while the vibration frequency give significant effect (p-value < 0.05) on the separation efficiency. The coefficient of determination of the model was found to be qualified (R2 = 0.78) to predict separation efficiency (table 4). Fig. 2a showed that there is an increase in separation efficiency when we increase the vibration efficiency from 10 m/s to 20 m/s. This mean, vibration frequency is significant to separate the basic product from contaminants. The increase in air velocity form 5 m/s to 8 m/s also increased the separation efficiency, especially for the light impurity contaminant and dry leaves. However, the suction channel was not effective for higher density contaminant such as broken rice. Since the aerodynamic properties of paddy seed and broken rice are in same level, thus to drag out the broken rice through suction channel will require higher air velocity, which also will increase the product losses.

According to table 5, air velocity and sieve angle give insignificant effect on the separation productivity, while vibration frequency affect the separation productivity significantly (p-value < 0.05). The coefficient of determination of the model found to be fit (R2 = 0.89) to predict separation productivity (table 6). Fig. 2b showed that the vibration frequency has a linier effect on the separation productivity. More vibration frequency increase the productivity and less time to finish the separation process.

Table 3. Analysis of varians on separation efficiency.

Source	DF	Adj SS	Adj MS	F-Value	P-Value SE (%)
Model	3	0.009128	0.003043	24.02	0.000
Linear	3	0.009128	0.003043	24.02	0.000
Air Velocity (m/s)	1	0.000255	0.000255	2.01	0.171
Sieve Angle (degree)	1	0.000008	0.000008	0.06	0.804
Vibration Frequency (m/s)	1	0.008865	0.008865	69.97	0.000
Error	20	0.002534	0.000127		
Lack-of-Fit	4	0.000663	0.000166	1.42	0.273
Pure Error	16	0.001871	0.000117		
Total	23	0.011662			

Table 4. Model adequacy of separation efficiency.

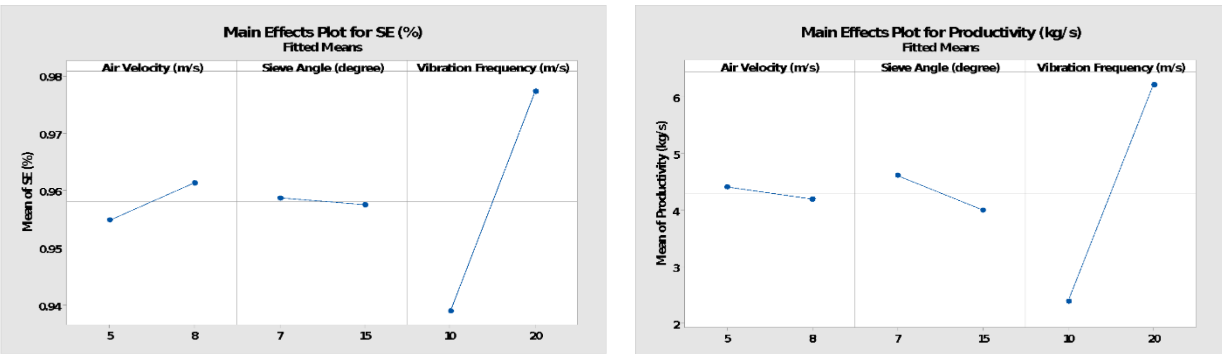
S	R-sq	R-sq(adj)	R-sq(pred)
0.0112559	78.27%	75.01%	68.71%

Table 5. Analysis of varians on separation productivity.

Source	DF	Adj SS	Adj MS	F-Value	P-Value Productivity (kg/s)
Model	3	90.761	30.2537	57.18	0.000
Linear	3	90.761	30.2537	57.18	0.000
Air Velocity (m/s)	1	0.273	0.2731	0.52	0.481
Vibration Angle (degree)	1	2.245	2.2448	4.24	0.053
Vibration Frequency (m/s)	1	88.243	88.2433	166.77	0.000
Error	20	10.583	0.5291		
Lack-of-Fit	4	4.241	1.0603	2.68	0.070
Pure Error	16	6.341	0.3963		
Total	23	101.344			

Table 6. Model adequacy of separation productivity.

S	R-sq	R-sq(adj)	R-sq(pred)
0.727412	89.56%	87.99%	84.96%



(a) (b)

Figure 2. Effect of the selected factors on responses: (a) Separation efficiency, (b) Separation productivity.

3.3. Optimum Setup Parameters

In order to obtain the robust machining setup that fit both responses, a multiobjective optimization was utilized to gain an optimal performance of the separation process using responses optimizer in matlab software. Figure 3 showed the recommended setup parameter for both separation efficiency and separation productivity. To obtain the optimum vibro-pneumatic separation process, one should set the process parameter using 8 m/s of air velocity, 7 degree of Sieve angle and 20 m/s of vibration frequency. The mentioned setup parameters may give the optimum machining performance based on different responses.

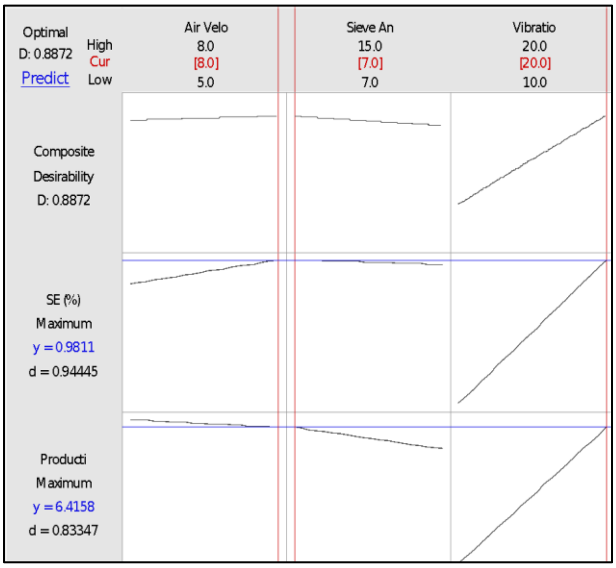


Figure 3. Optimal machining setup for both response.

4. CONCLUSION

Accroding to the experimental results and statistical data, it was found that only vibration frequency factor is significant for both separation efficiency and separation productivity. Increasing the vibration frequency increased the separation efficiency and separation productivity. According to response optimizer, the optimum setup was found using 8 m/s of air velocity, 7 degree of Sieve angle and 20 m/s of vibration frequency to obtain the optimum separation efficiency and separation productivity. This approach gives alternative to not only study the bahvior of machining parameters on separation performance but also gives the robust setup parameters that fit to one or more responses to increase the overall performance of the separation operation for grain cleaning prosess and also for other machining proses.

ACKNOWLEDGMENTS

The authors wish to thank to the Universitas Gadjah Mada for providing fund through RTA program and to Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology for providing all of laboratory facilities during the experiment.

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