Geometry Optimization of PET Regrind Plastic Dust Separator Machine

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Article Information

Manuscript Received 2025-05-25
Manuscript Revised 2025-05-25
Manuscript Accepted 2025-06-18
Manuscript Online 2025-06-30

ABSTRACT

This study aims to analyze the effect of various operational factors on the weight of dust collected by a dust collector machine. Using a multilevel factorial design, this study evaluates the interaction between frequency (Hz), hose length (m), and tube height (m). Analysis of variance shows that all three factors have a significant effect on the dust weight response (P-Value <0.05). The regression model with an R^2 of 99.15% shows a very high prediction accuracy. Parameter optimization was carried out to maximize the weight of dust collected, resulting in optimal conditions at a frequency of 50 Hz, a hose length of 2 m, and a tube height of 0.3 m with a dust weight of 72.75 g.

Keywords: *Dust collector, factorial design, optimization, dust weight, variance analysis.*

1. INTRODUCTION

Dust collectors play an important role in the industry to control the emission of dust particles that can be harmful to the environment and workers' health. The efficiency of dust collectors is affected by various operating parameters such as operating frequency, hose length, and tube height. In this study, these parameters were analyzed to understand their effects on the weight of dust collected, as well as to identify the combination of parameters that results in optimal performance. Therefore, in this article, the dust collector machine is used more as a dust separator because this machine functions to separate dust from plastic regrind

Recycling of regrind plastic poses a challenge in single-screw extrusion due to irregular particle shapes, which affect the yield and melt temperature [1]. New feed zone geometry and simulation methods can improve regrind material processing [1], [2]. Experiments show that regrind exhibits fluctuating results and higher actual bulk density compared to fresh material. [2]. Studies on the performance of recycled plastics show that a wide range of regrind ratios can be used without significantly reducing product quality [3]. Plastic recycling is essential to reduce environmental impacts, oil use, and carbon dioxide emissions. Although recycling has grown in recent decades, particularly for packaging materials, challenges remain in collection, sorting, and reprocessing. Continued efforts from communities, industries, and governments are needed to divert plastic waste from landfills to recycling. [4].

Factorial design is a powerful statistical approach used in a variety of research fields to efficiently investigate multiple factors and their interactions [5]. In biotechnology, it has been applied to study the regulation of mesenchymal stromal cells on macrophage plasticity, identifying PGE2 as a key factor in macrophage reprogramming [6]. Environmental scientists have used fractional factorial designs to evaluate the effects of multiple factors on biodegradation rates, significantly reducing the number of experiments required [7]. In materials science, factorial design has been used to optimize processing parameters for mixing polycarbonate grades, analyzing their impact on color formulation [8]. Similarly, in concrete research, factorial designs have been used to model the effects of mix parameters on the properties of self-compacting prestressed concrete, allowing investigation of trade-offs between variables and comparisons between different responses [9].

Recent research focuses on optimizing plastic production and recycling processes. A multicriteria design optimization methodology for automotive plastic components has been developed, which increases objectivity and efficiency in the design review process [10] [11]. Blockchain technology has been proposed to improve plastic waste management and recycling efficiency by enabling better tracking and collaboration among stakeholders [12]. To reduce moisture-related defects in injection molded components, methods that optimize plasticization parameters have been investigated, potentially reducing drying time and energy consumption [13]. For regrind processing in single-screw extruders, a new feed zone geometry has been developed to align the regrind throughput with the new material, expanding the processing window. Numerical simulations using a new hysteresis contact model and superquadric particle shape have shown improved accuracy in predicting extruder performance with regrind material [14], [15].

The multilevel factorial design method was chosen for this experiment because of its ability to evaluate the main effects and interactions between several factors simultaneously. Thus, the results of this study not only provide insight into important operating parameters but also provide practical guidance for more efficient dust collector machine settings. In the end, in addition to obtaining optimal geometric parameters in separating dust from regrind plastic. This study also aims to downstream dust separator machines in the industry to increase productivity in processing recycled regrind plastic so that it can reduce environmental pollution due to plastic.

3. RESEARCH METHODS

3.1 Format

This type of research is quantitative research, namely the causal relationship of factors that affect the dust separation process. The implementation of the research with an experimental method that provides treatment and testing on the independent variables, namely the frequency of the dust separator machine, the height of the tube and the length of the hose and how it affects to the dependent variable, namely the weight of the dust. The heavier the dust that can be separated from the plastic regrind indicates the success of the performance of this dust separator machine.. This experiment was designed using Design Of Experimen Factorial with three main factors as shown in Table 1.

Table 1. Main Factors

Frequency (Hz)	10	30	50
Length of Hose (m)	2	4	6
Height of Tube (m)	0,3	0,5	-

The experimental design involved 18 basic combinations replicated 4 times, resulting in a total of 72 runs experiments. These factors were selected based on their relevance to the performance of the dust collector machine. One of the machines used in the experiment is a dust separator machine as shown in Figure 1

Figure 1. Dust separator machine

The specifications of the dust separator machine consist of a 304 stainless steel cyclon pipe with 8", a 300 G plastic auto loader material suction, and an 8" suction blower with a voltage of 380V2800 rpm/7.5kw, and a 38 mm spiral hose. The height of the tube is varied at 0.3 m and 0.5 m. The results of the dust separation are then weighed using a digital scale with an accuracy level of 0.001.

3.2 Experimental Procedure

Experiment implementation in the Production Workshop of the Mechanical Engineering Department. The raw material of plastic regrind material used in the experiment comes from the industry that is a partner of the research collaboration. Each combination of parameters is tested under controlled laboratory conditions. The weight of the collected dust is measured in grams after each test. The collected data is analyzed using statistical software to identify patterns and relationships between the factors tested. The stages of the dust separation process consist of 3 processes, namely the separation process with a separator machine, followed by a washing machine and finally with a drying machine which can be seen in full in Figure 2.

The results of the experiments that have been carried out in the Production Workshop of the Department of Mechanical Engineering, State Polytechnic of Malang, have been validated in the industry, namely at PT. Rapidplast and have shown consistent results. This has been proven from 300 kg of plastic regrind that was processed for cleaning, it turned out to produce 13.82 kg of dust that could be separated (4.6%).

Figure 2. Completely machine of dust separator process

3.3 Data Analysis

The data were analyzed using the two way analysis of variance (ANOVA) with interaction method to determine the significance of the influence of factors and their interactions on the weight of dust collected. A linear regression model was also developed to predict the weight of dust based on a combination of parameters. The analysis of variance (ANOVA) method is widely used in various research fields to determine the significance of factors that affect the results of experiments. This method has been applied to analyze the performance of solar collectors, carbon flux estimation from remote sensing data, and slurry erosion on polymer paint coatings [16], [17], [18]. ANOVA helps identify significant factors that affect system performance, such as collector type and airflow rate in solar collectors, or slurry concentration and impact angle in paint erosion. Additionally, regression models are often developed based on ANOVA results to predict outcomes, as seen in slurry erosion studies. [18]. The functional ANOVA approach extends this method to incorporate spatiotemporal correlations, which is particularly useful for analyzing carbon flux estimates [17]. ANOVA has also been used in materials science to optimize processing parameters for polymer composites in automotive applications [19].

4. RESULTS AND DISCUSSION

As shown in Figure 3. ANOVA results show that all main factors (“frequency”, “hose length”, and “tube height”) have a very significant effect on dust weight (P-Value < 0.05). In addition, the interaction between these factors is also significant, indicating a combination effect that cannot be ignored. Specifically: Frequency (Hz): The largest effect is seen at the highest frequency (50 Hz), which significantly increases the weight of dust collected. Hose Length (m): Shorter hose length (2 m) produces optimal performance compared to longer hose lengths. Tube Height (m): A tube height of 0.3 m gives the best results in optimizing the weight of dust collected. This model has an R^2 of 99.15%, indicating excellent predictive ability. R^2 shows that the model of the influence of the independent variables of frequency, tube height and hose length affects the dependent variable of dust weight by 99.15%. This shows that the influence of the three independent variables and their interactions is very significant. The Adjusted R-squared (98.88%) and predicted R-squared (98.49%) parameters also support the validity of this model.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	17	14220.1	836.48	371.00	0.000
Linear	5	12403.1	2480.62	1100.23	0.000
Frekuensi(Hz)	2	5941.8	2970.88	1317.68	0.000
Panjang selang(m)	2	966.3	483.17	214.30	0.000
Tinggi tabung(m)	1	5495.0	5495.01	2437.21	0.000
2-Way Interactions	8	1746.1	218.27	96.81	0.000
Frekuensi(Hz)*Panjang selang(m)	4	38.7	9.67	4.29	0.004
Frekuensi(Hz)*Tinggi tabung(m)	2	1660.0	830.01	368.14	0.000
Panjang selang(m)*Tinggi tabung(m)	2	47.4	23.72	10.52	0.000
3-Way Interactions	4	70.9	17.72	7.86	0.000
Frekuensi(Hz)*Panjang selang(m)*Tinggi tabung(m)	4	70.9	17.72	7.86	0.000
Error	54	121.8	2.25		
Total	71	14341.9			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.50154	99.15%	98.88%	98.49%

Figure 3. ANOVA results

As in table 2. Optimization is done to maximize the weight of dust collected. The optimal solution produced is as follows:

Table 2. Optimization Solution

Frequency (Hz)	50
Length of Hose (m)	2
Height of Tube (m)	0,3

As shown in Figure 4. In this combination, the maximum dust weight produced is 72.75 g with a composite desirability index of 0.946721, indicating a high level of optimization. These results confirm that the setting of operational parameters has a great influence on the efficiency of the dust collector machine. High frequency increases the suction power of the machine, while shorter hose length reduces airflow resistance. Lower tube height helps improve the efficiency of dust particle collection by minimizing turbulence in the tube. The efficiency of dust particle collection in a vacuum system is affected by various factors. Higher airflow rates and pressure drops generally improve the efficiency of particle suction [20], [21]. Reducing the distance between the suction port and the surface improves particle removal [21]. Slower sweeper speeds also contribute to better collection efficiency. [20], [22]. In electrocyclones, increasing the applied voltage and decreasing the wire diameter improve the collection efficiency, especially for small particles at low flow rates. The design of system components, such as vortex finders, can significantly affect performance. [23]. Computational fluid dynamics (CFD) modeling has been used to analyze and optimize these systems, with some studies achieving particle suction efficiencies of 95% or higher. Controlling airflow and optimizing operational parameters can result in substantial improvements in dust collection and reductions in harmful emissions. [21].

Response Optimization: berat debu(g)

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
berat debu(g)	Maximum	15	76		1	1

Solution

Solution	Frekuensi(Hz)	Panjang selang(m)	Tinggi tabung(m)	berat debu(g) Fit	Composite Desirability
1	50	2	0.3	72.75	0.946721

Multiple Response Prediction

Variable	Setting
Frekuensi(Hz)	50
Panjang selang(m)	2
Tinggi tabung(m)	0.3

Response	Fit	SE Fit	95% CI	95% PI
berat debu(g)	72.750	0.751	(71.245, 74.255)	(69.384, 76.116)

Figure 4. Optimization Results

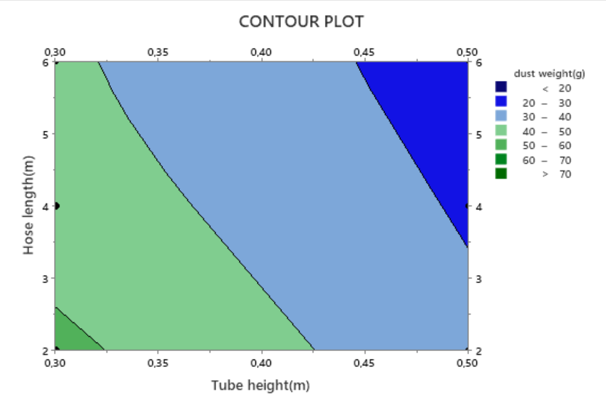
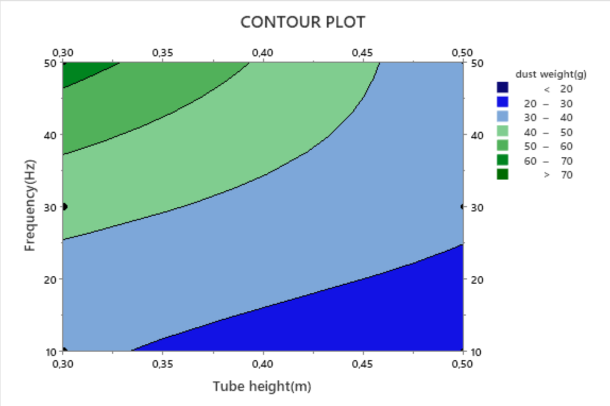


Figure 5. Contour Plot of the Effect between Hose Length and Tube Height to Weight

Figure 5 shows the resulting contour plot consisting of various color variations. Where each variation shows the range of the magnitude of the dust weight response produced. The maximum condition for the plot above is in dark green with a dust weight value above 70 g. This color range will provide an outline of the location of the optimum point of the variable. To determine the combination of process variable levels that can produce an optimal response, it is done with the help of the plant flag in Minitab through random at the center of the optimum contour.



Gambar 6. Contour Plot of the Effect between Frequency and Tube Height to Dust Weight

The results shown in the Anova table, Optimal Solution (Figure 4), and contour plot of Figure 5, are also reinforced by the contour plot in Figure 6 which shows that the combination of the height factor level of the tube and frequency will provide maximum dust weight results at a height of the tube level of 0.3 m and a frequency level of 50 Hz (dark green contour). This is in accordance with the results of the optimal solution at that level.

Based on the interaction analysis of the Anova table and the optimum solution, The response of dust weight will reach the maximum if the dust separator machine parameter setting is at a frequency level of 50 Hz, a tube height of 0.3 m and a hose length of 2 m. By taking the range of hose length and tube height at that level, the dust weight will exceed 70 g. From several combinations obtained as figure 5, the optimum point of each factor can be determined, namely 2 m for the hose length variable and 0.3 m for the tube height variable. Determination of the optimum conditions of the above factors is proven by the shape of the three-dimensional curve that forms the optimum peak as depicted in figure 6 below:

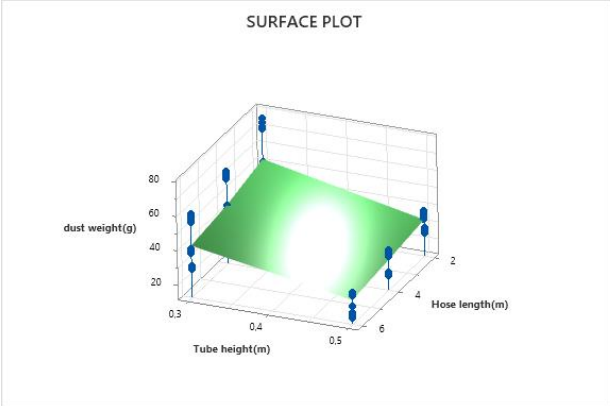


Figure 6. Surface Plot

The surface plot displays a contour plot in three dimensions. Similar to the contour plot, it can be seen in the image above that the weight of the dust will be greater if the height of the tube is between 0.3 m while the length of the hose is 2 m. However, it is still difficult to clearly know the magnitude of the independent variable in optimizing the response with the surface plot. The results obtained are in the form of a fairly large range.

Surface Plot generated from the Experiment Factorial output is one of the optimization techniques using three-dimensional surface images to display the results of the experiment so that it can be used to optimize between levels of independent variables. The function of this Surface plot is similar to the output generated by the Response Surface Methodology (RSM) Experimental Design to obtain optimal values. The difference is that in the Factorial experimental design, interpolation and extrapolation techniques are not carried out outside the points of the experimental factor levels, while in RSM these techniques are used to determine the responses outside the points of the experimental factor levels. As is known, RSM is a statistical technique used to optimize processes with several variables that affect one or more responses [24]. Although in this study, the RSM experimental design was not used.

The effect of frequency, height of the tube and length of the hose and their interaction in this research is very significant because the frequency of the blower and suction machines can determine the inlet speed between 20-70 m/s [25], then the height of the tube can also affect the amount of dust that can be sucked into the outlet hole because with a certain weight of dust if the tube is too high then the potential for dust to float and fall back to the bottom of the tube due to gravity will be greater. The length of the hose also affects the amount of dust that can be collected because the longer the hose that can cause dust to stick to the inner surface of the hose which results in less dust coming out of the hole from the hose.

Similar research on dust collectors or dust separators has been conducted by [25], [26], [27], [28], [29], [30], and [31]. The difference in this research is that they only carried out the separation process using the cyclon technique, while the current dust separator machine process consists of 3 stages, namely separation with a cyclon, washing and drying. The use of these 3 stages is because the separated product is dust that sticks to the plastic regrind material so that there is still an electrostatic effect on the dust that is still attached. Therefore, a washing and drying process is required at a certain temperature.

The obstacle faced in this research process is that the distance of the industry to carry out field validation is relatively far, so it requires the right time schedule to carry it out. For the purpose of development in further research, it is carried out on other parameters such as the washing process and the drying process. There are many variables that can still be observed and studied.

5. CONCLUSIONS

This study successfully identified the significant effects of frequency, hose length, and tube height on the weight of dust collected by the dust separator machine. The optimal parameter combination is a frequency of 50 Hz, a hose length of 2 m, and a tube height of 0.3 m. These results provide practical guidance for users to improve the efficiency of dust collector machines.

6. AKNOWLEDGEMENTS

This research is funded by the Government. My gratitude goes to the Directorate of Vocational Studies of the Ministry of Higher Education, Science and Technology, PT. Rapidplast Tbk, as a research collaboration partner and to the Director of the State Polytechnic of Malang and the Research Team for all the permits given and the good cooperation in carrying out this research.

7. AUTHOR CONTRIBUTIONS

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