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Determining Optimal Operating Setting Point of Injection Moulding Machine Using Design of Experiment

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ABSTRACT

This research wants to study about determining optimum machine setting on making product of injection molding machine. The quality of product on injection molding machine is influenced by interaction between several variables. The interaction between these variables can not be determined using OFAT system (One Factor at a Time) or just change the level on one variable. Design of Experiment method show these interactions and help the improvement on process and quality of product.

In this article 2^{6-2} fractional factorial design is used to determine optimum setting for injection molding machine. The objective of this research is to reduce the flash volume on castor wheel product. The result show that the optimum setting are 190^0 C for inject temperature, 191 Bar for pressure, 17.0 for cycle time before charge, 23.0 s for cycle time after charge and 840 mm for volume inject, with reducing flash volume 91.34 %.

Keywords: Optimum setting point, fractional factorial, flash volume

1. INTRODUCTION

1.1. Research Background

In the industrial processes that use rubber and plastic materials in the production process, the strength of interaction between variables greatly affects the performance of final products. Interactions between variables / factors can not be determined if only changing one factor alone. Design of experiments (DOE) technique will show the interaction that will assist on enhancing the efficiency of the process and product quality.

Quality managers who use the DOE method will significantly improve the opportunity to create policies that ensure product quality and product efficiency. This will reduce costs and increase the advantage gained by the company. DOE method not often used in the company because it requires the knowledge of planning and application of statistics drafts. Quality professionals will be able to reduce these barriers by opening the opportunity to work with the academy at the university.

Mega Andalan Kalasan Co. Ltd. as a company that produces a lot of hospital equipments uses injection molding machine to make plastic components of the products. Products made from plastic materials are produced specifically in the Unit Plastic and Castor. The largest amount produced on Plastic Unit is castor wheel – a wheel as a part of the patient's bed, wheelchair, stretcher, and so on. Determination of *injection molding* machine settings for the service is done by trial and error according to the range of suppliers recommended setting materials.

That way, the engine settings are not determined exactly so that the resulting product quality is less. Defect that is often found to Castor Wheel Out product is defective type flash. The number of products having flash on it shows that the machine setting was not effective yet. To repair that defect can be done using the design of experiment (DOE) method which then can be determined the optimum machine settings to minimize / eliminate the flash defects.

From the field studies conducted, there are 6 injection molding machines used to make plastic products. The most produced are the Castor Wheel. The product observed in this study is 5-inch Castor Wheel Out for flash type product defect.

1.2. Problem Definition

From the background, it can be formulated that to determine the factors affecting the quality of injection molding products, research needs to be done by using DOE (Design Of Experiment) so that the factors and the interaction between correlated factor is known, so the optimum operating condition could be determined.

1.3. Research Scope

In order to be more focused on the research, several constraints and assumptions are taken, as follows:

1. The observed products are injection molding machines products 5" Castor Wheel Out.
2. Defects type observed in this study is flash defect.
3. Research conducted for a single injection molding machine.

1.4. Research Objectives

The purposes of this study are as follows:

1. Determining the factors that cause the flash defect.
2. Testing the operating conditions using the DOE method.
3. Determine the optimum operating conditions to minimize/eliminate the flash defect based on the previous testing.

2. THEORETICAL BACKGROUND

Studies on the injection molding process carried out to improve product quality and performance improvement of production processes. Research conducted by Anderson & Whitcomb (1997) states that in the product manufacturing process using plastic and rubber materials, interactions between factors affecting the final performance of a product. The use of design of experiments (DOE) method is recommended because it can prove the interaction between factors that will help on improving the process efficiency and product quality.

The use of DOE method by Antony & Capon (1998) is still limited and has not been applied correctly. There are gaps in the statistical knowledge required by an engineer as a problem solving tool. Engineer is usually able to solve the examples in the textbook and in the class, but find difficulties on applying the statistical theory on real work. It's commonly because the statistical theory discussed mainly about opportunity, distribution analysis, and tends to the mathematical aspects rather than practical technique for problem solving. Antony & Capon said the need for teaching the DOE techniques to the Industrial Engineers. There are several types of DOE methods that can be used, such as the Taguchi method, Response Surface method, and factorial design methods.

Research by Rahardja (2001), compare the Taguchi methods and Fractional factorial on fiberglass manufacturing process. The results showed no significant difference between both methods.

Factorial design method was used by Anderson & Whitcomb (1997) to solve the problems in the injection molding process to reduce shrinkage defects. The factorial design method proved to improve the product quality performance in terms of determining the proper setting to reduce shrinkage. The precise conditions on predicting the shrinkage affect on the accuracy in mold production.

Field studies conducted by studying the existing field conditions so that it can be concluded that the process which the production process ability will be analyzed, due to its complexity and reality on the real world.

3. RESEARCH METHOD

3. 1. Research Stages

Stages of research or the steps undertaken on conducting this research can be illustrated in flowchart as shown in the following Figure 1.

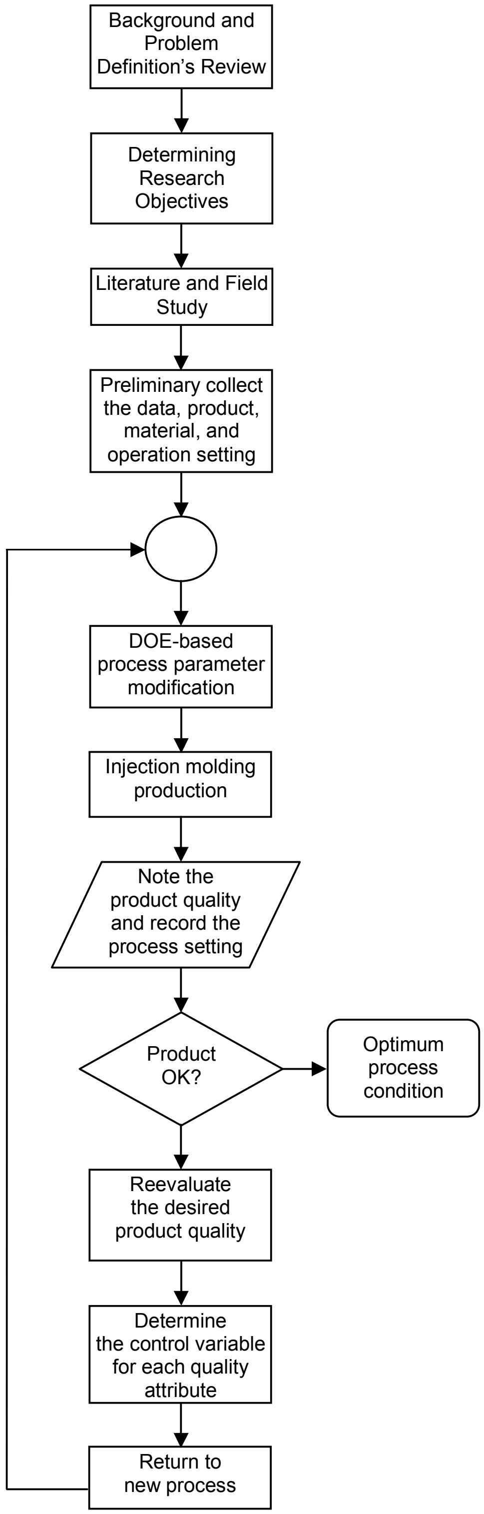

Figure 1. Research Steps Flowchart

3.2. Data collection

Research conducted at the research site in Castor and Plastics Unit at Mega Andalan Kalasan Co. Ltd, Yogyakarta, Indonesia. The data collected in the form of general data company, product data, and response data (volume flash) to several variations of the operation setting conditions of injection molding machines. Experiment setting condition variations are based on design of experiment (DOE) method. The design selected for use in this research is the fractional factorial design $2^{6-2.}$ The observed variables/parameters are determined based on the brainstorming with injection molding machine operator. There are six parameters taken from the process and each parameter used two standards: high and low. The six parameters are the mold temperature, holding pressure, charger, cycle time before a charge, cycle time after a charge, and volume inject.

Product Name = 5-inch Castor Wheel Out,
Material = Nylon

Table 1. Experimental Data

	Parameters		Low	High
A	Mold Temperature	^oC	190	200
B	Holding Pressure	Bars	90	100
C	Charger	%	65	85
D	Cycle Time before Charge	0.1 s	170	200
E	Cycle Time after Charge	0.1 s	230	250
F	Volume	mm	840	850

Experimental data Result resumed on Table 2, page 4.

4. RESULT AND DISCUSSION

4.1. Data Analysis

The next process is the existing data analyzed by using Minitab software version 14. From volume flash data on various existing operating conditions, then searched for the effect of each parameter. Then Pareto diagram and normal distribution test are also be done, so that the level of significance of the influence of each parameter change can be found. The next step is using the tool response optimizer to predict the optimum operating condition mathematically by software helps.

4.1.1. Calculation of main effects

The main effect can be expressed by the difference between the average response at low levels and the average response at high levels. For example, the effect of the control parameter A can be calculated as follows:

- The average volume on the flash at a high level = 1327.0
- The average volume on the flash at a low level = 1044.2

Then,

- Effect of control parameters A = 1327.0 - 1044.2 = 282.8

Table 2. Data Treatment and Volume Flash Results

Std Order	Run Order	CenterPt	Blocks	Temperature	Pressure	Charger	Cycle time before	Cycle time after	volume	code	Volume Flash (mm^3)
2	1	1	1	200	90	65	170	250	850	aef	1115,41
7	2	1	1	190	100	85	170	230	850	bcf	1796,34
6	3	1	1	200	90	85	170	230	840	ac	1517,6
14	4	1	1	200	90	85	200	230	850	acdf	668,93
16	5	1	1	200	100	85	200	250	850	abcdef	1554,74
10	6	1	1	200	90	65	200	250	840	ade	1166,81
13	7	1	1	190	90	85	200	250	840	cde	642,44
5	8	1	1	190	90	85	170	250	850	cef	1590,83
3	9	1	1	190	100	65	170	250	840	be	645,15
9	10	1	1	190	90	65	200	230	850	df	1801,39
11	11	1	1	190	100	65	200	250	850	bdef	544,62
8	12	1	1	200	100	85	170	250	840	abce	1616,54
15	13	1	1	190	100	85	200	230	840	bcd	996,59
1	14	1	1	190	90	65	170	230	840	-1	336,12
4	15	1	1	200	100	65	170	230	850	abf	1686,25
12	16	1	1	200	100	65	200	230	840	abd	1289,91

Positive and negative signs of the effect of the value declared the gradient/slope of a high-level and low-level value. If marked negative means the gradient of the line is negative. In other words, the average volume flash at low level is greater than at high levels. If a parameter has negative effect, when that parameter is raised it will decrease the flash volume. The complete calculations of main effect are presented in Table 3.

Table 3. Data Calculation for Plotting the Main Effect of Experiment

Parameter Control	The average high level	The average low-level	Effect
A	1327.0	1044.2	282.8
B	1266.3	1104.2	161.3
C	1298.0	1073.2	224.8
D	1083.2	1288.0	-204.9
E	1109.6	1261.6	-152.1
F	1344.8	1026.4	318.4

From the summary of the calculation of the main effects presented in Table 3 above, it can be seen that the main effect values for the control parameters A, B, C, and F are positive. This means that the greater the value of these parameters, the volume of flash that happens is also bigger. The parameters D and E have negative effect value, so if parameters D and E are increased, the volume of flash will happen to be decreased.

4.1.2. The main effects plot

To help on understanding of the data in Table 3 above, it can be presented in the form of the main effects plot as shown in Figure 2 below:

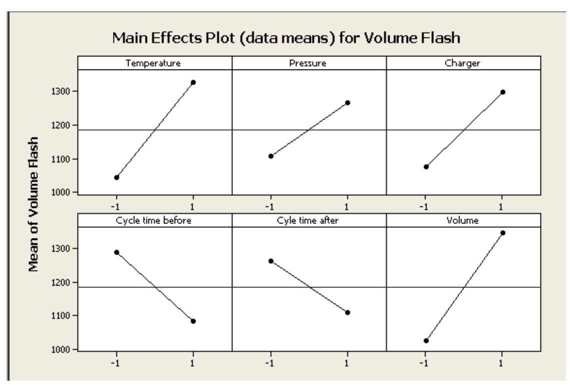

Figure 2. The Main Effects Plot (Average Data) of Volume Flash

Figure 2 shows the image of the main effects of the volume flash in the form of lines. For the positive value of main effect that is factor A, B, C, F, the lines will be skewed to the right, the greater the effect of a parameter, the line tend to be vertical, and the smaller the effect value, the line tend to be horizontal. Effect values D and E are having negative values; the lines will be skewed to the left. D parameter effect is greater than E parameter, so the line of D parameter becomes more vertical.

4.1.3. The calculation of interaction effects

Interaction between the parameters in this study reviewed only for the interaction of two parameters and some interaction for three variables. Interactions involving more than three parameters are considered small and negligible.
In this case under review is the interaction between:

- A x B
- A x C
- A x D
- A x E
- A x F
- B x D
- B x F
- A x B x D
- A x B x F

Suppose we want to calculate the interaction between A and F. To calculate the interaction, it must be first calculated the average volume of flash on any combination of the two parameters of the process. There are four combinations of the two parameters: A_{-1F-1}, A_{-1F+1}, A_{+1F-1}, and A_{+1F+1}. The average volume flash of all combinations is summarized in Table 4.

Table 4. The Average Response to the AF Interaction

A	F	Mean volume flash
-1	-1	655.1
-1	+1	1433.3
+1	-1	1397.7
+	+1	1256.3

The interaction effect of AB = ½ (A control parameter effect on the high B – A control parameter effect on the low B)
=½ [(1256.3 - 1433.3) - (1397.7 - 655.1)]
= 258.3

Or, for an alternative calculation of interaction effects between A and B can be obtained by multiplying the A and B at each level.

The interaction effect of AB = average volume flash of AB at high level – the average volume flash of AB in low level

In the same way, it can be obtained interaction value between variables for other parameters. The results presented in Table 5.

Table 5. Table of Interaction Effects

Interaction effects	Estimated effect
A x B	258.3
A x C	-199.9
A x D	-109.0
A x E	224.8
A x F	-459.8
A x F	-134.8
B x D	-134.8
B x F	-60.0
A x B x D	219.6
A x B x F	368.6

4.1.4. Plot of interaction effects

Plot of interaction effect is the graphical tool that is very useful on understanding the interaction effects. This plot gives a better outlook and more quickly to be understood to determine the interaction between the process parameters. Non parallel lines in the plot illustrates that there is interaction between two parameters. Whereas, the parallel lines illustrate that there is no interaction between variables. Interactions between variables are presented in Figure 3 as follows:

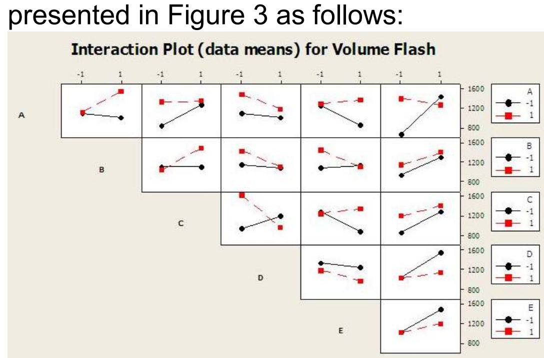

Figure 3. Interaction between Variables of Volume Flash

Based on the plot of the interaction between variables in Figure 3 can be seen that there are several lines tend to be parallel and some are not parallel. B and F interaction look closer to parallel so that the value of the interaction effects of both factors is small. In other words, the changing of the B value is not affected by the changing of the F value. For lines that are not parallel, the more less the parallelism, the greater the effect of interaction between both factors. This can also be shown by interaction effect values presented in Table 5.

4.1.4. Determination of significant factors using statistical principles

In the above calculation, the effect value for each parameter has been obtained. But it can not directly state the significance of each effect changes from the obtained calculation. It requires a necessary testing step using statistical methods. The method that can be used is a Pareto Diagram or also normality plots. Calculation for Pareto Diagram can be seen in the textbook (Montgomery, 2003), but to make it easier, it can be done by using Minitab software. The testing can use a significant level of 1% or 5%. Level of confidence is (1-alpha) for the 1% significance level, 99% confidence level. Tests conducted in this study are using a significance level of 5%.

By using Normality Plot it can be determined which factors significantly influence the process. Factors that are not straight-line approach are the significant factor. The non-significant factor will close to the straight line. Normality Plots can be seen in Figure 4.

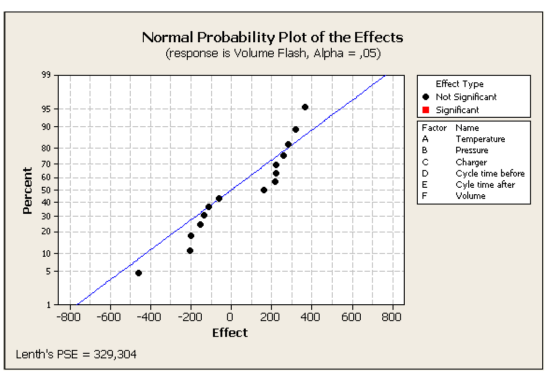

Figure 4. Normal Probability Plot Diagram

From the normal probability plot diagram above can be seen a few point approaching the straight line and there is also a few point that moves away from the straight line. Those points are the normal probability plot for the main effects and interaction effects. From the diagram, although some points are away from the straight line, but they are not on the state that is significantly need to be reviewed statistically.

To determine the significance can also be graphically illustrated using Pareto Diagram. The affecting effects are made into bar diagram. The bar that exceeds the limit-line is the significant factor. Diagram is hierarchically made up from the largest to the smallest of the significance of each factor. A more significant factor will be longer and a less significance factor will be shorter. Pareto Diagram of the effect can be seen in the Figure 5.

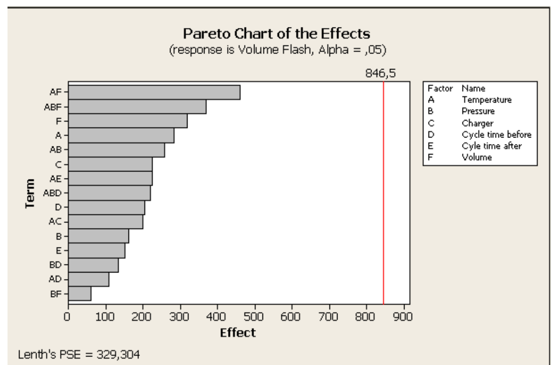

Figure 5. Pareto Diagram and the Effect of Interaction Effects

From the Figure 5 above it can be seen that all the effects are in the left side of the red line which means that the effects are not too significant. But, using Pareto Diagram can be seen the influence sequence of the effects from the greatest: interaction of AF, ABF, F, A, AB, and so on. For the factors that are not statistically significant according to Antony & Capon (1998), the determination of the optimum conditions is done by viewing the main effects and referring to the experimental data on table 2. The next step after the determination of significance is the determination of optimum conditions.

4.1.5. Determination of optimum conditions

The significance of factors that have been tested previously shows that those factors are not greatly influencing the changing of volume flash. The methods that can be done are referring to Table 4.2 or from experimental data tables. From the data can be seen that the optimum setting condition (the smallest flash volume value is 336.12) was achieved on the condition where all the parameters are on the low set. Detail is presented in Table 6 below.

Table 6. Optimum Conditions Parameter Settings Point

Parameter Control	Optimum Level
Temperature	Low level 190
Pressure	Low level 90 Bar
Charger	Low level 65%
Cycle time before charge	Low level 17.0 s
Cycle time after charge	Low level 23.0 s
Volume shot	Low level 840

To determine the optimum conditions can also be done by using the response optimizer with the help of Minitab software. This tool will find the most optimum setting by considering the coefficient of each effect and their interaction using the regression equation.

$$
\begin{aligned}
Y = {} & 1185.6 + 141.4A + 80.47B + 112.4C - 76D \\
& + 159.2F + 129.2AB - 100AC + -54.5AE \\
& - 229.9AF - 67.4BD - 30BF + 109.8ABD \\
& + 184.3ABF
\end{aligned}
$$

By using optimizer response method, Minitab search for an optimum setting to get the minimum volume of flash. The complete results are presented in Table 7.

Table 7. Optimum Condition Parameter Setting with the Response Optimizer

Parameter Control	Optimum level
Temperature	Low level 190
Pressure	191 Bar
Charger	Low level 65%
Cycle time before charge	Low level 17.0 s
Cycle time after charge	Low level 23.0 s
Volume shot	Low level 840

4.1.6. Confirmation Test

The confirmation tests was done to check the volume flash effect when using experimental setting based on the calculation result using response optimizer of Minitab software. From the confirmation test of 5 samples, the volume flash values obtained are as follows:

Table 8. Volume Flash in the Confirmation Test of 5 Samples

Sample Number	Volume Flash (mm^3)
1	152.1
2	90.3
3	130.2
4	184.6
5	116.2

The average of volume flash on the confirmation test's sample is 134.68 mm^3. The average volume of the sample flash before conducted research is 1554.74 $mm^{3.}$ From this, the reduction of the volume of flash is 91.34%. From the confirmation test's results, the final setting used are as shown in Table 7.

4.2. Discussion

The research conducted to observe the manufacture of products using injection molding, the product quality greatly influenced by the interaction of several variables. Based on the testing and experiments on this study, the observed factors/parameters of process are not too significant. This is possibly because the test was conducted without replication due to the limited time and tight production schedules. This causes a large relative error ratio.

Other possible cause is the range of the settings that are too narrow made the range of volume flash change is also not too wide when the parameters are changed. For the next testing, can be tried using a larger range of low and high levels. Further research could be done for observing the friction resistance of 5-inch Wheel Out by using different material.

Factorial design proved to reduce the volume of flash by doing experiment with the parameters set using a 2 stage. For more complex research can be done with each parameter is set at three different levels. By using a factorial design the number of samples did not have to be very large even though the parameters under review are many. Research using experimental design, the machine settings are not done with trial and error and the output are certainly more predictable. Determination of the operating setting is specific for one of material, when different materials are used then the output will also change.

5. CONCLUSION

Conclusions obtained from this study are:

1. The factors that are used as parameters to test the flash defects in this testing is A (Temperature), B (Pressure), C (Charger), D (Cycle time before charge), E (Cycle time after charge), and F (Volume Shot). The most decisive effect to the volume of flash in this research is the AF interaction, ABF interaction; factor A, AB, AE, ABD.
2. Tests using *Design of Experiment* method has proved able to reduce the amount of volume flash for 93.34%, but could not completely remove the flash. The replacement of mold with a new one or additional cavity can reduce the possibility of flash to zero.
3. Optimum conditions setting point obtained from the study are Temperature 190 ^{o}C, Pressure 191 Bar, Charger 65%, Cycle time before charge 17.0 seconds, Cycle time after charge 23.0 seconds, Volume Shot 840 mm.

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