CHAPTER 8

DESIGN OF EXPERIMENT

8.1 Experiment and Data Collection

For chapter 7, there is studying the effect that produces a part cleanliness of reused part. We would like some way to improve the cleanliness of a reused part that is produced from the effect. From past experience, if varying the temperature, the pressure, the CO_2 amount, and the distance of nozzle seems to change the part cleanliness result. Each one of affects the reaction is taken to consider for determining an appropriate condition. To make real improvements, we decide to run an experiment to determine the actual effected of the three factors.

What we will learn how to:

- design a factorial experiment to tell which factors are important to the reaction
- fit a full model to the data
- use several simple graphical methods to help determine which effects are active (important) or inactive
- fit a reduced model to the data, and then assess the adequacy of the model.

8.2 Create the Experimental Design

Since we have four factors that are of interest, we choose a full factorial design with 16 runs. A two level design with four factors 2^4 (or sixteen) possible factor combinations. By choosing a design with all possible combinations, called full factorial design, we will get results that show effects free from confounding, that is, all effect are distinguishable from other effects. We may also be able to obtain meaningful results by doing fewer runs or combinations. Designs that use less than all possible combinations are called factional factorial designs.

8.3 Collected Data

We decide that the full factorial design with 4 factors and 16 runs is more appropriate than the factorial design. At CO_2 cleaner, runs with the factors of interest --temperature, pressure, CO_2 amount and distance of nozzle—are not expensive or time-consuming. Also, the experiment can be performed at a non-peak period without difficult to perform, we may have made a different decision.

Name factors and set factor levels

In a two-level factorial design, there will set factors at two levels- a low level and a high level each run of the experiment consists of a combination of the factors at their low or high settings. After some deliberation, the factors were chosen for setting as follows,

Factor	Low Setting	Hign Setting
Completed Dry Air Heater Temp	80° C	120° C
Pressure	650 PSI	950 PSI
CO_2 amount	0.1	1
Distance of CO2 nozzle	0.5 Inch	2 Inch

Table 10 illustrated the setting of factor

8.4 Data Analysis of Experiment

Screen the design

When I screen a design, the object is to select factors that have large effects. We have created a factorial design and collected the response data, we can fit a model to the results and generate some graphs to evaluate the effects. We will use the output from fitting a mathematical model, and we will also use two graphical methods to help see which facters are improtant for improveing the yield in the reaction.

Fit a model

Since we have created a facroy design, we will notice that MiniTAB has enabled the DOE manu commands. If we plot the rsponses tather than the fitted values (least-squaresmeans), we can generate main effects plots, interaction plots, and cube plaots either before or after we actually fit a model. In shis samples of first group, we will fit the model first.

Identify important effect

We decide which effects are important to CO_2 cleaner for reworked parts.irst, we look at all factors.

Fractional Factorial Fit

Estimated Effects and Coefficients for LPC (coded units)

Term	Effect	Coef	StDev Coef	T	P
Constant		3119.8	105.7	29.52	0.000
Temp	-132.9	-66.4	105.7	-0.63	0.545
Pressure	-1353.5	-676.7	105.7	-6.40	0.000
CO2 amou	-904.2	-452.1	105.7	-4.28	0.002
Distance	-936.8	-468.4	105.7	-4.43	0.002
Pressure*CO2 amou	1143.3	571.6	105.7	5.41	0.000
Pressure*Distance	616.2	308.1	105.7	2.92	0.017

Analysis of Variance for LPC (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	14178702	14178702	3544676	19.83	0.000
2-Way Interactions	2	6747316	6747316	3373658	18.87	0.001
Residual Error	9	1608656	1608656	178740		
Total	15	22534674				

Fitting the full model, which includes the four main effects, three one-way interactions, and two two-way interactions. Referring the values in P column of the Estimated Effect and Coefficients table to determine which of the effects are significant. Using $\alpha = 0.05$, the main effects for Pressure, CO_2 amount and Distance of CO_2 nozzle; Pressure and CO_2 amount and Pressure and Distance of CO_2 nozzle interaction are significant; that is p-value are less than 0.05.

Effects plots

We will use the normal probaility plot and the pareto chart of the effects to see which effects inflience the response, Spray LPC data.

Active effects are effects that are significant or important. In the normal plot of the effects, points that do not fit the line well usually signal actives. Achieve effects are larger and further from the fitted line inactive effects. Inactive effects tend to be smaller and centered around zero, the mean of all the effects.

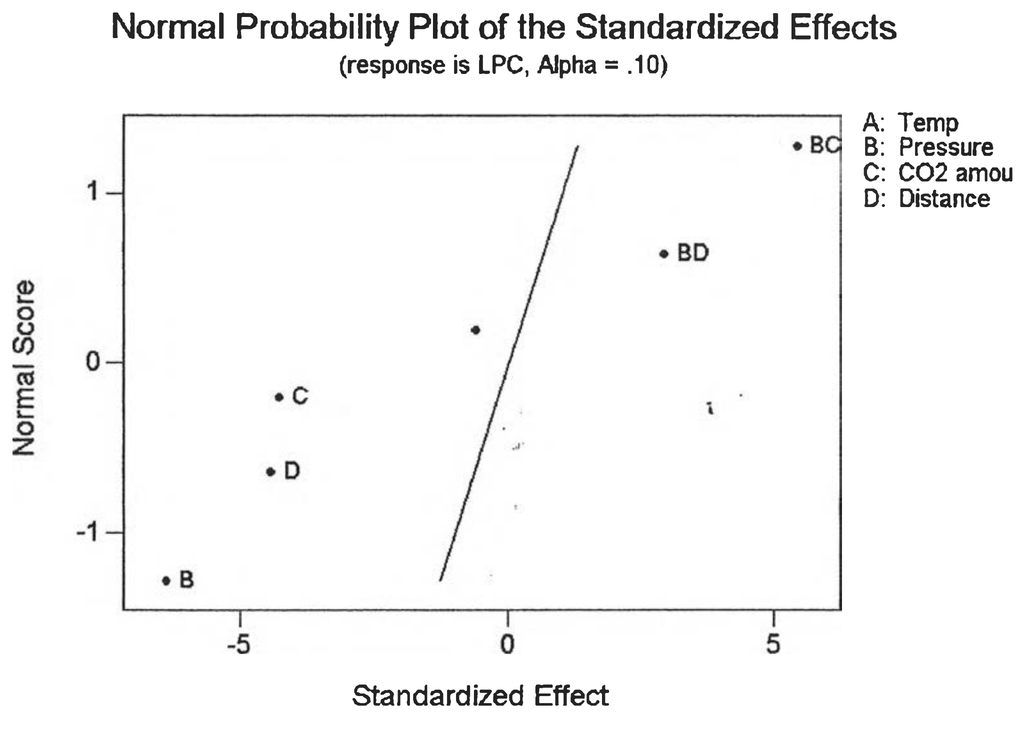

Figure 32 illustrated Normal Probability Plot of the Standardized Effect
Note: 0 is the approximated mean, while 1 and –1 are one standard deviation on either side.

The normal probability plot labels effects that are lower than the α level that I chose in the Analyze Factorial Design-Graphs subdialog box. Here, the effects of Pressure, CO_2 amount, Distance of CO_2 nozzle and the Pressure * CO_2 amount and Pressure * Distance of CO_2 nozzle interaction are significant using $\alpha = 0.10$.

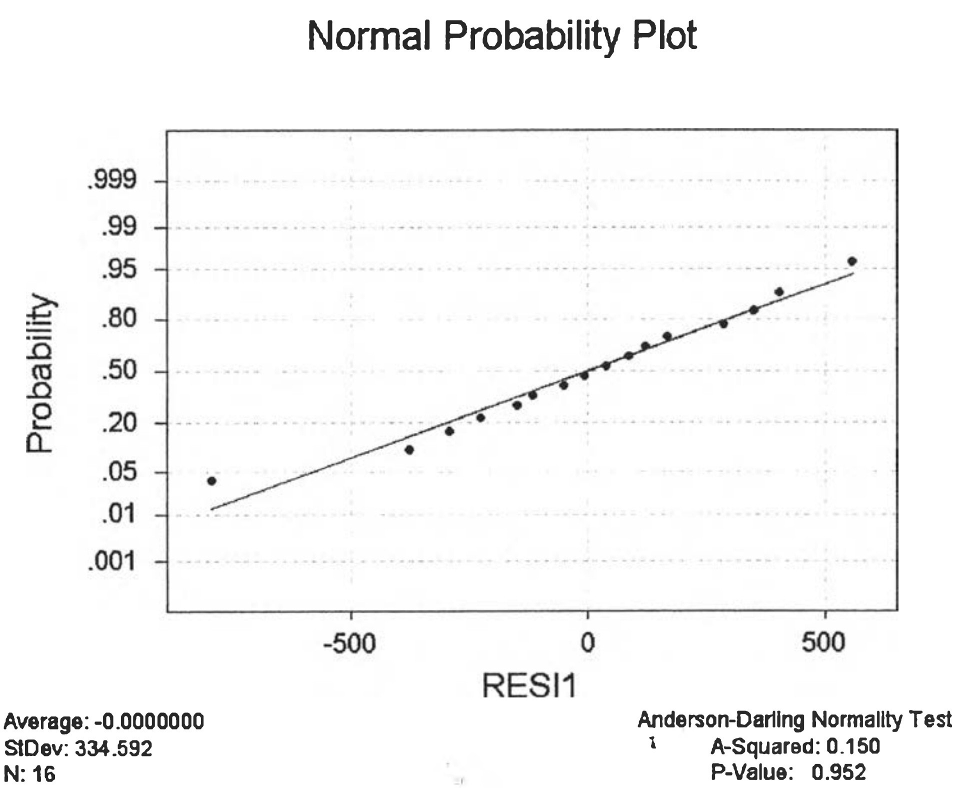

Figure 33 illustrated Normal Probability Plot

Coefficient of Determination

$$R^2 = 1 - \frac{SS_{Error}}{SS_{Total}}$$

$$R^2 = 1 - \frac{1679279}{22534674} = 92.7\%$$

This shows an appropriate experiment of data collection, it should be more than 80 per cent.

A Pareto chart of the effects is another useful tool that we can use to help determine which effects are active.

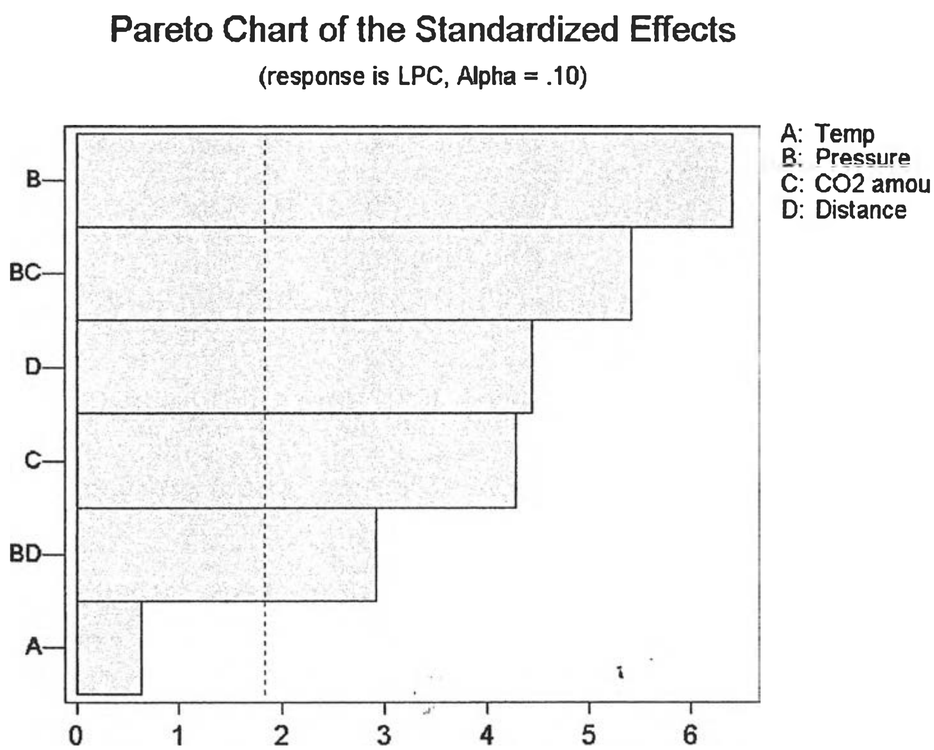

Figure 34 illustrated Pareto Chart of the Standardized Effect
Note: Any effects that extend beyond this line are significant. You can change the alpha value from the default level of 0.10.

The graph above displays the absolute value of the effects on the Pareto chart.

The Pareto chart uses the same α as the normal plot to determine the significance of effects. So, again we see that Pressure, CO_2 amount, Distance of CO_2 nozzle and the Pressure and CO_2 amount and Pressure and Distance of CO_2 nozzle interaction are significant ($\alpha = 0.10$).

Later, we will fit a model without the terms Temperature, Temperature and Pressure, Temperature and CO_2 amount and Temperature and Distance of CO_2 nozzle, which seem to be inactive. We will check to see how good the model is after we fit the reduced model.

Fit a Reduced Model

We want to fit a new model using only the terms you identified as important by looking at the results of fitting the full model—in other words, screen out the unimportant effects. After we fit the model, you will general several plots to visualize the effects, evaluate the fit of the reduced model, and do a residual analysis.

Therefore, we fit a model that includes Pressure, CO_2 amount, Distance of CO_2 nozzle and the Pressure * CO_2 amount and Pressure * Distance of CO_2 nozzle interaction.

Evaluate the Reduced Model

This can provide an information as to how good the model is. We examine the P column, which contained p-values for each of the terms in the model. A good standard by which to evaluate the model is to look at p-values. If all terms have p-values less than the α level appropriate for your experiment, you can be confident that you have a good model. Here, we choose to use $\alpha = 0.05$.

Fractional Factorial Fit

Estimated Effects and Coefficients for Spray (coded units)

Term	Effect	Coef	StDev Coef	T	P
Constant		3119.8	102.4	30.45	0.000
Pressure	-1353.5	-676.7	102.4	-6.61	0.000
CO2 amou	-904.2	-452.1	102.4	-4.41	0.001
Distance	-936.8	-468.4	102.4	-4.57	0.001
Pressure*CO2 amou	1143.3	571.6	102.4	5.58	0.000
Pressure*Distance	616.2	308.1	102.4	3.01	0.013

Analysis of Variance for Spray (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	14108079	14108079	4702693	28.00	0.000
2-Way Interactions	2	6747316	6747316	3373658	20.09	0.000
Residual Error	10	1679279	1679279	167928		
Lack of Fit	2	239462	239462	119731	0.67	0.540
Pure Error	8	1439817	1439817	179977		
Total	15	22534674				

The p-value for each term in the model is less than 0.05, indicating a model that is a good candidate for further exploration and validation. This model is considerably simpler and fits the data almost as well as the model with all terms. The residual error only increased by a small amount.

We can further check the model by using the residual plots. The fitted values are the results predicated by your model. The residuals are the actual Spray SEM data minus the predicted Spray SEM data. The following graphs should display:

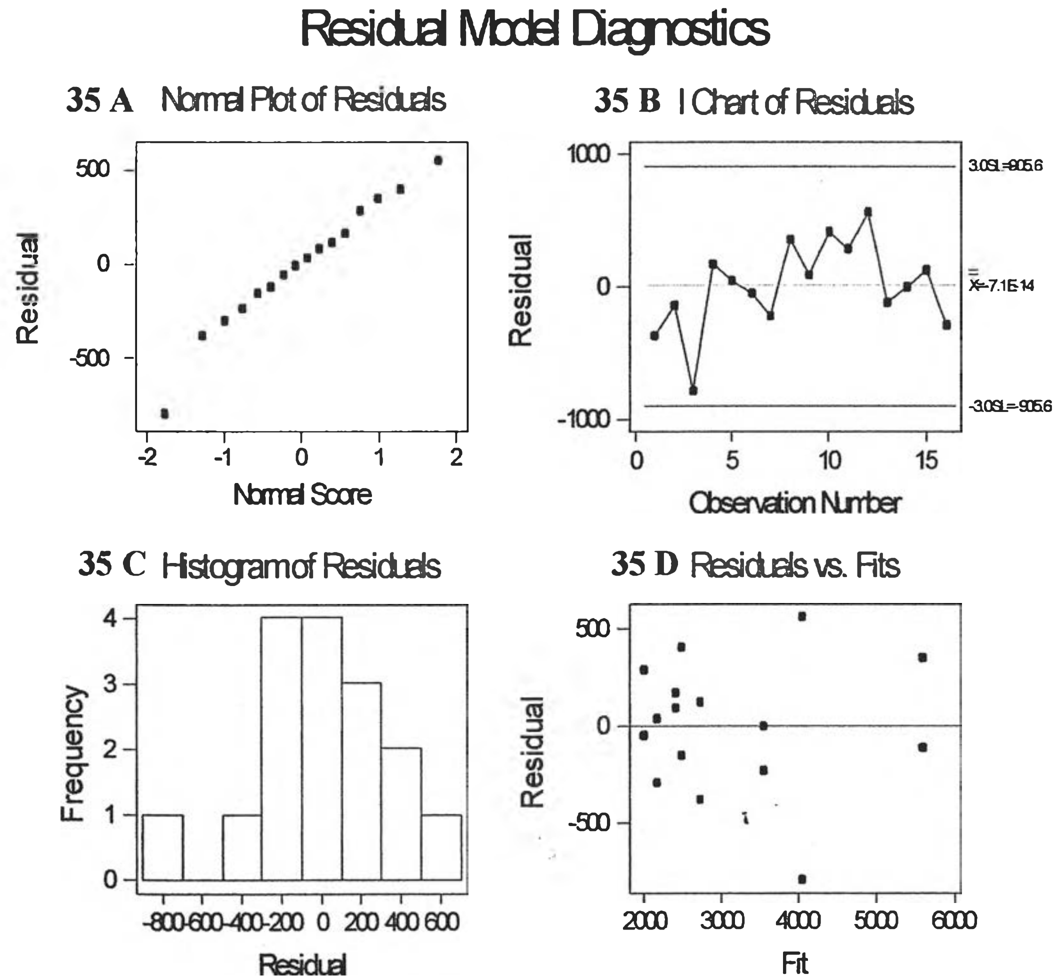

Figure 35 illustrated Residual Model Diagnostics
Note: *35 A This is a reasonably good normal plot.*

35 B This plot shows a good spread of points on either side of zero, with no patterns of increase or decrease.

35 C Although this histogram does not appear to represent a normal distribution, there is not enough information to make a judgment. It is very difficult to interpret a histogram with only 16 plotted points.

35 D This plot shows a reasonable pattern of dispersion. But again, it is difficult to interpret a plot with only 16 points.

The residuals plot were satisfactory, and showed no cause for concern.

8.5 Draw Conclusion

The factorial plots

We generate 3 graphs that will allow us to visualize the effect—a main effects plot and an interactions plot. When the plots are based on the means of the response data, you can generate them either before or after we actually fit a model to the data. We need to fit the model first.

Evaluate the plots

First, take a look at a plot that shows the basic effect of changing pressure, or, CO_2 amount, or Distance of CO_2 nozzle. These one-factor effects are called main effects. The numerical values for all effects are shown as figure 36.

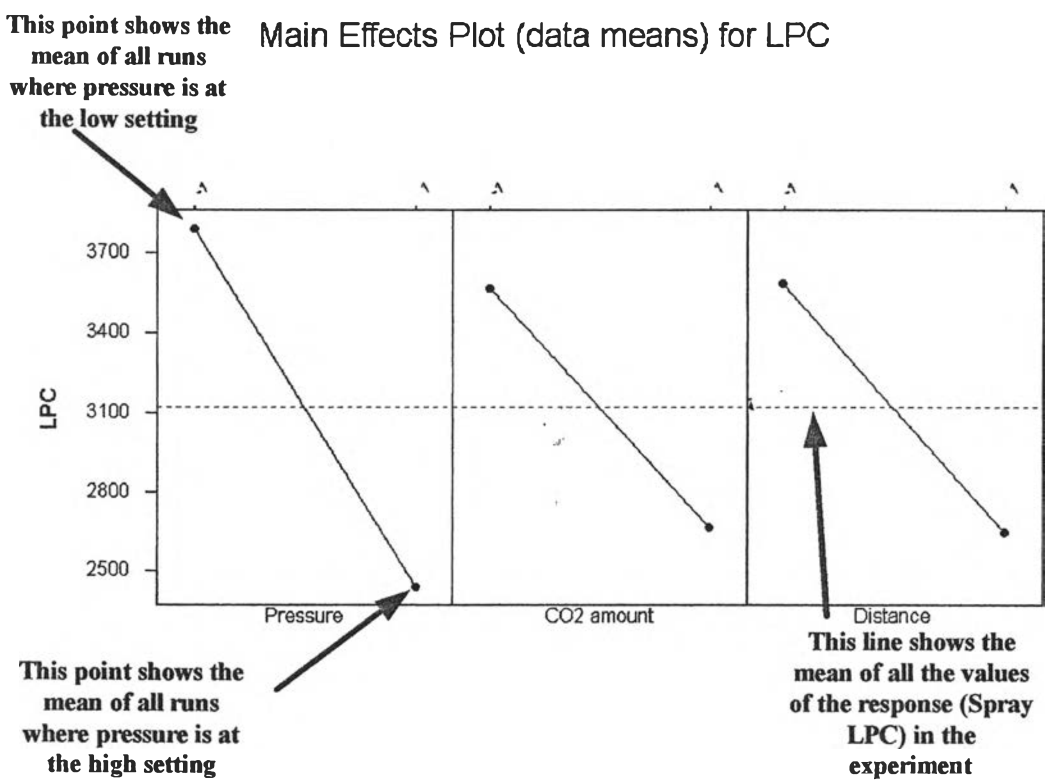

Figure 36 illustrated Residual Model Diagnostics

Three main effect plots display in graph below – one for pressure, one CO_2 amount and one for Distance of CO_2 nozzle. The main effect of:

- Pressure is difference between the low point and the high point on the graph
- CO_2 amount is difference between the low point and the high point on the graph
- Distance of CO_2 nozzle is difference between the low point and the high point on the graph.

We can see that the pressure has a bigger main effect than the amount of CO_2 and Distance of CO_2 nozzle on the plot above: the line connecting the mean responses for pressure, CO_2 amount and Distance of CO_2 nozzle has steeper slope than line connecting the mean response at the low and high settings of pressure, CO_2 amount and Distance of CO_2 nozzle. All types appear to affect the LPC, but setting high pressure is most factor consideration. However, it is very important to look at the interaction. An interaction can slightly magnify or cancel out a main effect.

To calculate main effects, MININTAB subtracts the mean response at the low or first level of the factor from the mean response at the high or second level of the factor. The table below summarizes the findings:

Factor	**Size of effect**	**Interpretation**
Pressure	-1353.5	run at 950 PSI of pressure had lower LPC than runs at 650 PSI of pressure
CO_2 amount	-904.2	run at 1 of CO_2 amount had lower LPC than runs at 0.1 of CO_2 amount
Distance of CO_2 nozzle	-936.8	run at 2 Inch of Distance of CO_2 nozzle had lower LPC than runs at 0.5 Inch of Distance of CO_2 nozzle

Table 11 illustrated main effects at low and high setting

Next step we look at the significant interaction. Although, we have already verified a significant interaction as mentioned above, we can look at the interaction plot to see how big this effect is.

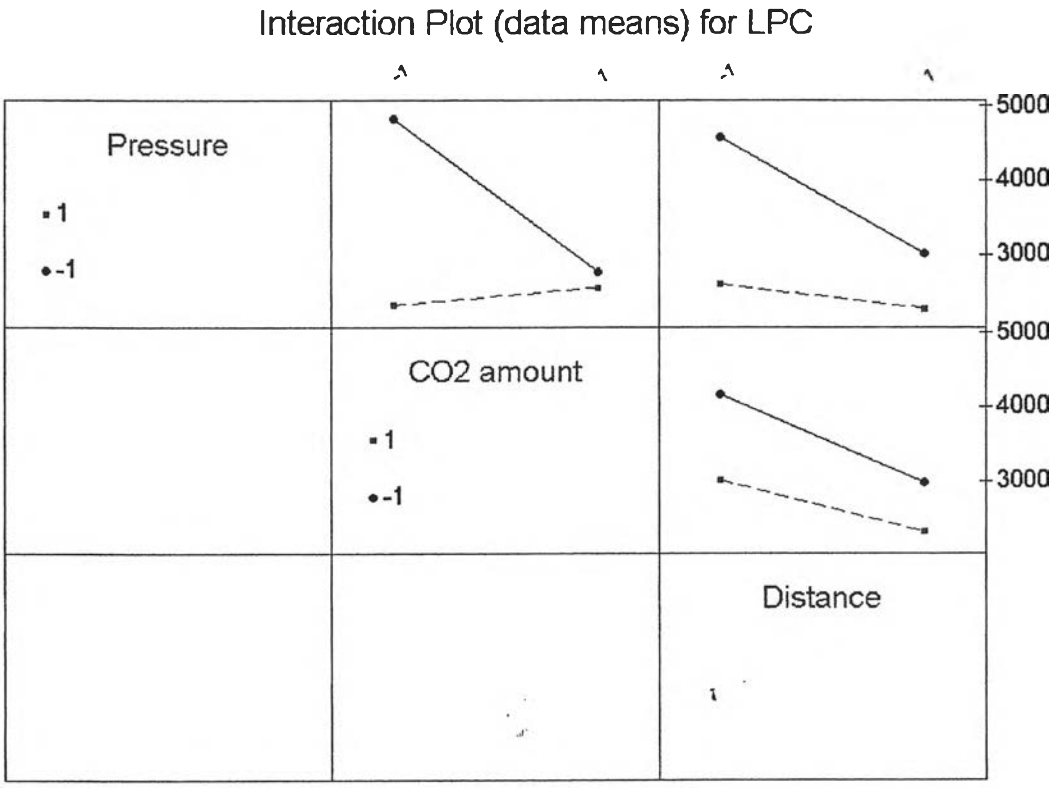

Figure 37 illustrated Interaction plot

An interaction plot shows the impact that changing the settings of one factor has on another factor. Because an interaction can magnify or diminish main effects, evaluating interactions is extremely important. The significant interaction among pressure, CO_2 amount and Distance of CO_2 nozzle shows up as two lines with sharply differing slopes.

The LPC for low setting CO_2 amount are smaller than high setting CO_2 amount at high pressure 950 PSI. And The LPC for high setting Distance of CO_2 nozzle are smaller than low setting Distance of CO_2 nozzle at high pressure 950 PSI. However, we can see that the difference in LPC between runs CO_2 amount using low setting and runs using high setting at 950 PSI is smaller than the difference in LPC between runs using low setting and runs using high setting at 650 PSI.

In order to get the lowest LPC for this experiment, based on results we should set 3 factors are as follows.

[1] pressure to 950 PSI

[2] set CO_2 amount to 0.1

And [3] set Distance of CO_2 nozzle to 2 Inch.

8.6 Appropriate Condition

From the result of experiment for finding appropriate condition. The parameter of temperature isn't significantly different. Therefore, we determine an appropriate conditions of CO_2 are as follows,

Factor	Setting
Completed Dry Air Heater Temp	Not Significant
Pressure	950 PSI
CO_2 amount	0.1
Distance of CO2 nozzle	2 Inch

Table 12 illustrated setting an appropriate condition for CO2 cleaning for reused part

8.7 Confirmation Experiment

8.7.1 Experiment and Data Collection

The purpose of this experiment is to confirm an appropriate condition based on previous experiment result. There are three factors to be set for this confirmation as follows,

[1] Set pressure to 950 PSI

[2] Set CO_2 amount to 0.1

[3] set Distance of CO_2 nozzle to 2 Inch.

The results of this experiment will be used to compare with the results of the experiment for finding an appropriate condition.

Table for data collection after setting pressure to 950 PSI, CO_2 amount to 0.1 and set Distance of CO_2 nozzle 2 Inch.

			Observations			
Sample Number	1	2	3	4	5	6
LPC (Count/Part)						

Table 13 the table for data collection of confirmation experiment.

The six samples observations will be completed in to table 13. The data from this confirmation experiment is used to be evidence data to determine an appropriate condition.

8.7.2 Collected Data

The data collection of this confirmation experiment are illustrated in table 14.

	Observations						AVG
Sample Number	1	2	3	4	5	6	
LPC (Count/Part)	1,461	2,093	1,493	1,259	1,864	1,973	1,691

Table 14 the Data of confirmation experiment

Note : AVG stands for average and STD stand for standard deviation.
LPC stands for Liquid Particle Counter and the units of measurement is count per part.
All samples were measured by Liquid Particle Counter Analyzer.

8.7.3 Data Analysis of Experiment

Based on data, they show that the setting pressure to 950 PSI, CO_2 amount to 0.1 and set Distance of CO_2 nozzle 2 Inch. can keep the LPC data of reused part in term of repeatability and reproducibility. The previous data of first run at the same parameter, the actual data are showed in table 15.

	Observations at First Run			AVG
Sample Number	1	2	3	
LPC (Count/Part)	1,787	1,779	2,043	1,869

Table 15 the Data of first observations at the same parameter setting

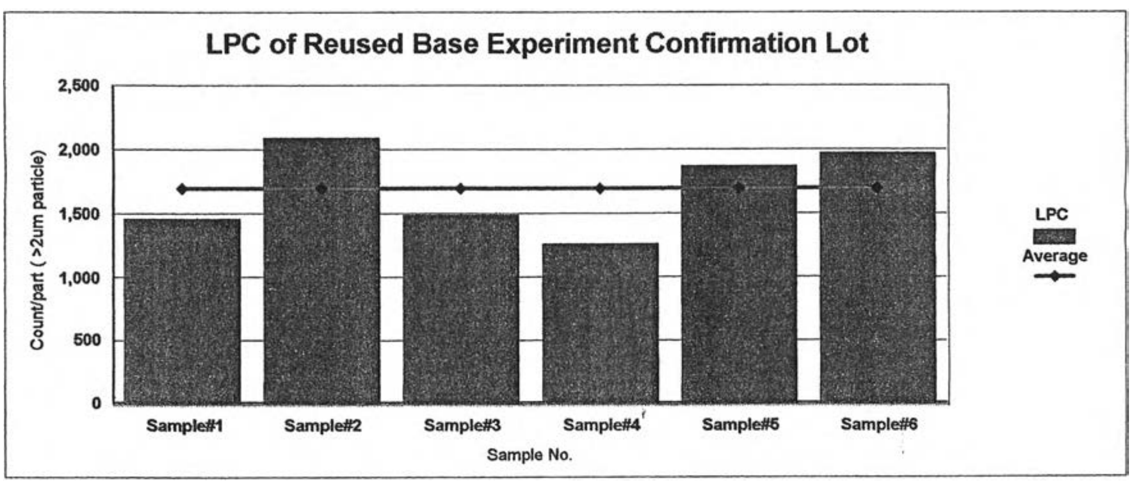

Figure 38 illustrated Confirmation Experiment Lot Result

8. 8 Result Conclusion

8.8.1 The problem cause of reused part is particle contamination which impacts to product quality. The efficient cleaning with CO_2 cleaner to reused part is the most important method for quality improvement. The purpose of this thesis is to establish parameter setting standardization into cleaning process. The main effect and reaction effect are to be considered to determine an appropriated condition for CO_2 cleaner.

8.8.2 There are four factors as below were selected to perform design of experiment, screening experiment, preliminary experiment and experiment confirmation in order to determine an appropriated condition.

• Completed Dry Air Heater Temp.(C°)	80 (min) - 120 (max)
• Pressure (PSI) setting	650 (min) - 950 (max)
• CO_2 amount setting	0.1 (min) - 1 (max)
• Distance of CO_2 nozzle (Inch)	0.5 (min) - 2 (max)

8.8.3 The design of experiment 2^k factorial :The Four factors (k=4) with two levels (2^4), minimum and maximum level is used for finding an appropriate condition. The purpose is to screen out the factors that do not affect to reused part cleanliness. Based on experiment result, the Completed Dry Air Heater Temp.(C°) was screened out because it doesn't affect for to reused part cleanliness.

8.8.4. The data collection are tested by using MINITAB to analyzed factorial design as step by step bellows,

Note : the result of each step is illustrated in chapter 8

[1] Use 2^k single replication sample to verify at $\overline{X}$-R chart

[2] Make effect plot to find out significantly factor effect to LPC data.

[3] Reduce model to screen our the factor that doesn't significant in order to move them to error term.

[4] Check Model adequacy checking to ensure our collect data are normal observations at I-chart and .

[5] Check R^2 (coefficient of determination), from calculation, $R^2 =$ 92.7%

[6] Check P-value at Fraction Factorial Fit . From P-value, it can be concluded that Temperature is not significant factor. So we fit a model that includes Pressure, CO_2

amount, Distance of CO_2 nozzle and the Pressure * CO_2 amount and Pressure * Distance of CO_2 nozzle interaction.

8.9 Analyze Factorial Design from data observation

From data observation, the significant of main effect and interaction effect cab be observed. They are analyze the Significant effect at significant level = 95 % (alpha = 0.05) as follows,

1. Pressure is main effect on minus side.

2. CO_2 amount is main effect on minus side.

3. Nozzle distance is main effect on minus side.

4. Interaction between " Pressure & Nozzle distance " are an interaction effect on plus value side .

5. Interaction between " Pressure & CO2 amount " (BC) are an interaction effect on plus value side.

8.10 Setting factor Optimization.

Three factors involve determining optimal conditions (factor settings) that will produce the "best" value for the response. We need to determine the operating conditions that result in a reused part more cleanliness. Since each mentioned factors are important in determining the cleanliness of reused part, we need to consider those factors (responses) simultaneously.

For this, we use Minitab's Response Optimizer to help identify the combination of input variable settings that jointly optimize a set of responses. The overall desirability is a measure of how well we have satisfied the combined goals for all the responses. This optimization plot allows us to interactively change the input variable settings to perform sensitivity analyses and possibly improve the reused part cleanliness. From figure 39, the best parameter are consist of

[1] Set pressure to 950 PSI
[2] Set CO_2 amount to 0.1
And [3] set Distance of CO_2 nozzle to 2 Inch

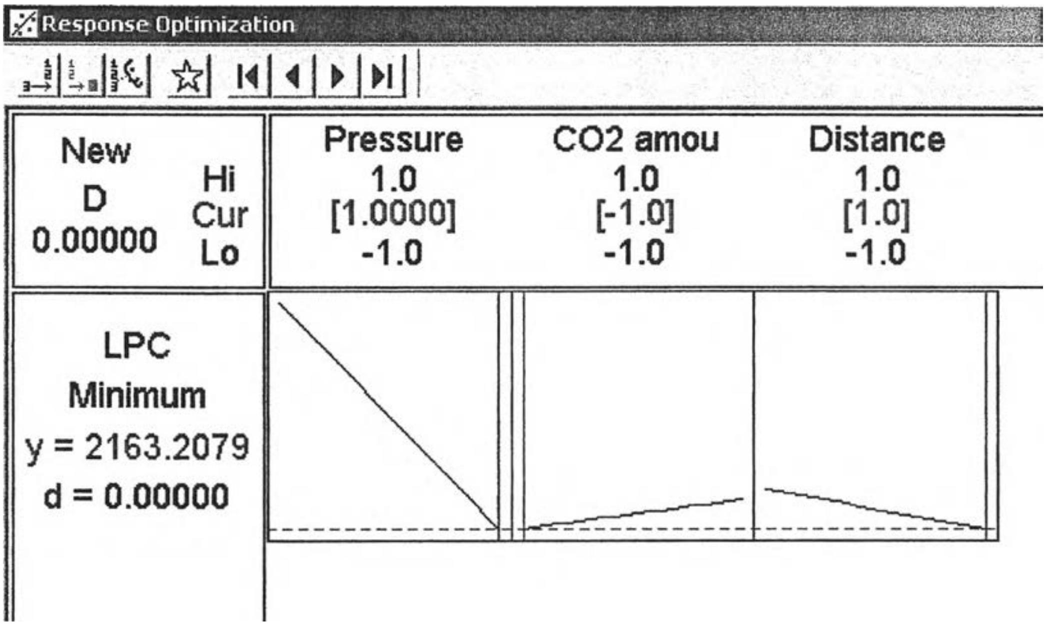

Figure 39 illustrated optimization for CO_2 setting.

After setting the parameter above, six samples were performed for experiment confirmation. The average results showed low LPC value as expectation. Based on experiment, those parameters are applied for reused part CO_2 cleaning in production line. The result after implementation, the yield of product is getting better and the main problem failed product is not related to particle contamination.

8.11 What we have learned from factorial design, experiment and analysis

They can be summarized as follows,

1. Decided on a design for the experiment, then determine Factorial Design.

2. Ran the experiment and data collection.

3. Fitted the full model to look at some numerical values and generated two effects plots to see which terms seemed to be active.

4. Screened out unimportant effects, then fit a reduced model.

5. Generated main effects and interactions plots with the Factorial Plots to visualize the effects.

6. Evaluated the reduced model with the p-values in Factorial Design analysis and the various residuals plot.

- From looking at the effects plots, we determined that pressure, CO_2 amount, Distance of CO_2 nozzle, the interaction between Pressure and CO_2 amount and interaction between Pressure and Distance of CO_2 nozzle interaction were active.

Evaluating interactions is extremely important, because an interaction can magnify or cancel out main effects.

- It can eliminate (screen out) the other terms without significantly affecting predictions.

- There will have a model to predict the LPC of reused part, then we can apply this model to help obtain lower LPC in future experiments.

In order to get the lower LPC for CO_2 cleaner with appropriate condition, from results suggest that the best parameter should:

- Set pressure at high pressure 950 PSI

- Use CO_2 amount 0.1

- Evaluate distance of CO_2 nozzle with future experiments