CHAPTER IV
ANALYSIS OF TEST DATA

4.1 The Result from ANOVA

This chapter is concerned value of the critical ***F*** obtained, the result of ANOVA test by using software called "Minitab", and the conclusion of the analysis.

Refers to **2.3** on page 29, the critical ***F*** will be obtained as $F_{(\alpha, df1, df2)}$, from appendix A, where:

	α	= significance level
	df1	= numerator degree of freedom
	df2	= denominator degree of freedom

while, refers to **2.3.2** on page 30, : -

df1 $= k-1$

df2 $= k(n-1)$

when : n = size of each sample

k = number of samples

4.1.1 Material

4.1.1.1 Critical F

For analysis of material, there were 2 types of material tested at $\alpha = 0.05$ with 10 replicates.

So, Numerator degree of freedom = k-1 = 2-1 = 1

Denominator degree of freedom = k (n - 1) = 2 (10 - 1) = 18

Thus, the rejection region bounded by $F_{(0.05, 1, 18)} = 4.41$

4.1.1.2 Result

The result of ANOVA analysis by, using Minitab, are shown in appendix D, page 93 to116.

4.1.1.3 Conclusion

From ANOVA analysis, the material tends to have an effect on percent shrinkage of the filter eventhough the test in some conditions failed to reject the null hypothesis.

Table 4-1 : Conditions that failed to reject an equal effect of material's types are shown as hatched.

Condition #	Amplitude							
	70		80		90		100	
	%SHL	%SHW	%SHL	%SHW	%SHL	%SHW	%SHL	%SHW
Die 1	1	2	3	4	5	6	7	
Die 2	9		11	12		14		16
Die 3	17	18	19	20	21			

The failed cases may be caused by other factors that are not concerned in this experiment.

4.1.2 Amplitude

4.1.2.1 Critical F

For analysis of amplitude, there were 4 set point of amplitude or 4 treatments with 10 replicates. The analysis is done at $\alpha = 0.05$, so

Numerator degree of freedom = $k-1 = 4-1 = 3$

Denominator degree of freedom = $k(n-1) = 4(10-1) = 36$

From Appendix A, $F_{(0.05,3,30)} = 2.92$

$F_{(0.05,3,40)} = 2.84$

Thus, by interpolation, the rejection region bounded by $F_{(0.05,3,36)} = 2.872$

4.1.2.2 Result

The analysis is done by using Minitab with regarding to the data in appendix C. The results of the analysis are as shown in appendix D, page 117 to 128.

4.1.2.3 Conclusion

From ANOVA analysis, the level of amplitude tends to have an effect on percent shrinkage of the filter eventhough the test in some conditions failed to reject the null hypothesis.

Table 4-2 : Conditions that failed to reject an equal effect of amplitude's level are shown as hatched.

Condition #	Type of Filtrete			
	GSB-70		G-100	
	%SHL	%SHW	%SHL	%SHW
Die 1	25		27	28
Die 2			31	32
Die 3	33	34		

The failed cases may be caused by other factors that are not concerned in this experiment.

4.1.3 Die's Characteristic (cutting edge, edge seal, inner width and inner length)

4.1.3.1 Critical F

In this experiment, 3 different dies were used with 3 replications. The data are as shown in appendix C.

Consider at $\alpha = 0.05$, so the degrees of freedom are: -

Numerator degree of freedom = $k-1 = 3-1 = 2$

Denominator degree of freedom = $k(n-1) = 3(10-1) = 27$

Thus, the rejection region bounded by critical value of $F_{(0.05, 2, 27)} = 3.35$

4.1.3.2 Result

The analysis of the data was done according to One-Way ANOVA method by using the statistical software called "Minitab". The result of the analysis can be shown as in appendix D, page 129 to 144.

4.1.3.3 Conclusion

From ANOVA analysis, the characteristics of the die tends to have an effect on percent shrinkage of the filter eventhough the test in some conditions failed to reject the null hypothesis.

Table 4-3 : Conditions that failed to reject an equal effect of die's characteristics are shown as hatched.

Condition #	Type of Filtrete			
	GSB-70		G-100	
	%SHL	%SHW	%SHL	%SHW
Amplitude 70	[illegible]	38	39	40
Amplitude 80	41	42	43	44
Amplitude 90	[illegible]	46	47	48
Amplitude 100	49	50	51	52

The failed cases may be caused by other factors that are not concerned in this experiment.

4.1.4 Conclusion of ANOVA Test

From the ANOVA test as described in section 4.1.1, 4.1.2 and 4.1.3, the results of the test showed that:

- Effect of material type: 7 conditions (No. 8,10, 13, 15, 22, 23 and 24 as shown in table 4-1) out of 24 conditions rejected the null hypothesis of equal percent shrinkage by using different materials.

- Effect of amplitude: 5 conditions (No. 26, 29, 30, 35 and 36 as shown in table 4-2) out of 12 conditions rejected the null hypothesis of equal percent shrinkage by applying different amplitude.

- Effect of the die's characteristic (cutting edge, edge seal, inner length and inner width): 2 conditions (No. 37 and 45 as shown in table 4-3) out of 16 conditions rejected the null hypothesis of equal percent shrinkage by using different dies.

The causes of different outcome of hypothesis testing may be resulted from other factors that were not considered in this experiment, or could not be controlled. Those factors may include:

1. The weight variation within a lot of material.
2. The output amplitude from the ultrasonic welding machine may not be correct as shown on the panel.
3. The adjusted spring underneath die's foundation may be unbalance. The level of foundation is balanced at the first installation of the die. In fact, after operating for a certain period, it may be unbalance and requires readjustment.

However, it can be concluded from the majority of the results that the types of material, level of amplitude applied and characteristics of the die have an effect on percent shrinkage of recirculation filter.

4.2 Multiple Regression Analysis

From the conclusion of the ANOVA tests, material, amplitude and characteristic of the die had an effect on the percentage of shrinkage. Thus, the multiple regression can be implied to the test data for predicting the percent shrinkage by using those factors. By applying the assumption that:

$$\%SHL \approx f(\text{material,amplitude,characteris tic of the die})$$

and

$$\%SHW \approx f(\text{material,amplitude,characteris tic of the die})$$

4.2.1 Result of Multiple Regression

The result of regression analysis at $\propto = 0.05$ were shown as analysis reports in table 4-4 to 4-7:

Table 4-4 : Analysis report of multiple regression for percent shrinkage in length for G-100

Regression Analysis

* Inner Length is highly correlated with other X variables
* Inner Length has been removed from the equation

* Inner Width is highly correlated with other X variables
* Inner Width has been removed from the equation

The regression equation is
M100 %SHL = 2.72 + 0.00606 Amp + 1.16 Cutting Edge - 2.82 Edge Seal

Predictor	Coef	StDev	T	P
Constant	2.7183	0.2697	10.08	0.000
Amp	0.006062	0.002974	2.04	0.044
Cutting	1.1639	0.1876	6.20	0.000
Edge Sea	-2.8203	0.3685	-7.65	0.000

S = 0.3642 R-Sq = 47.4% R-Sq(adj) = 46.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	13.8617	4.6206	34.83	0.000
Error	116	15.3890	0.1327		
Total	119	29.2508			

Source	DF	Seq SS
Amp	1	0.5512
Cutting	1	5.5385
Edge Sea	1	7.7721

Unusual Observations

Obs	Amp	M100 %SH	Fit	StDev Fit	Residual	St Resid
84	70	3.5579	2.7891	0.0728	0.7688	2.15R
87	70	4.5774	2.7891	0.0728	1.7884	5.01R
91	80	2.0971	2.8497	0.0595	-0.7526	-2.09R
96	80	2.0462	2.8497	0.0595	-0.8035	-2.24R
99	80	3.6629	2.8497	0.0595	0.8132	2.26R
101	90	3.7944	2.9103	0.0595	0.8841	2.46R
107	90	1.8936	2.9103	0.0595	-1.0167	-2.83R
109	90	3.6760	2.9103	0.0595	0.7657	2.13R

R denotes an observation with a large standardized residual

Table 4-5 : Analysis report of multiple regression for percent shrinkage in width for G-100

Regression Analysis

* Inner Length is highly correlated with other X variables
* Inner Length has been removed from the equation

* Inner Width is highly correlated with other X variables
* Inner Width has been removed from the equation

The regression equation is
M100 %SHW = 2.02 + 0.0187 Amp - 2.34 Cutting Edge + 3.55 Edge Seal

Predictor	Coef	StDev	T	P
Constant	2.0167	0.3444	5.86	0.000
Amp	0.018734	0.003797	4.93	0.000
Cutting	-2.3443	0.2396	-9.79	0.000
Edge Sea	3.5457	0.4704	7.54	0.000

S = 0.4650   R-Sq = 65.9%   R-Sq(adj) = 65.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	48.553	16.184	74.84	0.000
Error	116	25.085	0.216		
Total	119	73.639			

Source	DF	Seq SS
Amp	1	5.264
Cutting	1	31.005
Edge Sea	1	12.284

Unusual Observations

Obs	Amp	M100 %SH	Fit	StDev Fit	Residual	St Resid
4	70	3.2392	4.4591	0.0930	-1.2199	-2.68R
13	80	5.6677	4.6464	0.0759	1.0213	2.23R
29	90	5.8049	4.8338	0.0759	0.9711	2.12R
71	100	2.5536	3.5505	0.0930	-0.9969	-2.19R
78	100	2.4581	3.5505	0.0930	-1.0924	-2.40R
87	70	4.8627	3.6881	0.0930	1.1746	2.58R
90	70	4.6881	3.6881	0.0930	1.0000	2.19R

R denotes an observation with a large standardized residual

Table 4-6 : Analysis report of mMultiple regression for percent shrinkage in length for GSB-70

Regression Analysis

```
* Inner Length is highly correlated with other X variables
* Inner Length has been removed from the equation


* Inner Width is highly correlated with other X variables
* Inner Width has been removed from the equation


The regression equation is
M70 %SHL = 1.12 + 0.0132 Amp + 0.321 Cutting Edge - 0.602 Edge Seal

Predictor        Coef       StDev          T        P
Constant       1.1216      0.2526       4.44    0.000
Amp          0.013245    0.002785       4.76    0.000
Cutting        0.3208      0.1757       1.83    0.070
Edge Sea      -0.6016      0.3450      -1.74    0.084

S = 0.3410      R-Sq = 18.3%     R-Sq(adj) = 16.2%

Analysis of Variance

Source        DF         SS         MS         F        P
Regression     3     3.0248     1.0083      8.67    0.000
Error        116    13.4915     0.1163
Total        119    16.5163

Source        DF      Seq SS
Amp            1      2.6313
Cutting        1      0.0398
Edge Sea       1      0.3537

Unusual Observations
Obs       Amp   M70 %SHL       Fit  StDev Fit   Residual    St Resid
 84        70     3.0620    1.9803     0.0682     1.0817      3.24R
 95        80     1.4009    2.1127     0.0557    -0.7118     -2.12R
101        90     2.9323    2.2451     0.0557     0.6871      2.04R
113       100     3.9263    2.3776     0.0682     1.5487      4.63R
114       100     1.6783    2.3776     0.0682    -0.6993     -2.09R
115       100     3.1140    2.3776     0.0682     0.7364      2.20R
120       100     3.1920    2.3776     0.0682     0.8144      2.44R

R denotes an observation with a large standardized residual
```

Table 4-7 : Analysis report of multiple regression for percent shrinkage in width for GSB-70

Regression Analysis

* Inner Length is highly correlated with other X variables
* Inner Length has been removed from the equation

* Inner Width is highly correlated with other X variables
* Inner Width has been removed from the equation

The regression equation is
M70 %SHW = 1.38 + 0.0113 Amp - 6.56 Cutting Edge + 11.1 Edge Seal

Predictor	Coef	StDev	T	P
Constant	1.3751	0.4219	3.26	0.001
Amp	0.011285	0.004652	2.43	0.017
Cutting	-6.5616	0.2935	-22.36	0.000
Edge Sea	11.0941	0.5763	19.25	0.000

S = 0.5697 R-Sq = 85.4% R-Sq(adj) = 85.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	220.920	73.640	226.89	0.000
Error	116	37.649	0.325		
Total	119	258.569			

Source	DF	Seq SS
Amp	1	1.910
Cutting	1	98.745
Edge Sea	1	120.265

Unusual Observations

Obs	Amp	M70 %SHW	Fit	StDev Fit	Residual	St Resid
4	70	4.3725	5.7952	0.1139	-1.4227	-2.55R
7	70	4.5638	5.7952	0.1139	-1.2314	-2.21R
16	80	7.3983	5.9081	0.0930	1.4903	2.65R
21	90	8.4601	6.0209	0.0930	2.4392	4.34R
31	100	4.4298	6.1338	0.1139	-1.7040	-3.05R

R denotes an observation with a large standardized residual

4.2.2 Conclusion of the Multiple Regression Analysis

From multiple regression analysis results, the inner length and inner width were neglected because they were highly correlated with percent shrinkage in both directions.

The critical value F for the four equations will be obtained from appendix A as $F_{(0.05,\ 3,\ 116)}$. Referring to appendix A, $F_{(0.05,\ 3,\ 60)} = 2.76$ and $F_{(0.05,\ 3,\ 120)} = 2.68$. Thus, $F_{(0.05,\ 3,\ 116)} = 2.6853$.

The regression equations are as following : -

- The percent shrinkage for material G-100

```
M100 %SHL = 2.72 + 0.00606 Amp + 1.16 Cutting Edge - 2.82 Edge Seal   (Eqn.4-1)
R-Sq(adj) = 46.0%
F = 34.83     P = 0.000
```

For this equation, $F_0 = 34.83$, which greater than F-critical value. It means that the three predictors (amplitude, cutting edge, and edge seal) are correlated with the dependent variable (M100 %SHL : percent shrinkage in length direction). Thus, this equation can be used for predicting the percent shrinkage. The R-Sq(adj) = 46.0% indicate that 46.0% of the variation in the percent shrinkage in length direction of filter, which is made from G-100 material can be explained by the above equation.

```
M100 %SHW = 2.02 + 0.0187 Amp - 2.34 Cutting Edge + 3.55 Edge Seal   (Eqn.4-2)
R-Sq(adj) = 65.1%
F = 74.84     P = 0.000
```

By using Minitab, $F_0 = 74.84$, which greater than F-critical value, thus this equation can be used to predict the percent shrinkage in width direction for material G-100 The R-Sq(adj) = 65.1% indicate that 65.1% of the variation in the percent shrinkage in width direction of filter, which is made from G-100 material can be explained by the above equation.

- For material GSB-70

```
M70 %SHL = 1.12 + 0.0132 Amp + 0.321 Cutting Edge - 0.602 Edge Seal   (Eqn.4-3)
R-Sq(adj) = 16.2%
F = 8.67     P = 0.000
```

As same as two above equation, F_0 of this equation is greater than F-critical value. However, R-Sq(adj) is very small The R-Sq(adj) = 16.2% indicate that only 16.2% of the variation in the percent shrinkage in length direction of filter, which is made from GSB-70 material can be explained by the above equation. It means that this equation is not appropriate to use for predicting the percent shrinkage.

```
M70 %SHW = 1.38 + 0.0113 Amp - 6.56 Cutting Edge + 11.1 Edge Seal   (Eqn.4-4)
R-Sq(adj) = 85.1%
F = 226.89     P = 0.000
```

Referring to the F_0, this equation can be used as prediction the percent shrinkage in width direction of filter that made from material GSB-70. Moreover, the R-Sq(adj) = 85.1% indicate that 85.1% of total variation in the percent shrinkage in width direction of filter can be explained by this equation.

As discussed above, there are only three equations suitable for predicting the percent shrinkage of filters; equation 4-1, 4-2, 4-4. Equation 4-3 is not appropriate for using because it may have other factors that have more influence on the percent shrinkage.

The prediction interval and confidence interval can be solved manually or by Minitab software. The illustrations of calculation are shown in appendix E.

However, the multiple regression equation obtained this studying is limited for used only when: -

- amplitude are 70, 80, 90 and 100 percent
- 0.096 mm $\leq$ Cutting Edge $\leq$ 1.9812 mm
- 0.165 mm $\leq$ Edge Seal $\leq$ 1.2141 mm

From the equations, F_0 of all equation are greater than F critical value, so all of them can be used as reference equations for predicting percent shrinkage of filters. However, they have the variation that can not be explained by these multiple regression equations. It may be affected by other factors as stated in previous section (4.1.4). However, the analysis shown that the factors (material types, amplitude and die's characteristic) that are considered in this study affect the percent shrinkage of the filter.

4.2.3 Interaction

The results from interaction analysis of those three factors at $\alpha = 0.05$ are as follows:

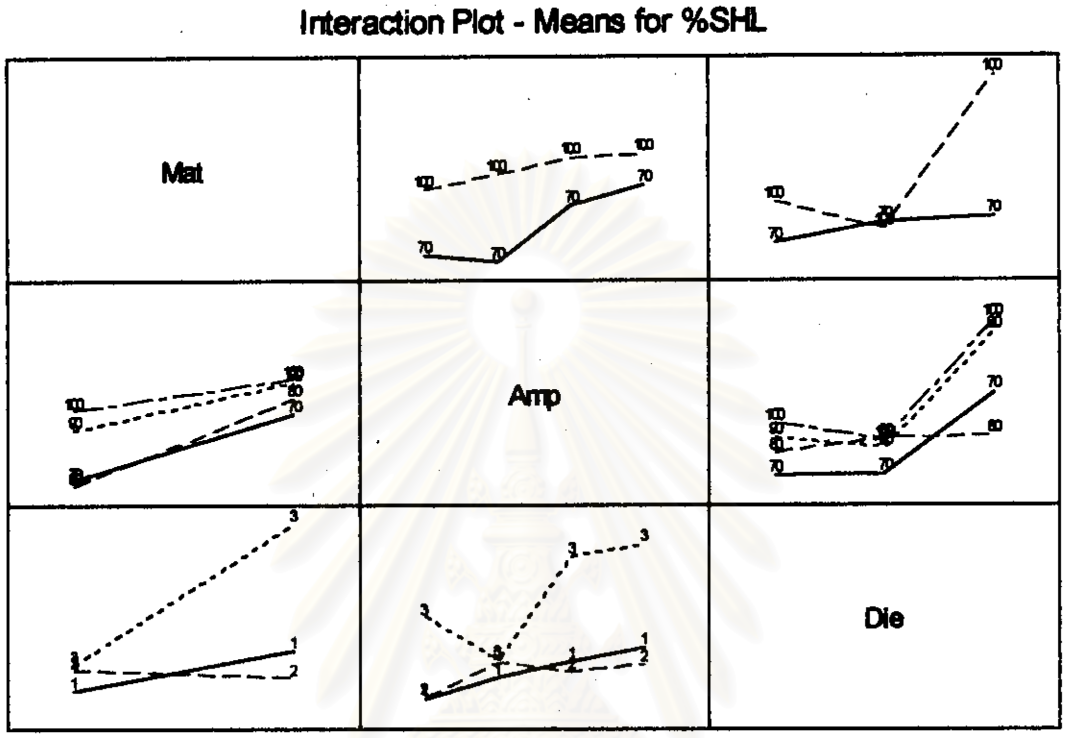

Figure 4-1 : Interaction plot of percent shrinkage in length

Table 4-8 : Analysis of variance (Balance Design) of percent shrinkage in length

Analysis of Variance (Balance Design)

Factor	Type	Levels	Values			
Mat	fixed	2	70	100		
Amp	fixed	4	70	80	90	100
Die	fixed	3	1	2	3	

Analysis of Variance for %SHL

Source	DF	SS	MS	F	P
Mat	1	5.0333	5.0333	44.91	0.000
Amp	3	3.0407	1.0136	9.04	0.000
Die	2	8.0405	4.0203	35.87	0.000
Mat*Amp	3	0.6511	0.2170	1.94	0.125
Mat*Die	2	5.6635	2.8318	25.27	0.000
Amp*Die	6	2.3768	0.3961	3.53	0.002
Mat*Amp*Die	6	1.7854	0.2976	2.65	0.017
Error	216	24.2091	0.1121		
Total	239	50.8004			

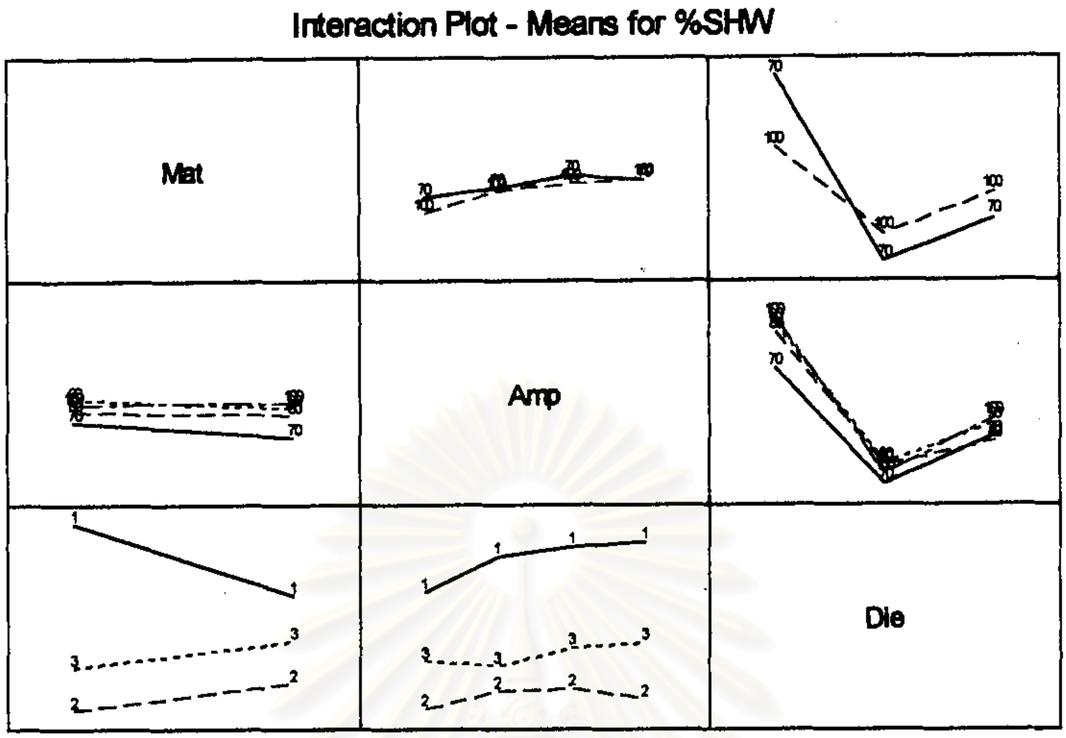

Figure 4-2 : Interaction plot of percent shrinkage in width

Table 4-9 : Analysis of variance (Balance Design) of percent shrinkage in width

Analysis of Variance (Balance Design)

Factor	Type	Levels	Values			
Mat	fixed	2	70	100		
Amp	fixed	4	70	80	90	100
Die	fixed	3	1	2	3	

Analysis of Variance for %SHW

Source	DF	SS	MS	F	P
Mat	1	0.703	0.703	2.89	0.091
Amp	3	7.850	2.617	10.74	0.000
Die	2	224.918	112.459	461.56	0.000
Mat*Amp	3	0.713	0.238	0.98	0.405
Mat*Die	2	37.381	18.691	76.71	0.000
Amp*Die	6	4.403	0.734	3.01	0.008
Mat*Amp*Die	6	4.316	0.719	2.95	0.009
Error	216	52.628	0.244		
Total	239	332.911			

From the interaction plot as shown in figure 4-1 and 4-2, and table 4-8 and 4-9, and the results from analysis of variance, it shown that:

1. Amplitude, type of materials, and die's characteristics had interaction among themselves in influencing the percent shrinkage of recirculation filters for both length and width directions except interaction of material and amplitude. In the width direction, this interaction is very dominant. Refers to figure 4-1 and 4-2, the percent shrinkage at each amplitude have the same trend (the line is parallel) without effect from type of materials.

2. The interaction of amplitude, type of materials, and die's characteristics has an influence on the percent shrinkage in both directions, especially in width direction. It can be described by the equations 4-1 to 4-4. The equations for the percent shrinkage in width direction have a value of R-square (adj) more than in length direction.

3. From the interaction analysis for the width direction, the percent shrinkage is not influenced by type of materials as shown on figure 4-2 (The percent shrinkage at each amplitude have the same trend (the line is parallel) without effect from type of materials.).

4.3 Conclusion

The study showed that types of material, amplitude of the energy applied, and characteristics of the die (edge seal and cutting edge) had an influence on the percent shrinkage of recirculation filter. The relationship of each factors and the percent shrinkage can be explained by multiple regression equations with the confidence and prediction intervals as discussed above. However, the coefficient of determination for equation 4-3 shows that the percent shrinkage of recirculation filter might be influenced by other factors that are beyond the scope of this study. It should be taken into consideration for the further study.