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Image Analysis: A Novel Technique to Determine the Efficiency of Wiping Cloths

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Abstract: The ability to absorb liquid and the dust removal performance are important factors for wiping cloths used to remove contaminants. We have developed a method that can determine the contaminant removal performance of wiping cloths. In the gravimetric method, experimental errors are unavoidable because the contaminant plate is much heavier than the contaminant material. However, we used image analysis to reduce the experimental errors, and did not use the heavy contaminant plate. The correlation coefficient between the image analysis and the gravimetric methods was very high, at R = 0.97, with a significance level of 95 %. From the correlation analysis and empirical data, the image analysis method is a useful tool for measuring wiping efficiency. The wiping efficiency measured using image analysis has a close relationship to the wiping speed, viscosity of the contaminant, and wiping pressure, at the significance level of 95 %.

Keywords: Ultra fine fiber, Wiping cloth, Image analysis, Wiping efficiency

Introduction

There are many test methods to determine wiping cloth properties and efficiency, and there are many institutions working on the properties of wiping cloths. The various test methods used and the institutions investigating wiping cloths are shown in Table 1. However, there are few test methods for measuring the dynamic wiping efficiency encountered in actual situations, for example, to determine the influence of manual operations.

Liquid absorption capability and dust removal performances are important factors for wiping cloths used to remove contamination. Oathout simultaneously measured the liquid absorption and particle elimination properties when determining the efficiency of wiping cloths used for clean room operations [1]. There have been researches on the absorption phenomena, and our research group has recently reported on an absorption test for wiping cloths that measures the real-time sorption characteristics of a fibrous assembly [2-5]. The absorption performance is determined using a comparatively low viscous fluid that is in contact with a solid surface wetted onto a surface of a fibrous assembly, and this is allowed to penetrate into the inner spaces of the wiping cloth. The fluid should not be released from the fibrous assembly, but be maintained in the wiping cloth. The rubbing performance is determined using a solid contaminant or a very high viscosity fluid that is removed from the solid surface by abrasion using a fibrous assembly surface, and the contaminant is attached to the surface of the wiping cloth, which is composed of fibers. In this process, any contaminants attached to the fibers lodge in morphological structures, such as cracks and pits, and remain in the inner spaces of the fibrous assembly. Donkai *et al.* reported on the rubbing performance of knitted acrylic using solid contaminants and very high viscosity fluids made from olive oil, butter, and lard [6].

Table 1. The institutions investigating wiping efficiency and the test methods employed by them

Test method	Reference organization	Web page
IST method	The Association of the Nonwoven Fabrics Industry	www.inda.org
ERT method	European Disposables and Nonwovens Association	www.edana.org
ASTM method	American Society for Testing and Materials	www.astm.org
IEST-RP method	The Institute of Environmental Sciences and Technology	www.iest.org
AATCC method	The American Association of Textile Chemists and Colorists	www.aatcc.org

The wiping efficiency can be determined from the characteristics of the fibrous assembly and the contaminant. The characteristics of the fibrous assembly are derived from its chemical structure, surface properties, cross-sectional shape of the constituent fibers, structure and twist of the yarn, and the construction method used to make the fibrous assembly. The characteristics of the contaminant are derived from the affinity of the fibrous assembly, its viscosity, its hydrophilic and oleophilic properties, the particle size, and the interaction between the solid and/or liquid contaminant.

We have developed a unique method to determine the contaminant removal performance of wiping cloths. Our method employed a scanner attached to a PC, and data were

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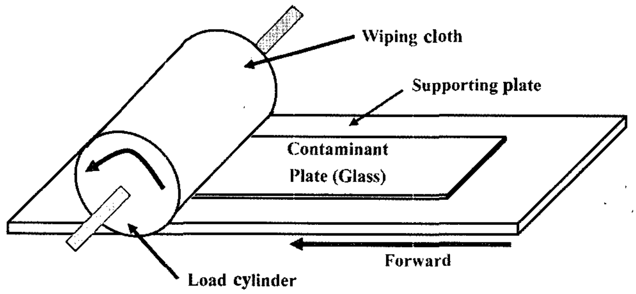

Figure 1. Schematic drawing of the wiping test apparatus.

analyzed using a commercial image analysis software package.

Experimental

The Wiping Test Apparatus

The wiping test apparatus used was designed and constructed in our laboratory to evaluate the wiping efficiency of wiping cloths. A schematic drawing of the wiping tester is shown in Figure 1. A wiping cloth was placed on the surface of a load cylinder, and the contaminant plate was placed on a supporting plate. Subsequently, the wiping performance was evaluated as the supporting plate, along with the contaminant plate, were moved forwards while the load cylinder was rotated. A range of wiping speeds and pressures can be applied using this apparatus. After the wiping tests, the wiping cloths were taken from the cylinder, and the contaminant plate was separated from the supporting plate to evaluate its performance.

Materials

Silicon oils (Dong Yang Silicon, Seoul, TSF-451) with viscosities in the range 500-3,500 cSt were used as contaminants, and carbon black (Korea Carbon Black Co. Ltd., Hiblack 5L) was dispersed in the silicon oils to obtain an image of the transparent silicon oil. The specific surface area of the carbon black was 68.1 mg/g, tested to the American Society for Testing and Materials (ASTM) Standard D-1510 [7], and the tint strength was 115.7 % tested to ASTM Standard D-3265 [8]. The wiping cloth selected for the wiping performance measurements was a commercial wiping cloth, which was made from split-type nylon/polyester conjugated fibers. The weight of the wiping cloth was 185 g/m^2, determined using the Korean Standard (KS) Standard K 0514 [9], and the woven density was 135/48, warp/weft gauge, determined using KS Standard K 0511 [10]. In addition, the thickness was determined to be 0.46 mm using KS Standard K 0506 [11]. The absorption capacity of the wiping cloth was 437.1 %, and the primary absorption rate was 39.45%s^{-1} [5]. The thickness of the glass plate used as the contaminant plate was 5 mm.

Measurement of the Wiping Performance

The contaminant was spread onto the glass plate (dimensions = 15 cm wide, 25 cm long, 0.17 mm thick). The weight of the contaminant before and after wiping was measured along with the weight of the contaminant plate. Wiping tests were performed using a wiping speed of 10-35 cm/s and a wiping pressure of 0.6-1.6 kg/cm^2. (A survey of graduate students found that the normal conditions used to determine the wiping performance were: wiping speed = 20 cms^{-1} and pressure = 1 kgcm^{-2}). The surface of the contaminant plate before and after wiping was imaged using a Hewlett-Packard HP Scanjet 6100 scanner using the following parameters: width 400 pixels, height 700 pixels, brightness 160, and contrast 157.

Evaluation of the Wiping Performance

Images of the contaminant plate were analyzed using a commercial image analysis software package, Image-Pro® Plus (Media Cybernetics Co., USA). The number of pixels was assessed using the lightness defined in 256 grades, and the total summation of the number of pixels was calculated using equation (1);

$$I = \sum_{L=0}^{255} \sqrt{(255-L)} \times N_p \qquad (1)$$

where I is the result of the image analysis, L is the lightness grade, and N_p is the number of pixels at each lightness grade. The wiping efficiency was then calculated using equation (2);

$$\text{Wiping efficiency (\%)} = \left(\frac{W_A - W_B}{W_A}\right) \times 100 \qquad (2)$$

where W_A is the weight of the contaminant from the image analysis before the wiping test was carried out, and W_B is the weight of the contaminant from the image analysis after the wiping test was carried out. Statistical analysis was undertaken to determine the wiping efficiency and the effect of wiping speed, contaminant viscosity, and wiping pressure.

Results and Discussion

Experimental errors are unavoidable in the case of the gravimetric method, because the contaminant plate is much heavier than the contaminant material. However, the experimental errors can be reduced in the case of the image analysis method, because the heavy contaminant plate need not be used. In our study, regression analysis was used to assess the applicability of the image analysis method.

Figure 2 shows scanned images of the contaminant plate with no contaminant (Figure 2(a)), before the wiping test was carried out (Figure 2(b)), and after the wiping test had been carried out (Figure 2(c)). Figure 3(a) shows that the lightness of the blank glass contaminant plate that acted as a control was concentrated in grade range of 220-240. Figure 3(b) shows the number of pixels graded by lightness for an image of a contaminant plate that contained contaminant material before a wiping test was carried out. It can be seen

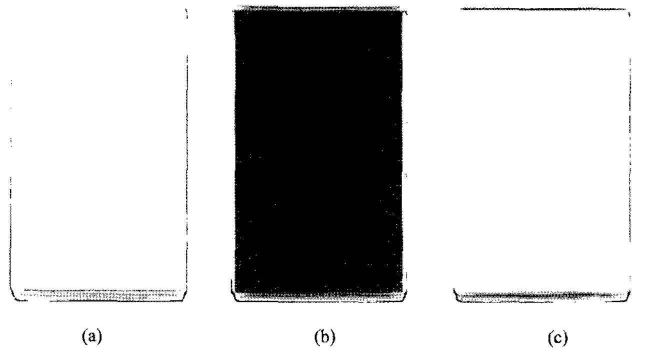

Figure 2. Scanned images of the contaminant plate; (a) no contaminant, (b) before wiping, and (c) after wiping.

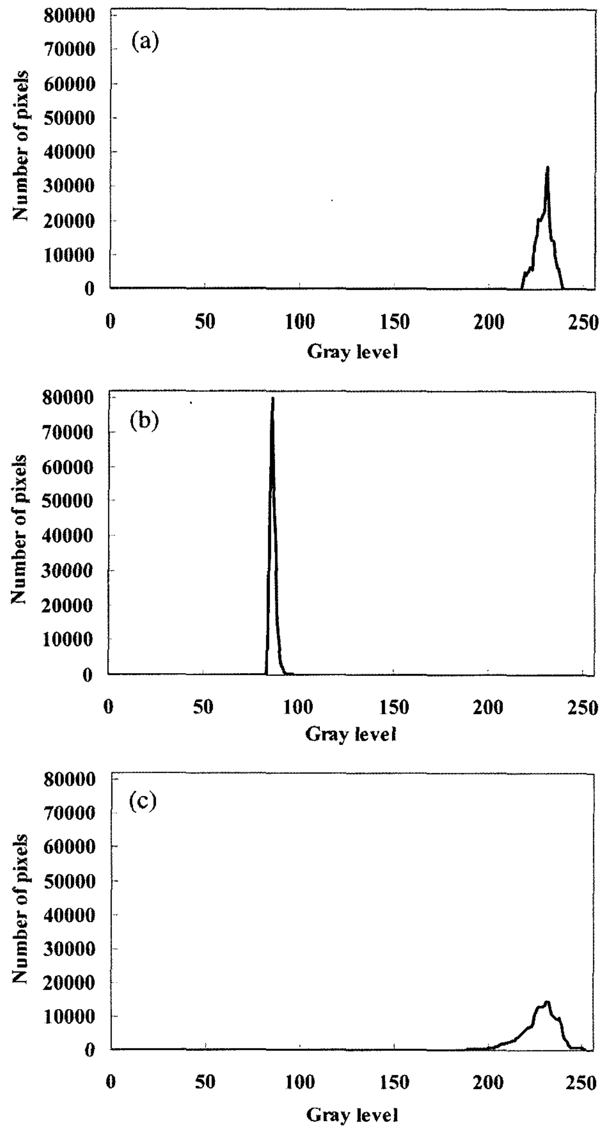

Figure 3. Number of pixels determined by lightness grade for the contaminant plate scanned image; (a) no contaminant, (b) before wiping, and (c) after wiping.

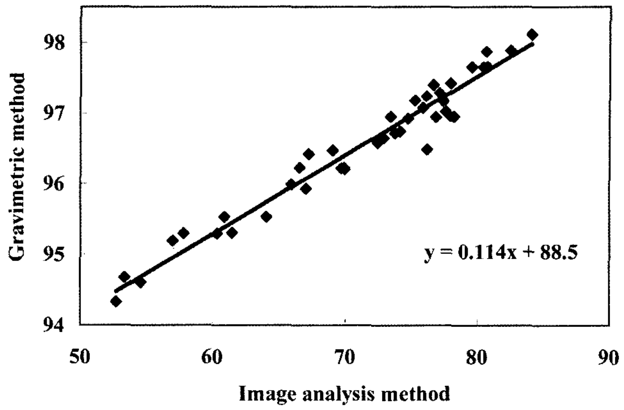

Figure 4. Correlation of the image analysis and gravimetric methods.

that the lightness was concentrated in the grade range 80-100, because a black contaminant material was used. Figure 3(c) shows the number of pixels graded by lightness for a scanned image of a contaminant plate after a wiping test. The lightness in Figure 3(c) was scattered over a comparatively wide range, which was caused by the presence of contaminant material.

Correlation of the Image Analysis and Gravimetric Methods

From a correlation analysis, the correlation coefficient, R, between the image analysis and gravimetric methods was very high, at R = 0.97, with a significance level of 95 %. However, there was a difference between the absolute values of the two factors in terms of their wiping efficiencies, and therefore, some compensation was required to correlate the two methods. Equation (3) and Figure 4 show the relationship between the two methods.

$$\text{Gravimetric method} = (0.114 \times \text{Image Analysis method}) + 88.5 \qquad (3)$$

Effect of Wiping Performance Variables

The following simple linear regression technique was used to analyze the data obtained;

$$\text{Wiping efficiency} = b_0 + b_1 x \qquad (4)$$

where x: the factor influencing the wiping efficiency (e.g., the wiping speed, viscosity of contaminant, and wiping pressure), b_0: intercept of the regression analysis, and b_1: the coefficient of the regression analysis of the factor influencing the wiping efficiency. The results of our analysis are shown in Tables 2-5. The first part of each table showing the output illustrates the estimated coefficients, along with their standard deviations. The parameter S is an estimate of the standard deviation about the regression line. The parameter R^2 is the coefficient of determination. The second part of each table shows the results of our analysis of the variance.

Table 2. Regression analysis of the wiping efficiency (Y) versus the wiping speed (X_1)

The regression equation used was $Y = 89.6 - 0.765\ X_1$.

Predictor	Coeff.	SE Coeff.	T	P
Constant	89.6	1.45	61.73	0.000
X_1	−0.765	0.06	−12.69	0.000

$S = 0.022$ and $R^2 = 91.0\ \%$

Analysis of the variance

Source	DF	SS	MS	F	P
Regression	1	768.78	768.78	161.01	0.000
Residual error	16	76.40	4.77		
Total	17	845.18			

Table 2 shows the results of our regression analysis on the wiping speed. An important aspect of statistical procedures is that they can indicate how well a derived model predicts the empirical data. A widely used measure of the predictive efficacy of a model is to use the value of the coefficient of determination, R^2: The F value of a given model tests how well the model as a whole accounts for a dependent variable's behavior. The F value of our model was found to be statistically significant at the 95 % level. From regression analysis on the results, the coefficient of determination of the model was found to be very high, at R = 91.0 %, and the F-value was also statistically significant at the 95 % level. Using the values of the intercept and the coefficient of the regression analysis, the prediction model for the wiping efficiency can be rewritten as;

$$\text{Wiping efficiency} = 89.6 - (0.765 \times \text{wiping speed}) \quad (5)$$

Figure 5(a) shows the change in wiping efficiency with wiping speed. The residual plot of the model shown in Figure 5(b) indicates a lack of fit to the sample data. Therefore, our regression model is suitable for use to measure the wiping efficiency.

Table 3 shows the results of regression analysis on the effect of the viscosity of the contaminant. From these data, the coefficient of determination of the model was found to be very high, at R = 92.5 %, and the F-value was statistically significant at the 95 % level. From the values of the intercept and the regression coefficients, the prediction model for wiping efficiency can be rewritten as;

$$\text{Wiping efficiency} = 84.7 - (4.83 \times 10^{-3} \times \text{viscosity of contaminant}) \quad (6)$$

Figure 6(a) shows the change in wiping efficiency with viscosity of the contaminant. The residual plot of the model, shown in Figure 6(b), indicates a lack of fit of the sample data, and therefore, this regression model is suitable to use to determine the effect of viscosity of the contaminant on the wiping efficiency.

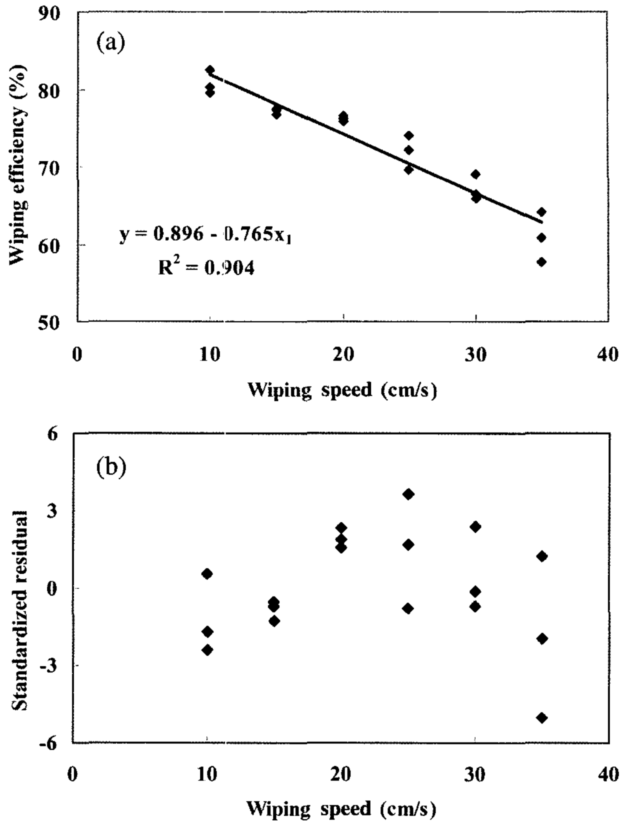

Figure 5. Regression analysis; (a) change in wiping efficiency with wiping speed and (b) standardized residual plot of the wiping efficiency.

Table 3. Regression analysis of the wiping efficiency (Y) versus contaminant viscosity (X_2)

The regression equation used was $Y = 84.7 - 4.83 \times 10^{-3}\ X_2$.

Predictor	Coeff.	SE coeff.	T	P
Constant	84.7	0.67	126.44	0.000
X_2	-4.83×10^{-3}	3.44×10^{-4}	−14.03	0.000

$S = 0.012$ and $R^2 = 92.5\ \%$

Analysis of the variance

Source	DF	SS	MS	F	P
Regression	1	305.62	305.62	196.84	0.000
Residual error	16	24.84	1.55		
Total	17	330.47			

Table 4 shows the results of regression analysis on the wiping speed. From these results, the coefficient of determination of the model was found to be moderately high, at R = 81.2 %, and the F-value was statistically significant at the 95 % level. From the values of the intercept and the regression coefficients, the prediction model for the wiping efficiency can be rewritten as;

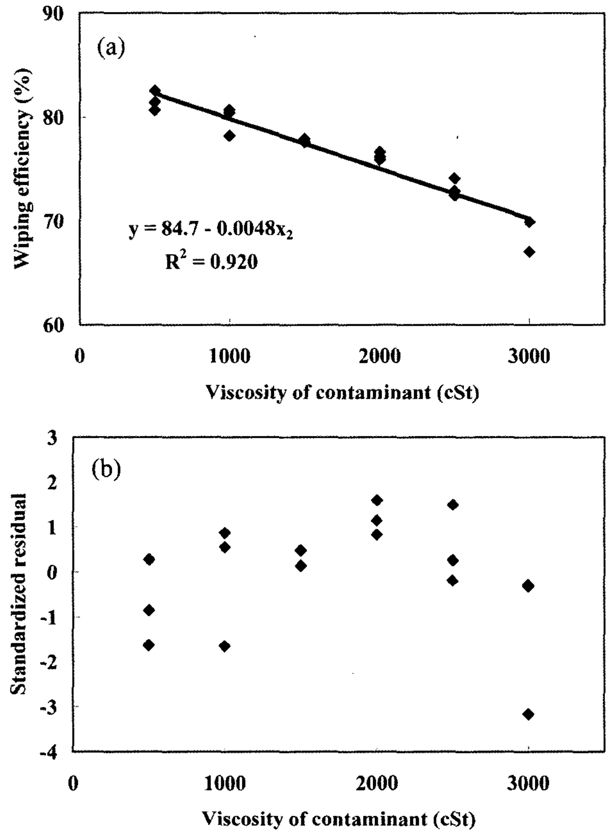

Figure 6. Regression analysis; (a) change in wiping efficiency with viscosity of contaminant, (b) standardized residual plot of the wiping efficiency.

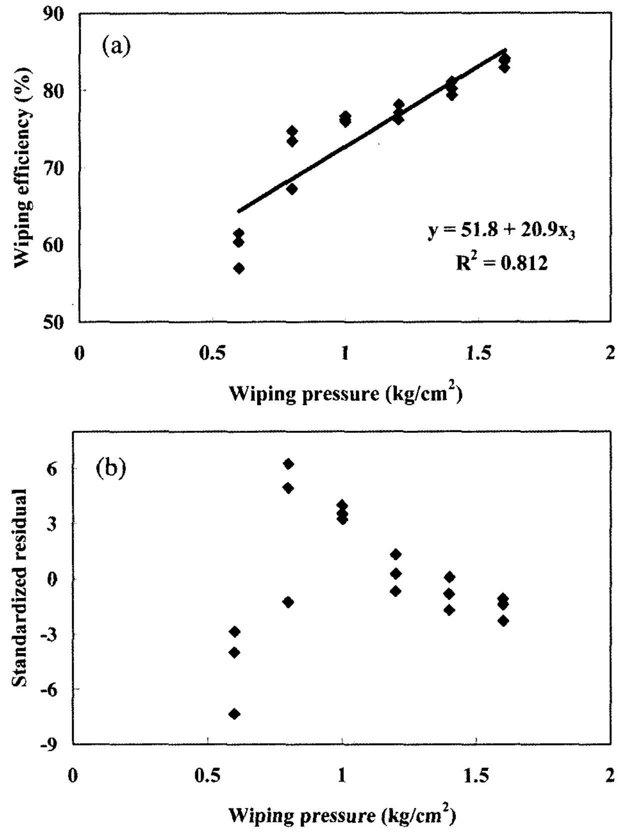

Figure 7. Regression analysis; (a) change in wiping efficiency with wiping pressure, (b) standardized residual plot of the wiping efficiency.

Table 4. Regression analysis of the wiping efficiency (Y) versus wiping pressure (X_3)

The regression equation used was $Y = 51.8 + 20.9\,X_3$.

Predictor	Coeff.	SE coeff.	T	P
Constant	51.8	2.78	18.62	0.000
X_3	20.9	2.42	8.63	0.000

$S = 0.035$ and $R^2 = 81.2$ %

Analysis of the variance

Source	DF	SS	MS	F	P
Regression	1	913.10	913.10	74.51	0.000
Residual error	16	196.07	12.25		
Total	17	1109.17			

$$\text{Wiping efficiency} = 51.8 + (20.9 \times \text{wiping pressure}) \quad (7)$$

Figure 7(a) shows the change in wiping efficiency with wiping pressure. The residual plot of the model in Figure 7(b) indicates a lack of fit of the sample data, and therefore, this regression model is suitable to model the change in wiping efficiency with wiping pressure.

A multiple regression technique was used to analyze the data for the collective effect of the wiping speed, viscosity of the contaminant, and the wiping pressure on the wiping efficiency. Table 5 shows the results of the multiple regression analysis on the effect of the wiping speed, viscosity of

Table 5. Regression analysis of the wiping efficiency (Y) versus wiping speed (X_1), viscosity of contaminant (X_2), and wiping pressure (X_3)

The regression equation used was $Y = 79.6 - 0.756\,X_1 - 5.15 \times 10^{-3}\,X_2 + 19.8\,X_3$.

Predictor	Coeff.	SE coeff.	T	P
Constant	79.6	2.72	29.31	0.000
X_1	−0.756	0.07	−10.68	0.000
X_2	-5.15×10^{-3}	7.07×10^{-4}	−7.29	0.000
X_3	19.8	1.77	11.19	0.000

$S = 0.026$, $R^2 = 85.7$ %, and $R^2(\text{adj.}) = 84.8$ %

Analysis of the variance

Source	DF	SS	MS	F	P
Regression	3	2,074.01	691.34	99.72	0.000
Residual error	50	346.65	6.93		
Total	53	2,420.67			

contaminant, and wiping pressure. From these results, the adjusted coefficient of determination of the model was found to be moderately high, at R = 84.8 %, and the F-value was statistically significant at the 95 % level. From the values of the intercept and the regression coefficients, the prediction model for the wiping efficiency was rewritten as;

$$\text{Wiping efficiency} = 79.6 - (0.756 \times \text{wiping speed}) - (5.15 \times 10^{-3} \times \text{viscosity of the contaminant}) + (19.8 \times \text{wiping pressure}) \quad (8)$$

Conclusions

Experimental errors cannot be avoided in the case of the gravimetric method, which is the general testing method used for determining the wiping efficiency, because the contaminant plate is much heavier than the contaminant material. However, using our image analysis method, the experimental errors can be reduced, because the heavy weight contaminant plate need not be used. The correlation coefficient between the image analysis and the gravimetric methods is as high as R = 0.97 at a significance level of 95 %. From our correlation analysis, the image analysis method is applicable to the measurement of the wiping efficiency, and based on the empirical data, the image analysis method can be a useful tool for the measurement of wiping efficiency. The results indicate that the wiping efficiency measured using our image analysis method has a close relationship to the wiping speed, viscosity of the contaminant, and wiping pressure at a significance level of 95 %.

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