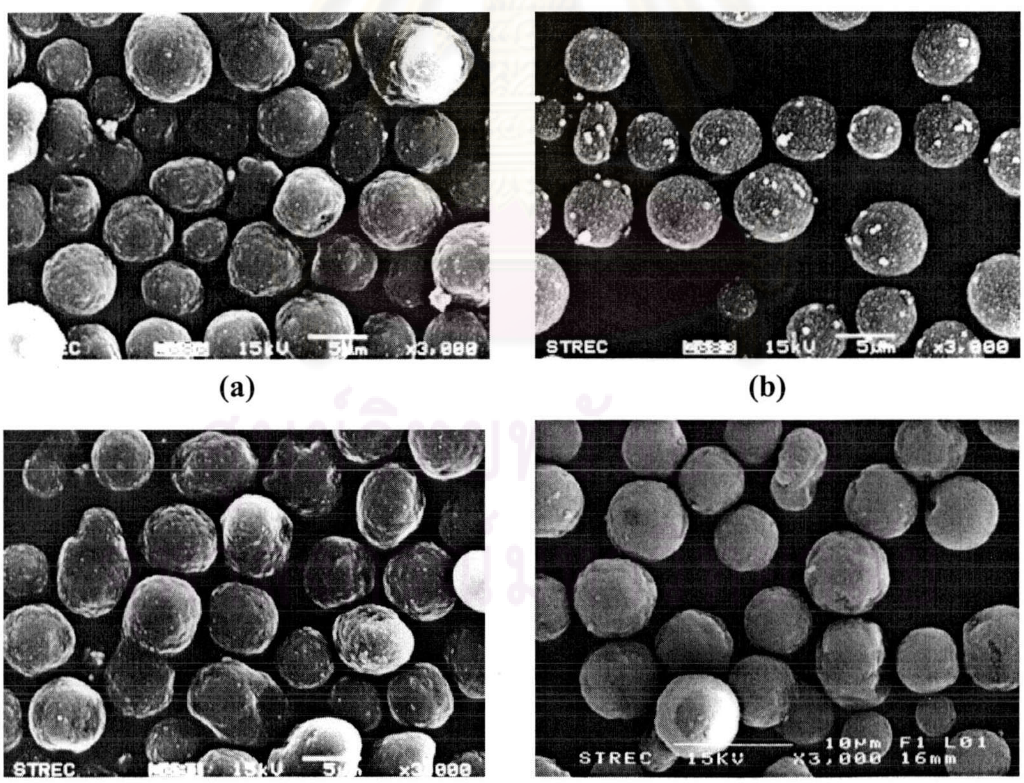
CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Morphology of the toner and carrier

The scanning electron micrographs of the four types of toners: black, magenta, yellow and cyan toners are shown in Figure 4-1. They are spherical in shape with a smooth surface. Their sizes are 5-6.5 micrometers in diameter, which are resulted from ten measurements of each particle type. They have the average particle sizes



(a) (b)

(c) (d)

Figure 4-1 Scanning electron micrographs of the four types of toners: (a) black toner, (b) yellow toner, (c) cyan toner, and (d) magenta toner about 6.31, 5.94, 6.38 and 6.50 micrometers for black, yellow, cyan and magenta toners, respectively. So, magenta toner has the biggest particle size, while yellow toner has the smallest particle size.

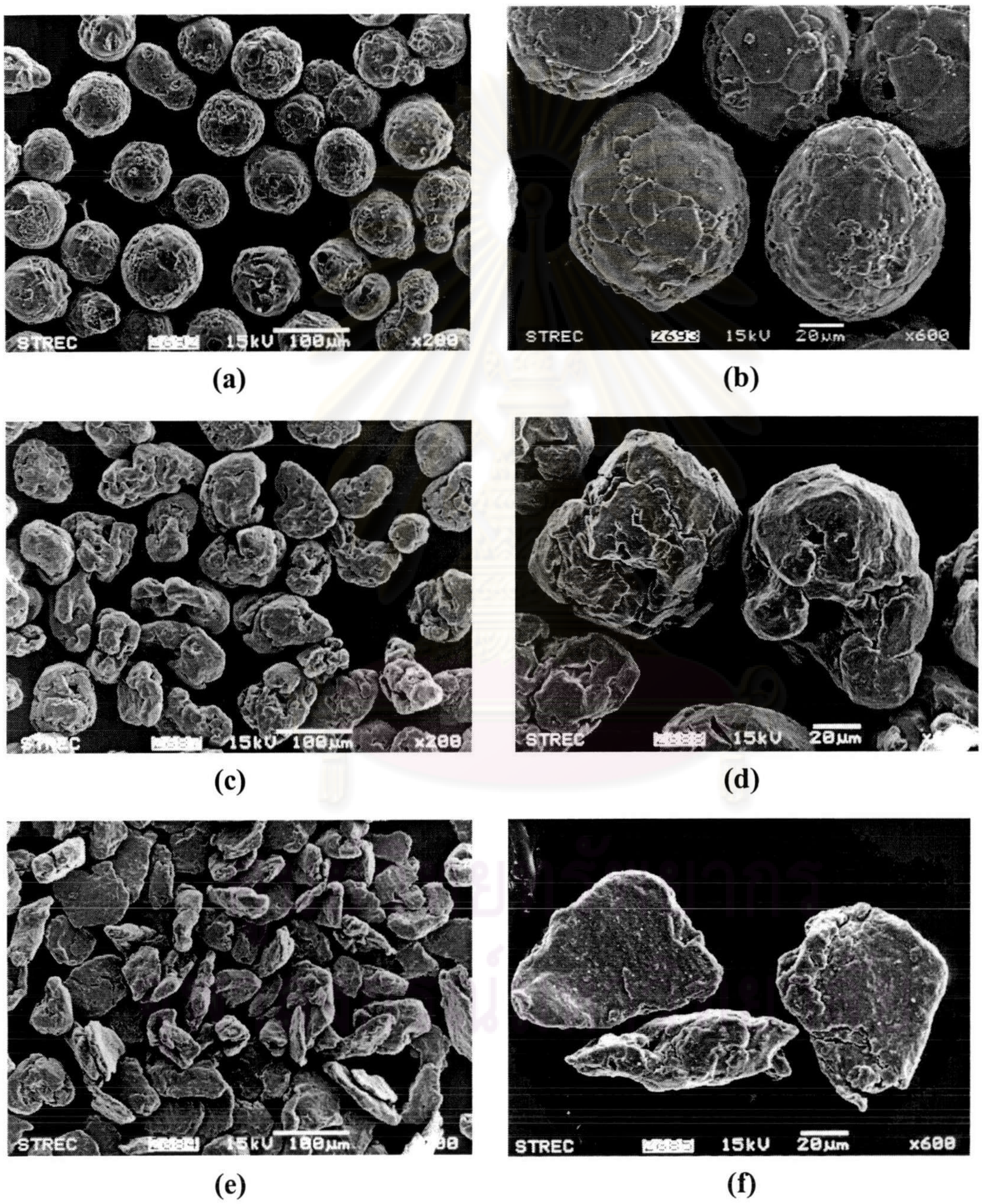


Figure 4-2 Scanning electron micrographs of the three types of carriers: (a) F-150, (b) F-150, (c) TSV-200, (d) TSV-200, (e) Z-250, and (f) Z-250.

The scanning electron micrographs in Figure 4-2 are for the three types of carrier: F-150, TSV-200 and Z-250. The TSV-200 and Z-250 are irregular shape with the rough surface while the shape of F-150 carrier is more spherical with the smooth surface than the other, which has the average particle sizes about 90 micrometers.

4.2 Measurement of toner charging properties

4.2.1 Toner charge dependence on toner concentration (wt%)

Four types of toner (cyan, magenta, yellow and black toner) were each mixed with TSV-200 carrier. These developers were prepared by various concentrations of the toner particles at 1, 3, 5, 7 and 10 wt% with 99, 97, 95, 93 and 90 wt% of the carrier, respectively. They were mixed thoroughly at a rotating speed of 800 rpm in Minishaker for the rotating times of 15, 30, 60, 90, 120, 240 and 360 seconds. After each rotating time, the mixed developer was measured for the q/m values. The q/m curves for the black toner and TSV-200 carrier are plotted in Figure 4-3 to obtain the charging stability with rotating time. The curves are in a similar tendency that toner charges changed rapidly when the rotating time of the developer proceeded from 15 to 90 seconds. After that, the q/m values changed slowly and became almost steady afterwards.

Figures 4-4 to 4-6 show the q/m curves for the three types of toner (cyan, magenta and yellow toner) mixed with the same carrier under the same condition as for the black toner, charging the rotating times from 15, 30, 60, 90, 120, 240 and 360 seconds to 3, 5, 10, 15, 30, 60, 90, 120, 240 and 360 seconds. At a short mixing time (3 to 15 seconds), increases in the q/m values at all toner concentrations are significant. After 15 seconds of mixing, the q/m values for all toner concentrations are stable at each individual plateau.

Figures 4-7, 4-9, 4-11 and 4-13 show the curves of q/m value in relation to the toner concentration of four types of the toner mixed with TSV-200 carrier. The q/m values decreased when the toner concentrations were increased in the toner concentration range from 1 to 10 wt%. At the high toner concentration, the coverage of the toner particles on the carrier surface was higher and occupied more than one layer. The outer layer had some free toner particles that could not be charged by rubbing with the carrier particles [16]. Thus, the q/m values decreased when the toner concentrations were increased.

Figures 4-8, 4-10, 4-12 and 4-14 give plots of the inverse q/m values of Figures 4-7, 4-9, 4-11 and 4-13. The curves of m/q values increased when the toner concentrations increased from 3 to 10 wt%. However, the curves of m/q values did not change significantly when changing the toner concentrations from 1 to 3 wt%, especially at higher rotating times. So, we should consider the curves of m/q values in Figure 4-15 in relation to the toner concentration of four types of the toner mixed with TSV-200 carrier at the rotating time of 360 seconds. It is shown that the m/q values were increased when the toner concentrations increased from 3 to 10 wt%. The surface state theory could explain this observation [21]. The mechanism of electrification has been discussed as due to the presence of the surface states in the forbidden gap of the polymer. Tribocharging was extremely sensitive to the surface states, and any surface change at the time and point of contact would have affected the value of the work function, which may be due to changes in the electronic surface states of polymer. So, the q/m value was changed when the rotating time and the toner concentration were changed.

The relationship between the toner charge-to-mass ratio (q/m) and toner concentration is an important metric for two-component xeroxgraphic developers. In general, the toner q/m generation process can be expressed as the product of terms related to the physics of charging, the chemistry of charging and the mechanics of charging [22], e.g.:

$$q/m = \underbrace{(A'/(C+C_0))}_{\text{physics}} \cdot \underbrace{(\phi_{toner} - \phi_{carrier})}_{\text{chemistry}} \cdot \underbrace{(1-\exp\{-\gamma\cdot t\})}_{\text{mechanics}} \qquad (4\text{-}1)$$

and extended toner/carrier mixing (i.e. $\exp\{-\gamma\cdot t\}\rightarrow 0$ for large values of t) is predicted to generate a simple inverse form for the q/m vs C relationship, i.e.:

$$q/m = (A'/(C+C_0)) \cdot (\phi_{toner} - \phi_{carrier}) \qquad (4\text{-}2)$$

$$= A/(C+C_0) \qquad (4\text{-}3)$$

where q/m is the toner charge-to-mass ratio. A toner weight% concentration of C, A' and C_0 are constants related to the size and density of the toner and carrier particles. The rate constant γ defines the rate of triboelectric charging, and is related to the mode of the toner/carrier mixing process. The ϕ_{toner} and $\phi_{carrier}$ terms represent the charging tendency of the toner and carrier particles, and the relative magnitude of these two terms directly governs the polarity of the toner particles, and also affects the magnitude of the toner charge.

Accordingly, an m/q vs C plot for charging data taken after an extended mixing should be linear with a slope of 1/A, however, most two-component xerographic developers do not follow Eqn. (4-3). The characteristic "constant" materials terms ϕ_{toner} and $\phi_{carrier}$ can be quite variable during a typical triboelectric charging experiment, as a result of mixing induced changes in toner and/or carrier composition. Additionally, such variability may be further affected by other controlling factors such as toner concentration and ambient conditions of temperature and humidity.

Because the surface of toner and carrier particles are typically composed of several components, e.g., binder resin, pigment, coating, etc., the ϕ_{toner} and $\phi_{carrier}$ terms in Eqn. (4-3) may be expressed in terms of surface-weighted contributions from the various components [23], e.g.,

$$\phi = P_i \cdot \mu_i + P_j \cdot \mu_j + \ldots \qquad (4\text{-}4)$$

where the total sum of the fractional weights, P_i, P_j etc., equals unity, and the parameters μ_i and μ_j etc. are characteristic charging factors for the various surface components.

The mechanical forces of the triboelectric mixing process affects the surface composition of toner and carrier particles, i.e., the P_i, P_j values are functions of the mixing time, and the resultant q/m values can be complex non-linear functions of mixing time.

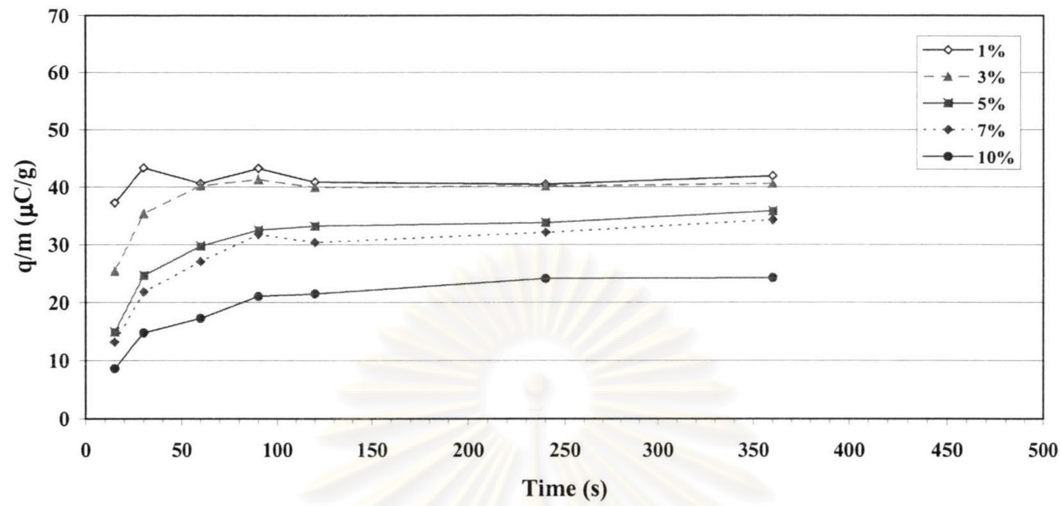


Figure 4-3 Dependence of q/m on developing time for black toner and TSV-200 at 800 rpm by blow-off method

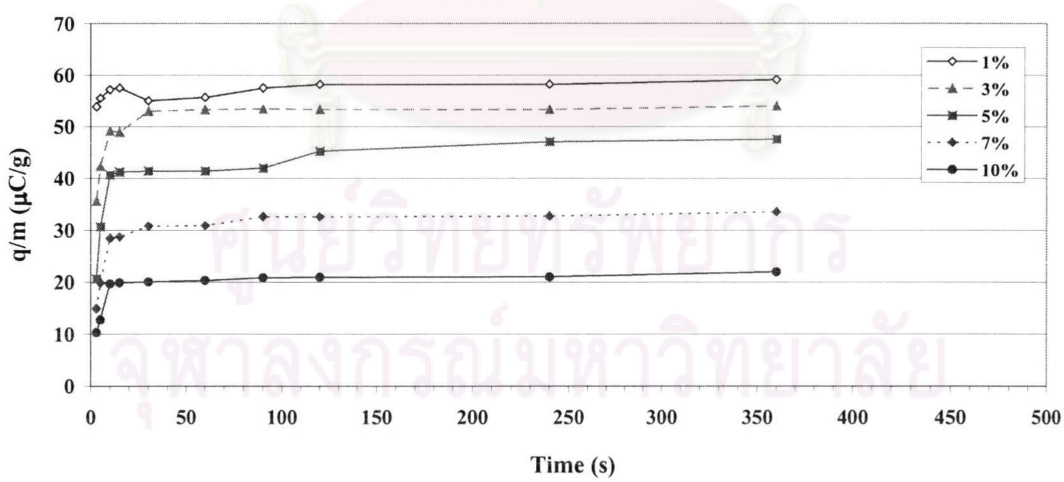


Figure 4-4 Dependence of q/m on developing time for cyan toner and TSV-200 at 800 rpm by blow-off method

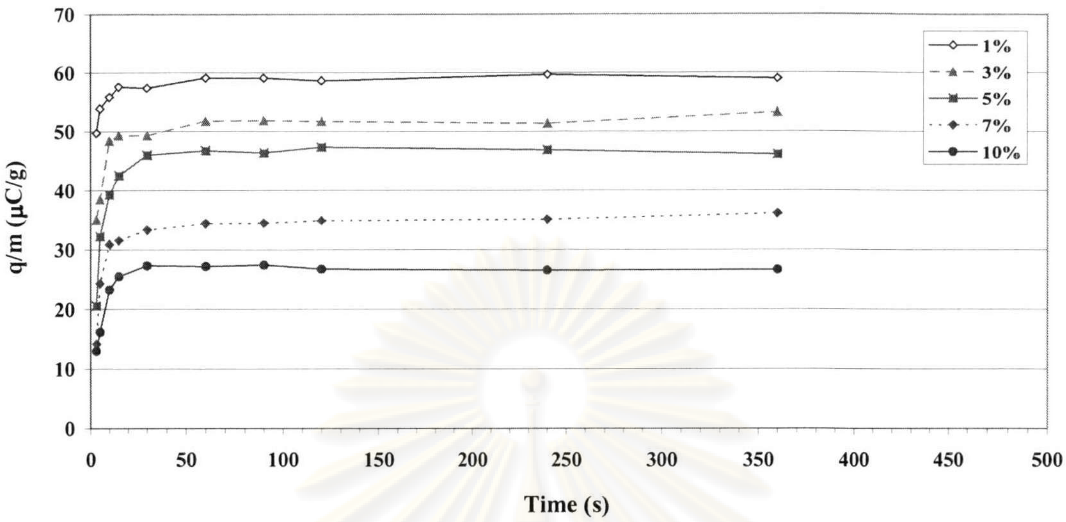


Figure 4-5 Dependence of q/m on developing time for magenta toner and TSV-200 at 800 rpm by blow-off method

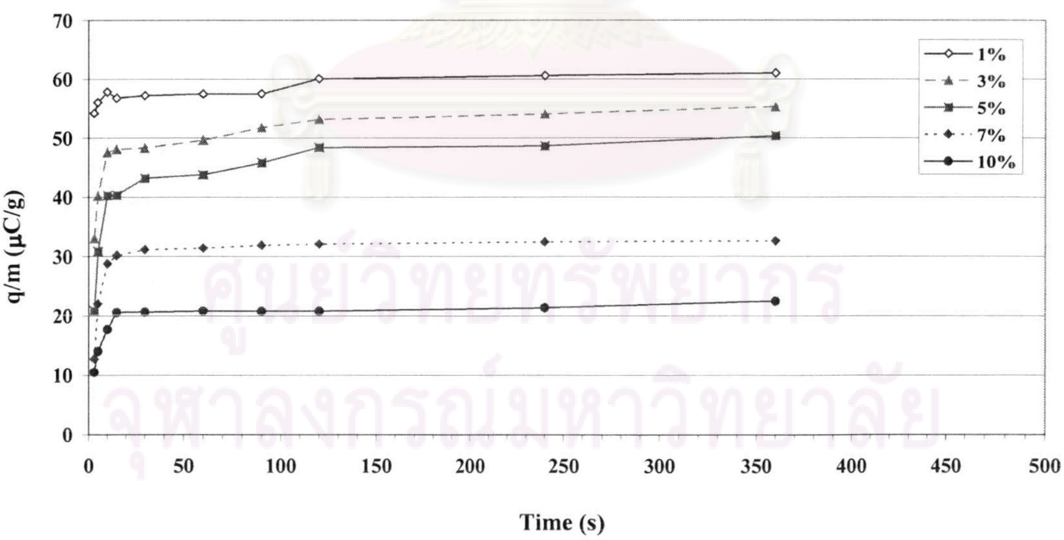


Figure 4-6 Dependence of q/m on developing time for yellow toner and TSV-200 at 800 rpm by blow-off method

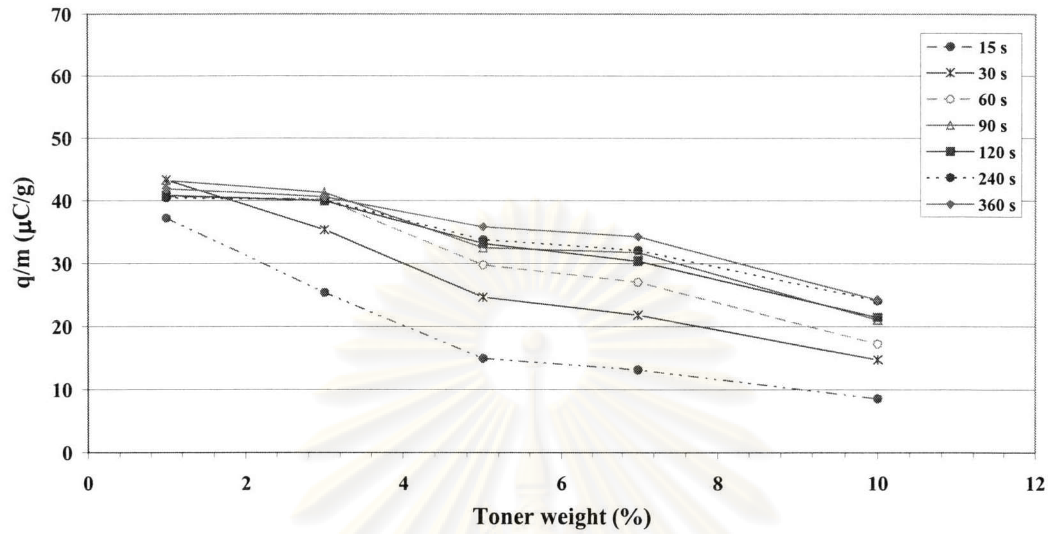


Figure 4-7 Dependence of q/m values on the toner concentration of the black toner at the different rotating times by blow-off method

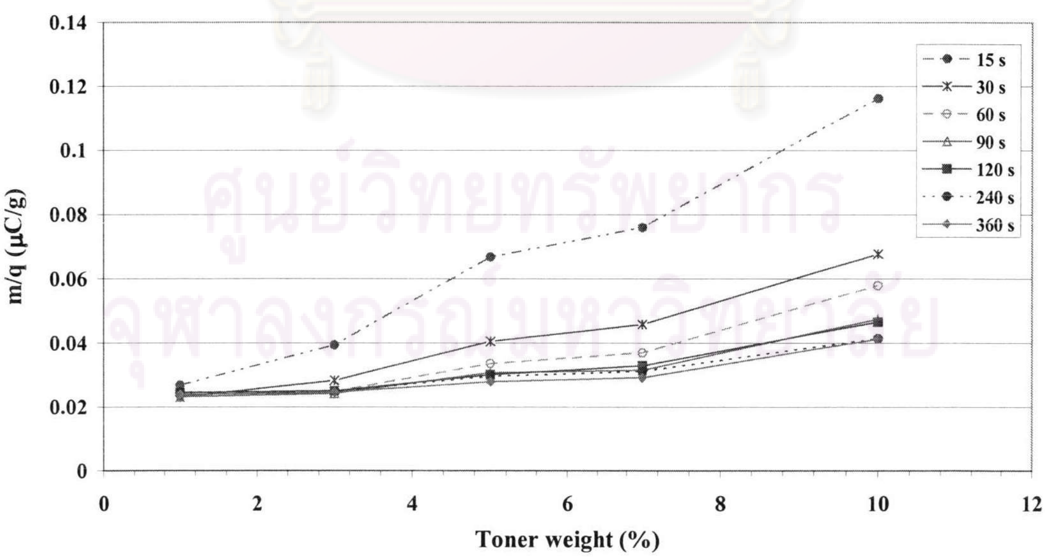


Figure 4-8 Dependence of m/q values on the toner concentration of the black toner at the different rotating times by blow-off method

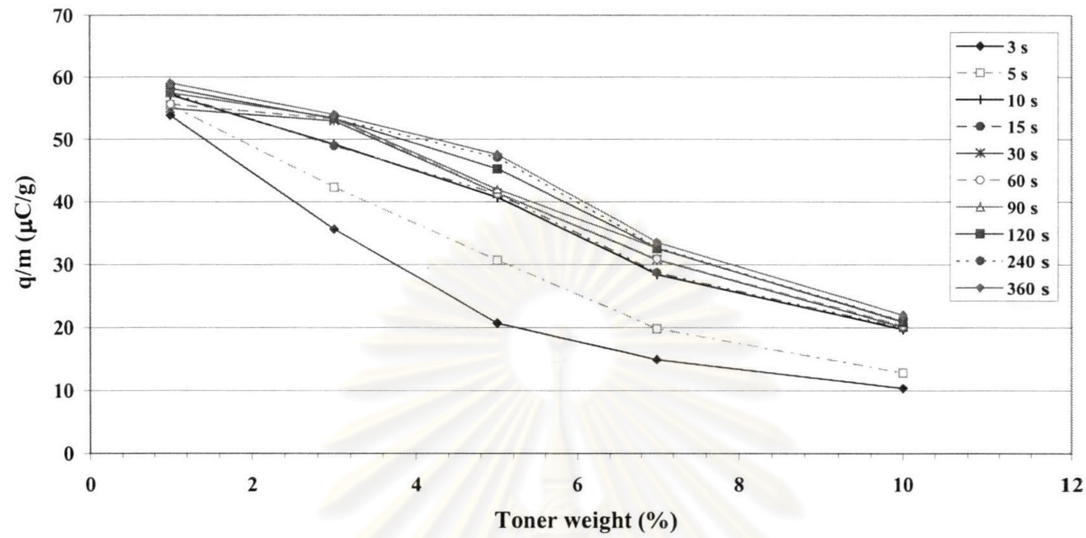


Figure 4-9 Dependence of q/m values on the toner concentration of the cyan toner at the different rotating times by blow-off method

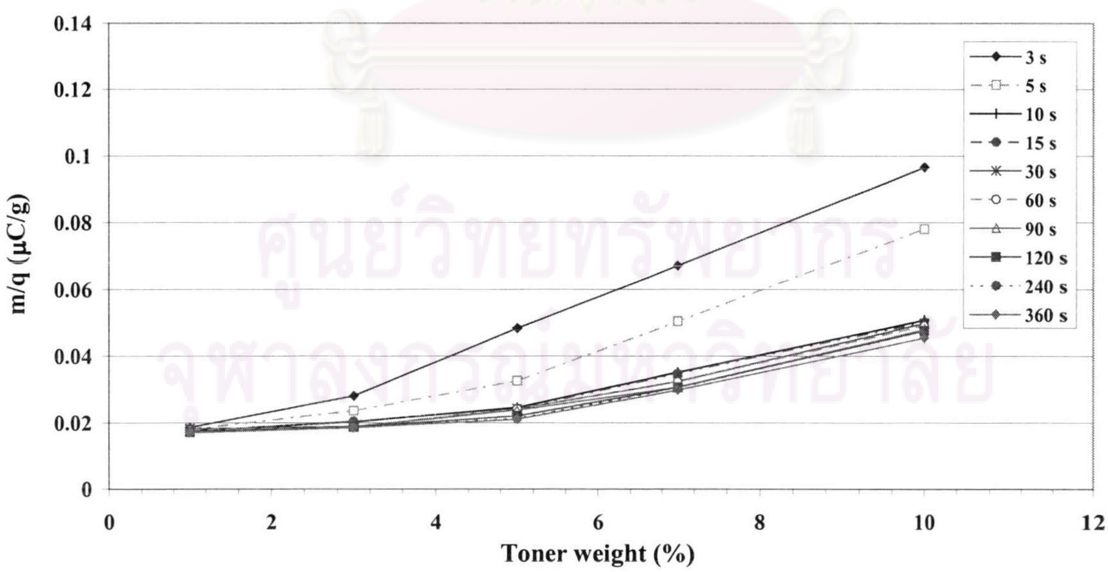


Figure 4-10 Dependence of m/q values on the toner concentration of the cyan toner at the different rotating times by blow-off method

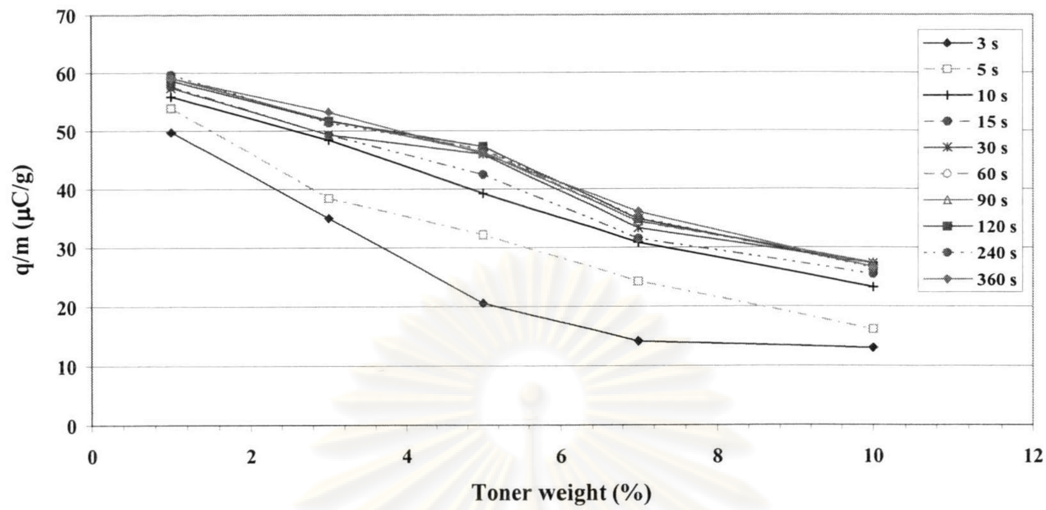


Figure 4-11 Dependence of q/m values on the toner concentration of the magenta toner at the different rotating times by blow-off method

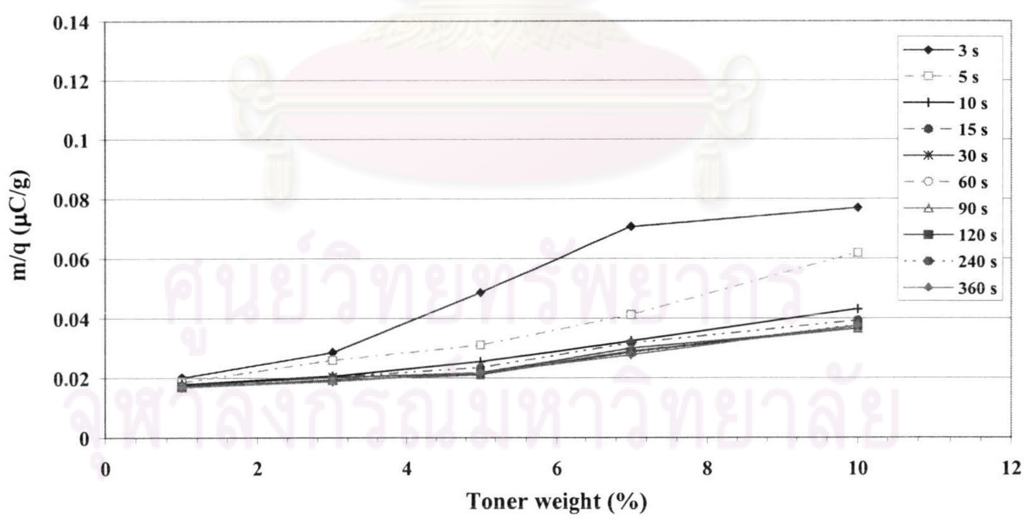


Figure 4-12 Dependence of m/q values on the toner concentration of the magenta toner at the different rotating times by blow-off method

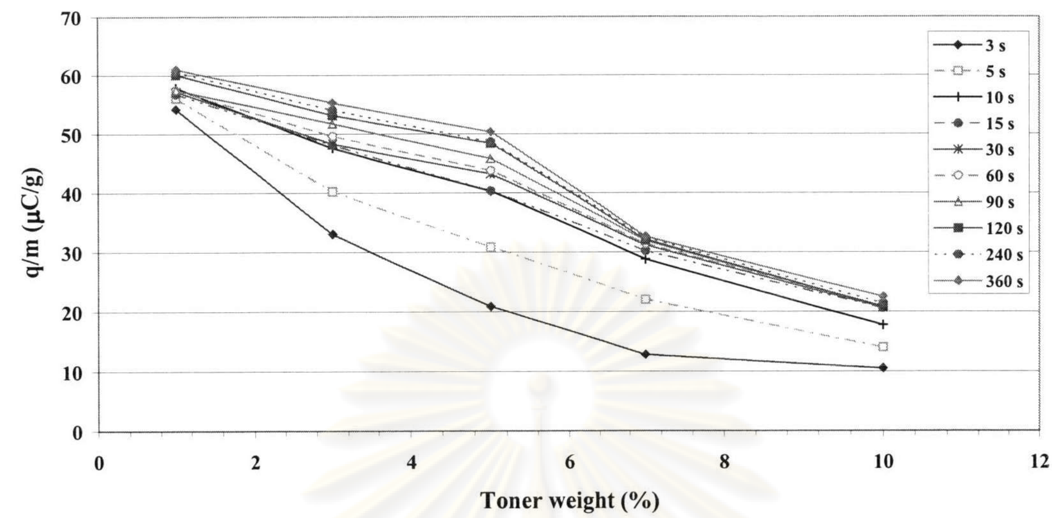


Figure 4-13 Dependence of q/m values on the toner concentration of the yellow toner at the different rotating times by blow-off method

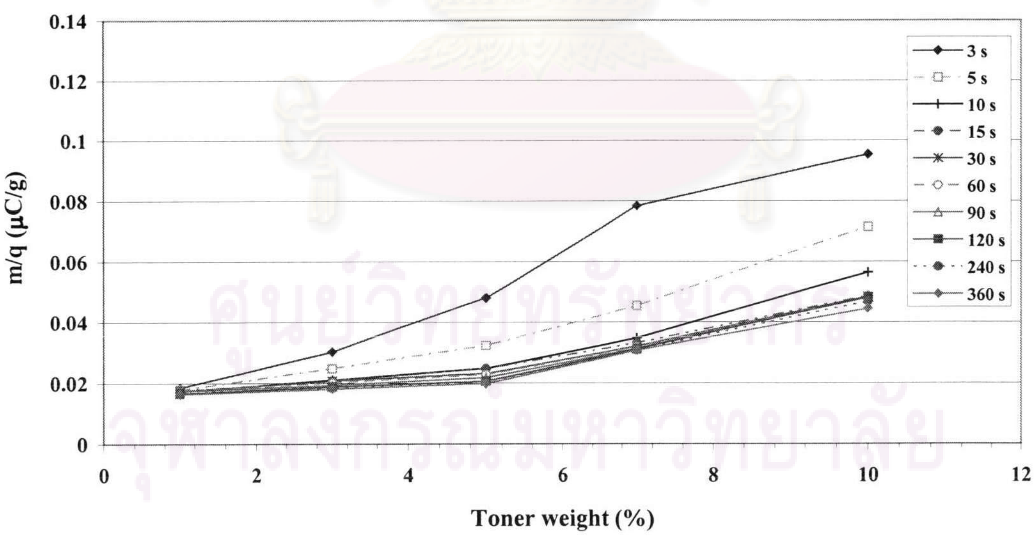


Figure 4-14 Dependence of m/q values on the toner concentration of the yellow toner at the different rotating times by blow-off method

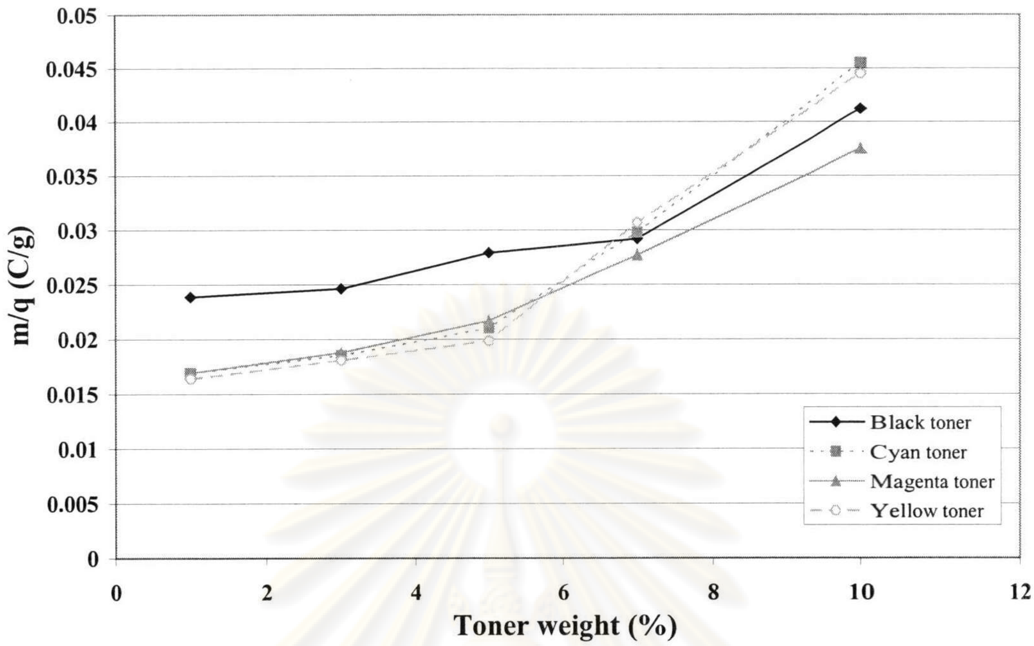


Figure 4-15 Dependence of m/q values on the toner concentration of the different types of toner at 360 seconds by blow-off method

4.2.2 Toner charge dependence on carrier types

The black toner was mixed with each type of the carrier (F-150, TSV-200 and Z-250 carriers) at 5 wt% of the toner based on the total weight at the rotating speed of 800 rpm in Minishaker and the rotating times of 15, 30, 60, 90, 120, 240 and 360 seconds. Figure 4-16 shows the q/m values of three types of carrier. The q/m value of Z-250 is highest and that of F-150 is lowest, however, the q/m value of Z-250 is slightly higher than the q/m value of TSV-200. All curves have the similar trend of toner charges in Z-250 carrier, and the q/m curves of the TSV-200 carrier change increase rapidly when the rotating time of the developer was continued from 15 to 90 seconds while the toner charges for F-150 carrier increased when the rotating time of the developer was continued from 15 to 120 seconds. After that, the q/m values changed slowly and became steady. Table 4-1 shows that the elements of F-150 carrier are mostly consisted of Fe (65.9%), Zn (18%) and Cu (15.7%), while only Fe is mainly or principally (up to 99.6%) found in TSV-200 and Z-250 carriers.

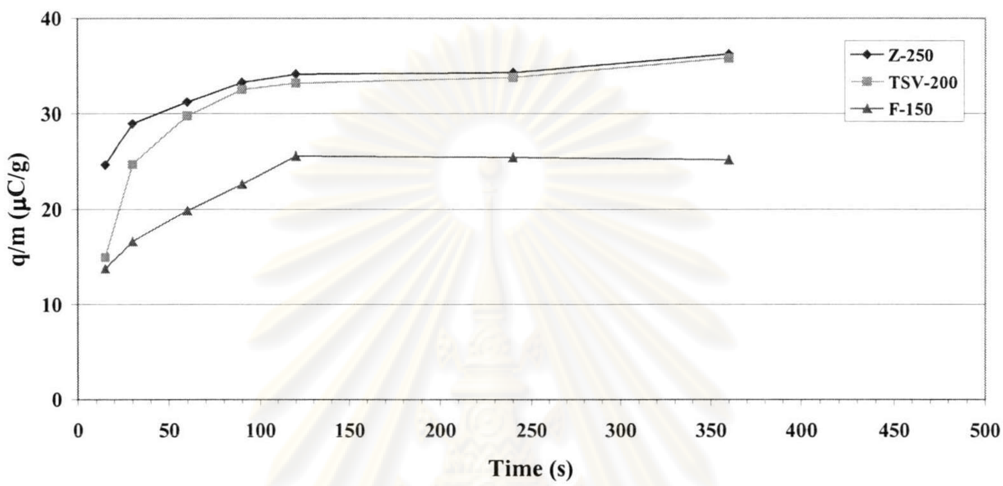


Figure 4-16 Dependence of q/m on developing time for black toner and Z-250, TSV-200 and F-150 at 800 rpm by blow-off method

The q/m value resulting for the developing of the black toner and Z-250 carrier is higher than those of TSV-200 and F-150 carrier. It is explained that charges transferred to polymers in contact with metals depend upon the relative work functions of the contacting materials [21]. Since TSV-200 and Z-250 carriers are consisted of Fe (99.7 and 99.5%) only, which have the high work function than that of F-150 which is consisted of Fe (65.9%), Zn (18%) and Cu (15.7%). Therefore, the Z-250 and TSV-200 carriers give the higher q/m values than F-150 carrier. At the beginning time (15 to 60 seconds), the q/m values of black toner and Z-250 carrier are higher than TSV-200. Difference in shape is responsible for the varied q/m values.

Table 4-1 The elemental components of the carriers

Type of element	Concentration of element in carrier, %		
	F-150	TSV-200	Z-250
Fe	65.894	99.673	99.506
Zn	17.966	-	-
Cu	15.684	-	-
Mn	0.286	0.046	0.047
V	-	0.048	0.045
Ti	-	0.058	0.07
Si	0.034	0.057	0.09
S	-	-	0.011
Ca	0.036	0.076	0.063
Mg	-	-	0.107
Al	0.033	0.041	0.062
Cr	0.043	-	-
P	0.025	-	-
Total	100	100	100

4.2.3 Toner charge dependence on mixing method

The black toner was mixed with each type of carrier (F-150, TSV-200 and Z-250 carrier) by vertical rotating and horizontal rotating. Figures 4-17 and 4-18 show the relationship between the q/m values and the rotating times of black toner and TSV-200 carrier at 1, 3, 5, 7 and 10 wt% of the toner based on the total weight and the rotating speed of 800 and 120 rpm, respectively. The q/m values of each mixing method show the similar tendency as mentioned in Section 4.2.1, i.e. the q/m values decreased when the toner concentrations increased.

Figures 4-19 and 4-20 display the relationship between the q/m values and the rotating times of the black toner with each type of the carrier at 5 wt% of the toner based on the total weight and the rotating speed of 800 and 120 rpm, respectively. The q/m values of each mixing method show the similar tendency as mentioned in Section 4.2.2.

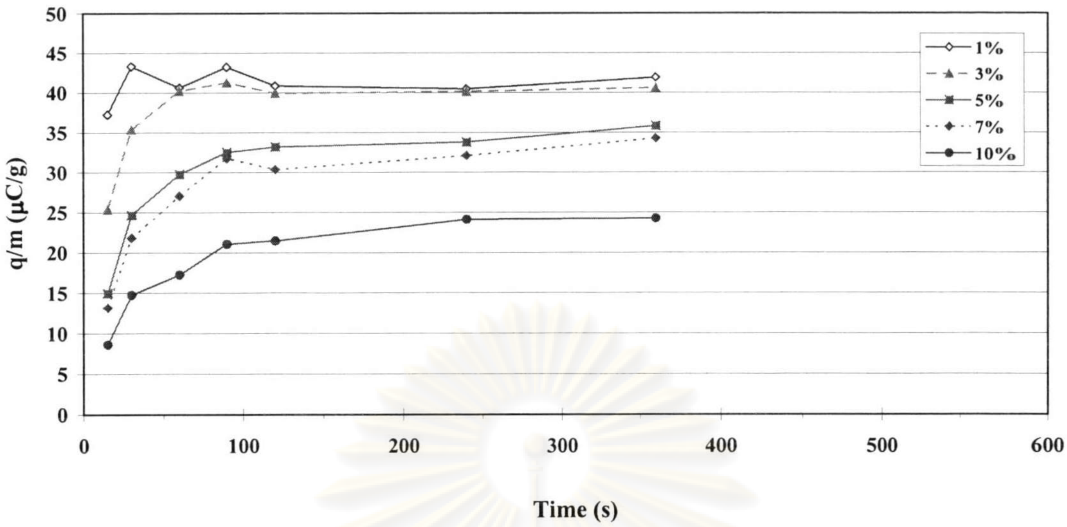


Figure 4-17 Dependence of q/m on developing time for black toner and TSV-200 at 800 rpm

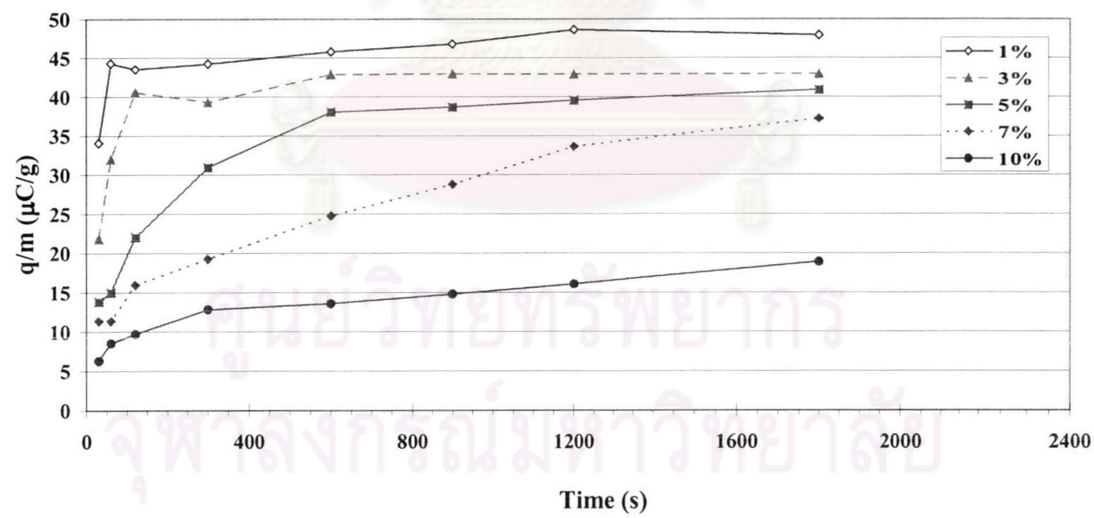


Figure 4-18 Dependence of q/m on developing time for black toner and TSV-200 at 120 rpm

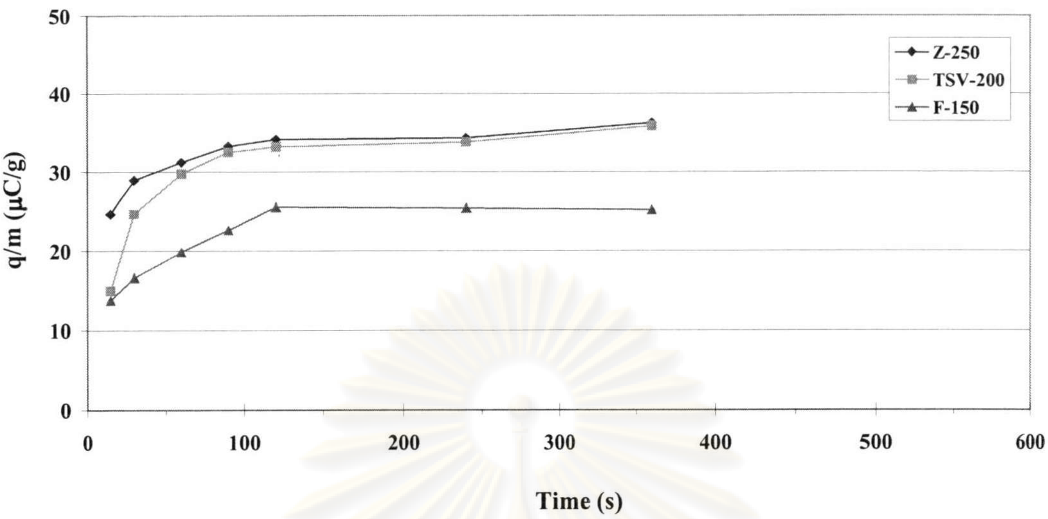


Figure 4-19 Dependence of q/m on developing time for black toner and Z-250, TSV-200 and F-150 at 800 rpm

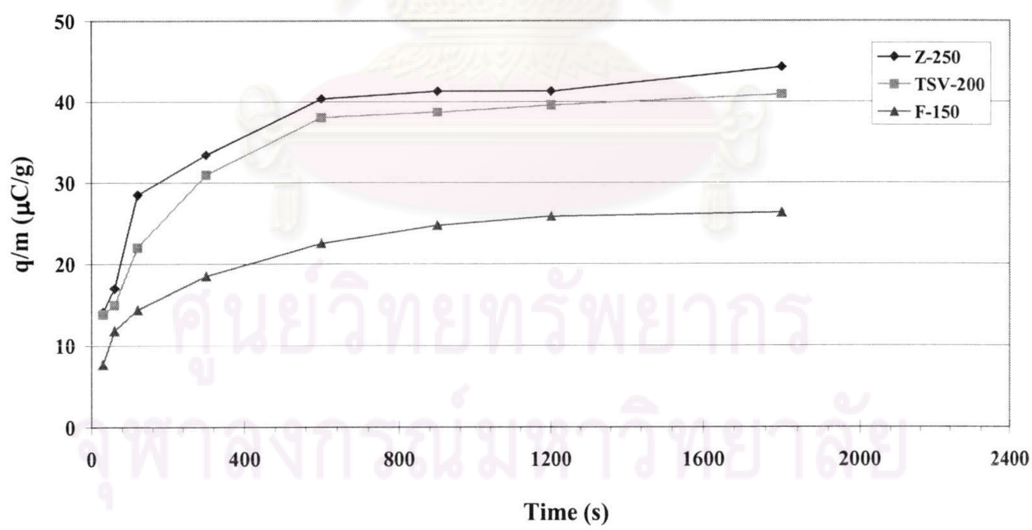


Figure 4-20 Dependence of q/m on developing time for black toner and Z-250, TSV-200 and F-150 at 120 rpm

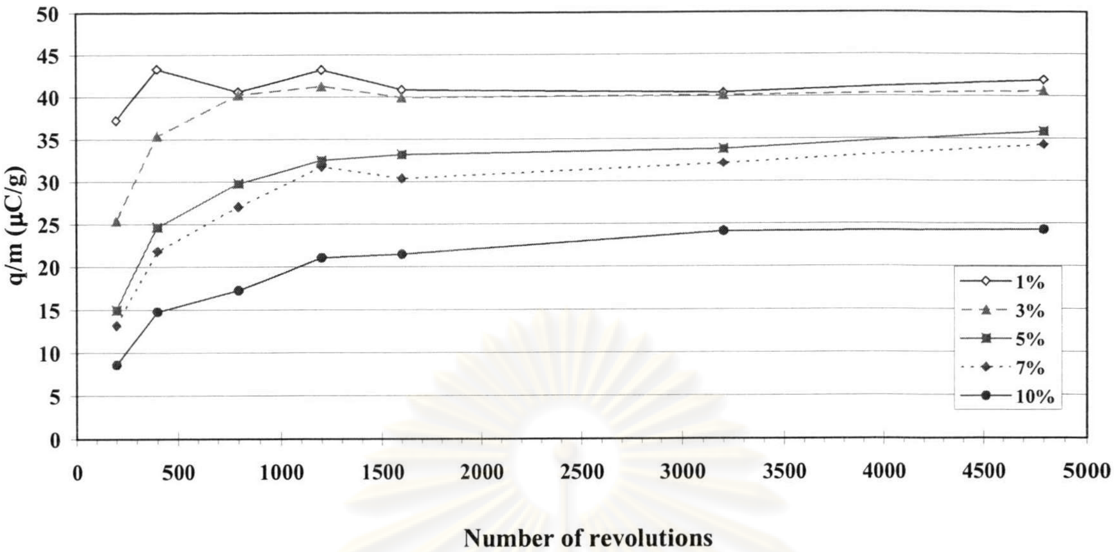


Figure 4-21 Dependence of q/m on rotating speed for black toner and TSV-200 at 800 rpm

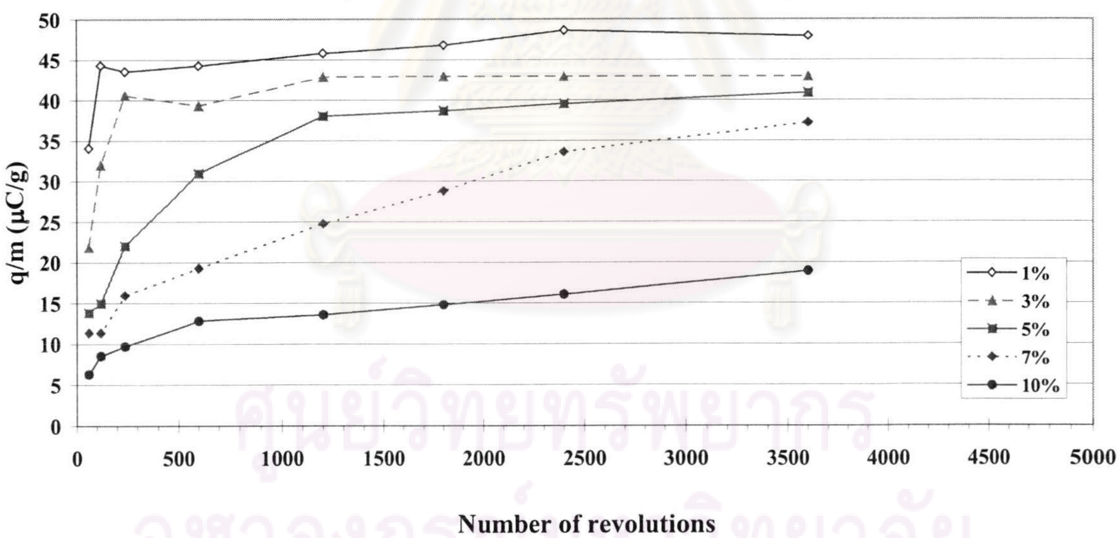


Figure 4-22 Dependence of q/m on rotating speed for black toner and TSV-200 at 120 rpm

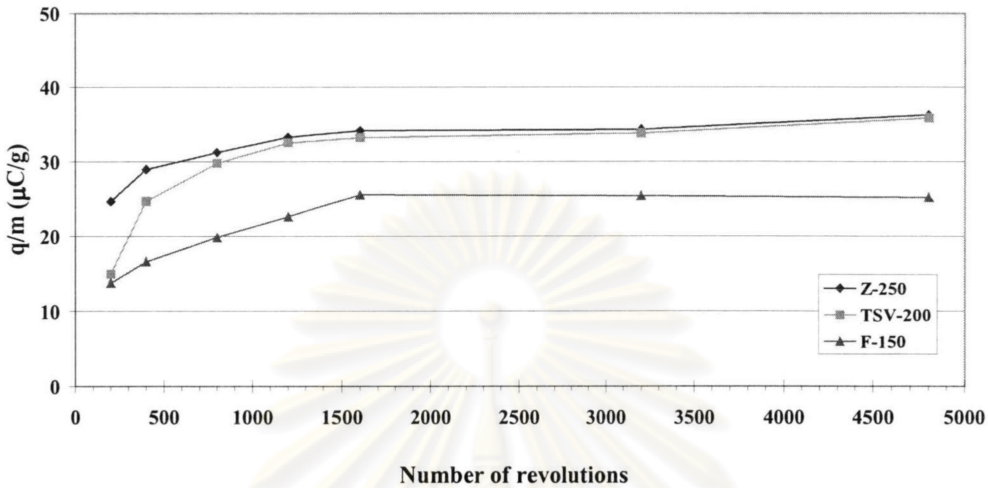


Figure 4-23 Dependence of q/m on rotating speed for black toner and Z-250, TSV-200 and F-150 at 800 rpm

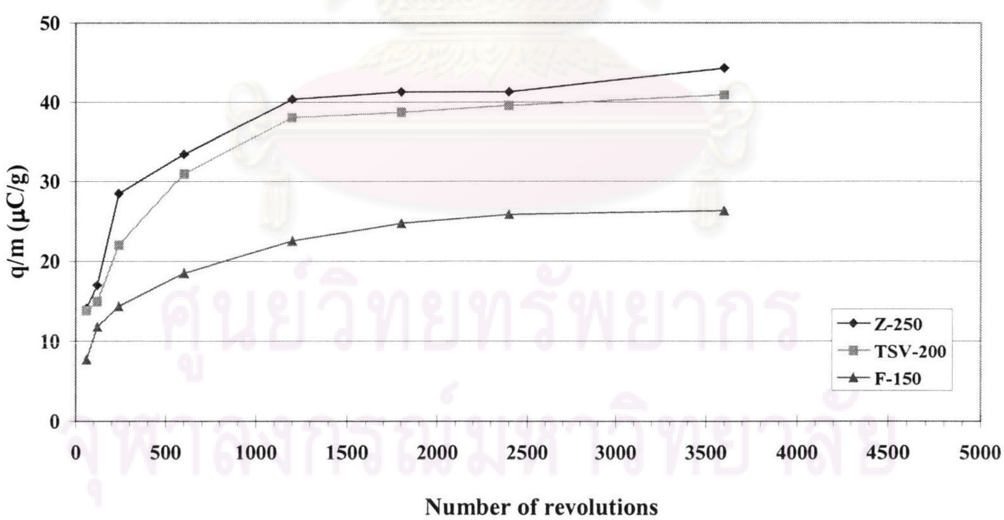


Figure 4-24 Dependence of q/m on rotating speed for black toner and Z-250, TSV-200 and F-150 at 120 rpm

Figures 4-21 and 4-22 show the relationship between the q/m values and the number of revolutions of black toner and TSV-200 carrier at 1, 3, 5, 7 and 10 wt% of the toner based on the total weight and the rotating speed of 800 and 120 rpm, respectively. The q/m values of vertical mixing method with 800 rpm are higher than the q/m values of horizontal mixing method with 120 rpm but become lower at the lower concentration, i.e. at 1 and 3 wt% of the toner based on the total weight. It is explained that the higher the mixing force, the greater the toner rubbing and collision. The toner charge increases with the mixing force and saturates to a certain value. The force between toner and carrier may be divided into three regions: elastic, plastic and destructive. In the elastic region, the contact area increases with the increase of force, so the q/m value increases [24].

Besides the main factor of the horizontal and vertical rotating, the gravity force is another important factor. As the bottle rotates the mix rides up one side and then falls back through the center of rotation creating a cascading effect with resultant collisions of developer as shown in Figure 4-25. The developer (toner and carrier) has the different densities. The toner is consisted of polymer while the carrier is consisted of metal. The carrier is fallen faster than the toner, the less the toner rubbing and collision. So, the q/m values of horizontal mixing method with 120 rpm are lower than the q/m values of vertical mixing method with 800 rpm. However, the q/m values are inverse at the lower concentration, i.e. at 1 and 3 wt% of the toner based on the total weight because the q/m values are mostly generated by rubbing between carrier and toner particles.

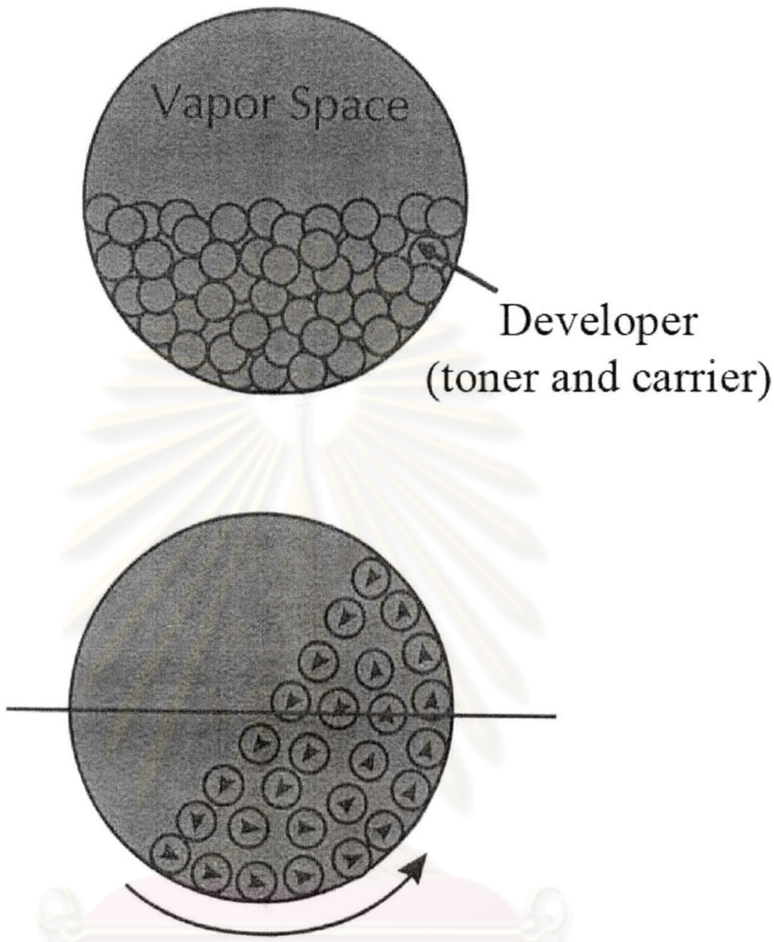


Figure 4-25 The model of horizontal mixing

Figures 4-23 and 4-24 show the relationship between the q/m values and the number of revolutions of the black toner with each type of the carrier at 5 wt% of the toner based on the total weight and the rotating speed of 800 and 120 rpm, respectively. The q/m values of each mixing method show the similar tendency as Figure 4-21 and 4-22 at 5 wt% of the toner based on the total weight.

Comparing between the vertical and horizontal mixing methods, initially, the q/m values of the vertical mixing method are higher than the q/m values of horizontal mixing method but become lower at the equilibrium state. When the mixture of toner and carrier are mixed by vertical mixing method that is vertically rotated with eccentricity. This eccentricity induces the developer powder to scatter upward from the bottom of the glass cell. At an initial state, the diffusive action induces the greater diffusion of the particles, the higher rubbing opportunities between the toner and the carrier particles occur. However, the diffusion of the particles is limited by the flinging and slipping toward the glass wall. This occurrence is reasonably assumed to decreasing the charging sites between the toner and the carrier particles. While, the mixture of toner and carrier are mixed by horizontal mixing method that the particles tumbling down the surface toward the bottom of the glass cell cause the diffusive action to occur. This action enhancing the particle diffusion and scattering of the separate particles results in redistribution [25].

From the previous discussion, the q/m values of vertical mixing method with 800 rpm are higher than the q/m values of horizontal mixing method with 120 rpm but become lower at the lower concentration, i.e. at 1 wt% of toner based on total weight. In the powder transporting process, the powder is charged both by interparticle collisions and collisions against the wall material of the transporting pipe. At the lower concentration, there are many more contact areas between toner and carrier in the horizontal mixing method than the vertical mixing method. While, the diffusion of the particles in the vertical mixing method is limited by the flinging and slipping toward the glass wall. The q/m values of horizontal mixing method are therefore higher than the q/m values of the vertical mixing method at the lower concentration.

4.3 Measurement of charge properties by the E-SPART analyzer

4.3.1 Toner charge dependence on toner concentration (wt%)

Various concentrations of 1, 3, 5, 7 and 10 wt% black toner were mixed with TSV-200 carrier and were each rotated at the rotating speed of 800 rpm in Minishaker for 4 minutes (240 seconds). Figure 4-26 shows that the toner charge is decreased when the toner weight is increased.

Figure 4-27 displays the curves of q/m values of the developer (black toner and TSV-200 carrier) and the toner weight (wt%) at 1, 3, 5, 7 and 10 wt% at the rotating speed of 120 rpm by a horizontal mixing machine for 10 minutes. The toner charge and concentration relationship is the same as that of Figure 4-26.

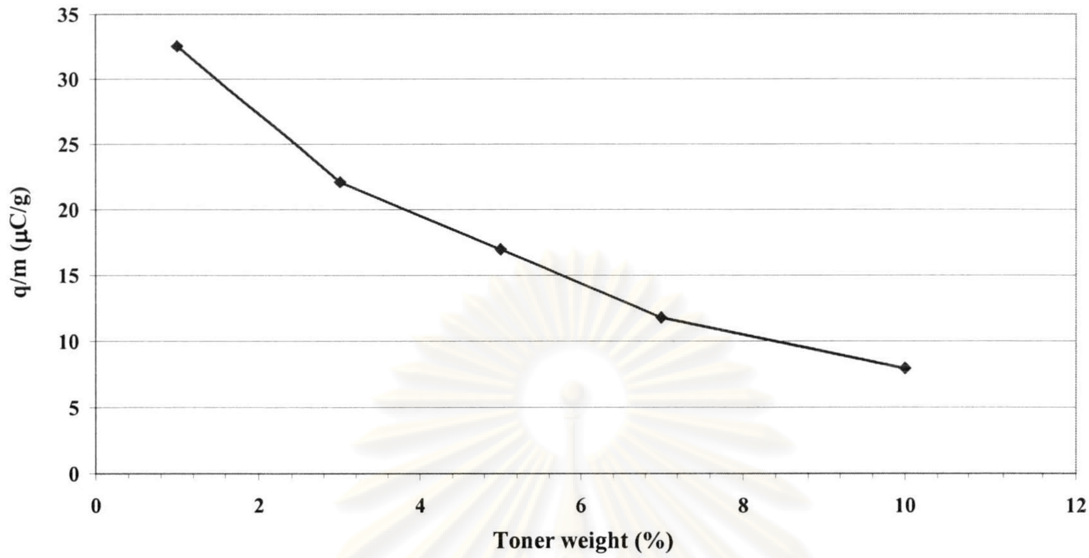


Figure 4-26 Dependence of q/m on developing time for black toner and TSV-200 at 800 rpm by E-SPART analyzer

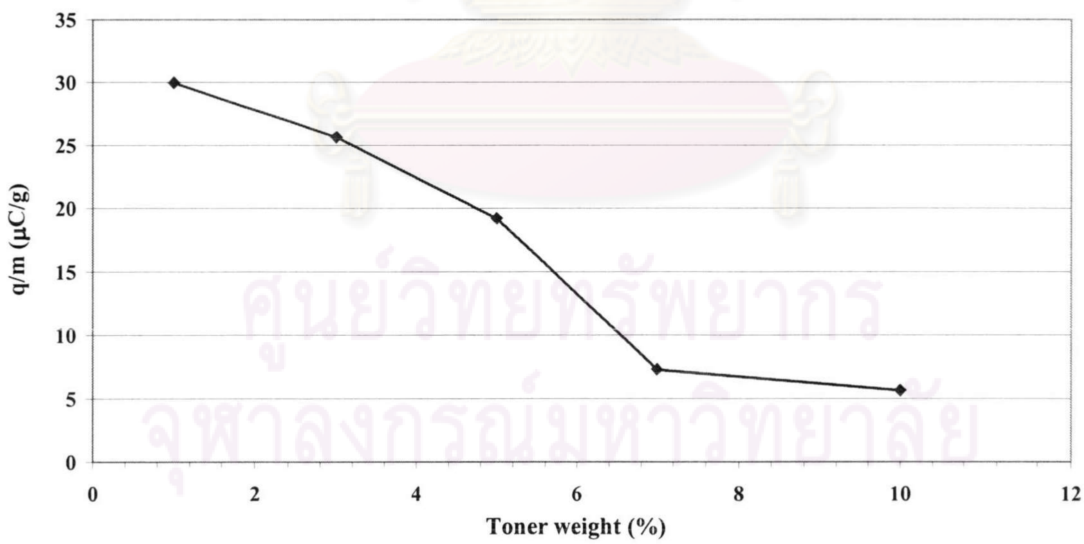


Figure 4-27 Dependence of q/m on developing time for black toner and TSV-200 at 120 rpm by E-SPART analyzer

Table 4-2 The q/d values of various concentrations of the black toner at the rotating speed of 800 rpm in a Minishaker for 4 minutes (240 seconds)

Number of measurement	Amount of black toner (wt%)									
	1		3		5		7		10	
	q/d	std dev.	q/d	std dev.	q/d	std dev.	q/d	std dev.	q/d	std dev.
1	-7.26	3.39	-3.91	3.42	-3.73	2.80	-1.82	1.75	-1.47	1.22
2	-6.74	3.57	-5.25	3.49	-2.44	2.47	-1.99	1.78	-1.69	1.41
3	-6.21	4.24	-4.01	3.66	-3.27	2.83	-2.24	1.82	-1.34	1.17
average	-6.74	3.74	-4.39	3.52	-3.15	2.70	-2.02	1.78	-1.50	1.27

Table 4-3 The q/d values of various concentrations of the black toner at the rotating speed of 120 rpm with horizontal mixing machine for 10 minutes (600 seconds)

Number of measurement	Amount of black toner (wt%)									
	1		3		5		7		10	
	q/d	std dev.	q/d	std dev.	q/d	std dev.	q/d	std dev.	q/d	std dev.
1	-5.93	2.73	-5.08	3.52	-3.43	2.51	-1.56	1.17	-0.98	0.68
2	-6.12	2.95	-4.61	3.30	-3.05	2.03	-1.19	1.04	-0.93	0.70
3	-5.80	2.96	-4.12	3.47	-3.14	2.25	-1.24	1.02	-1.22	1.00
average	-5.95	2.88	-4.60	3.43	-3.21	2.26	-1.33	1.08	-1.04	0.80

Tables 4-2 to 4-3 show that their q/d values are negative similar to the result for the q/m measurement. The q/d values also decreased when the toner concentrations were increased in the toner concentration range from 1 to 10 wt%. Figures 4-28 to 4-37 are the q/d chart of black toner and TSV-200 at various concentrations at the rotating speed of 800 and 120 rpm, respectively. They show that the toner charge values were negative charges than the positive charges to result in a total negative charge.

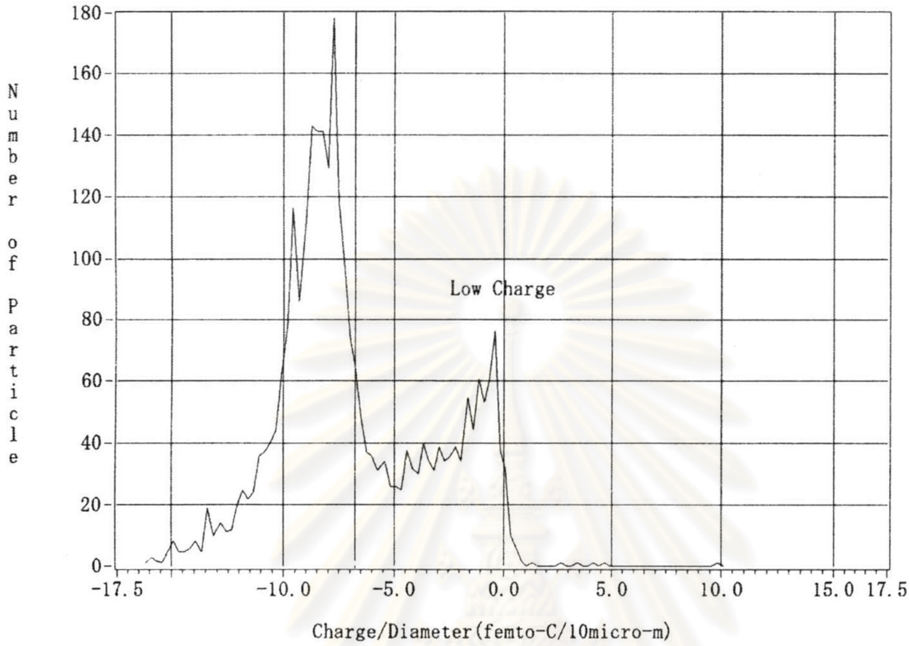


Figure 4-28 The q/d chart of black toner and TSV-200 at 1 wt% of toner at the rotating speed of 800 rpm in a Minishaker

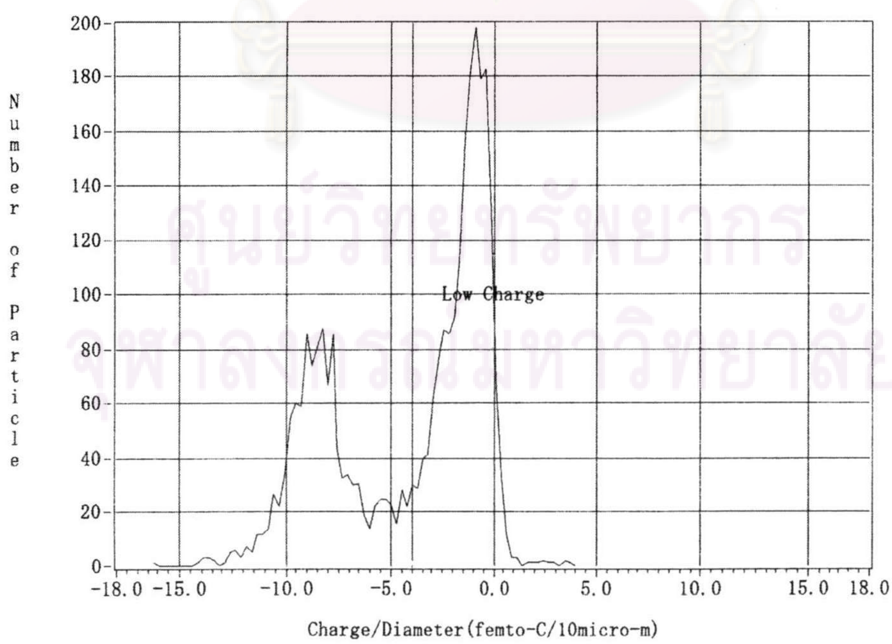


Figure 4-29 The q/d chart of black toner and TSV-200 at 3 wt% of toner at the rotating speed of 800 rpm in a Minishaker

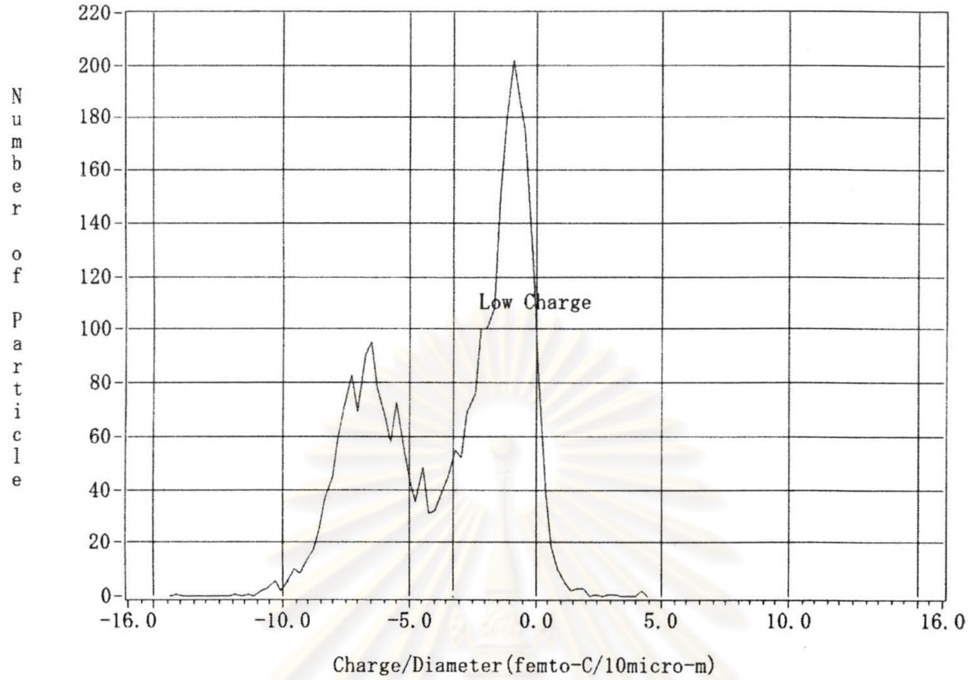


Figure 4-30 The q/d chart of black toner and TSV-200 at 5 wt% of toner at the rotating speed of 800 rpm in a Minishaker

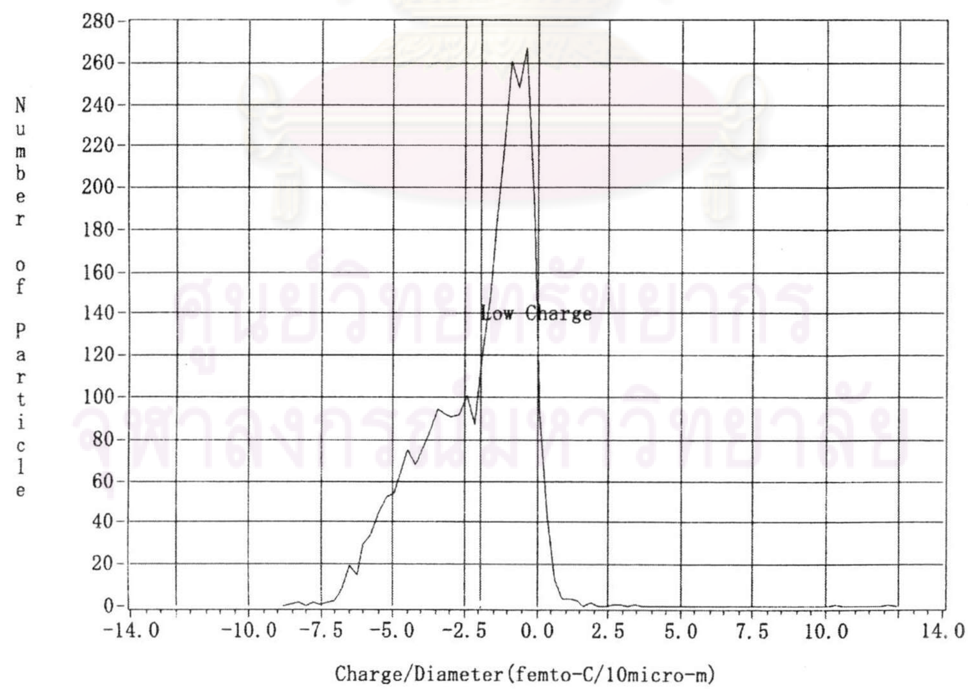


Figure 4-31 The q/d chart of black toner and TSV-200 at 7 wt% of toner at the rotating speed of 800 rpm in a Minishaker

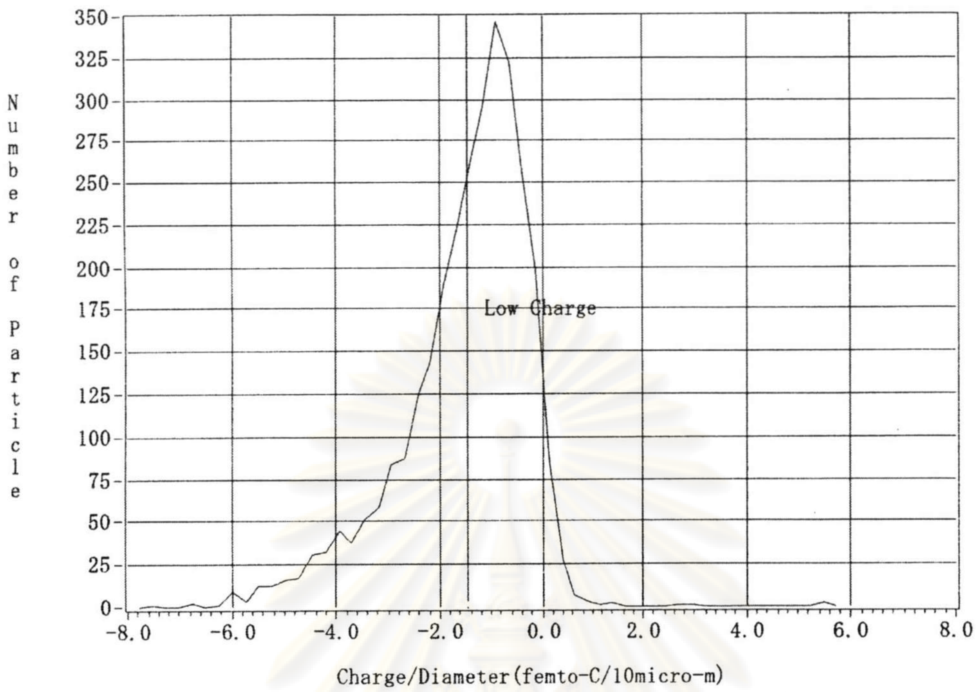


Figure 4-32 The q/d chart of black toner and TSV-200 at 10 wt% of toner at the rotating speed of 800 rpm in a Minishaker

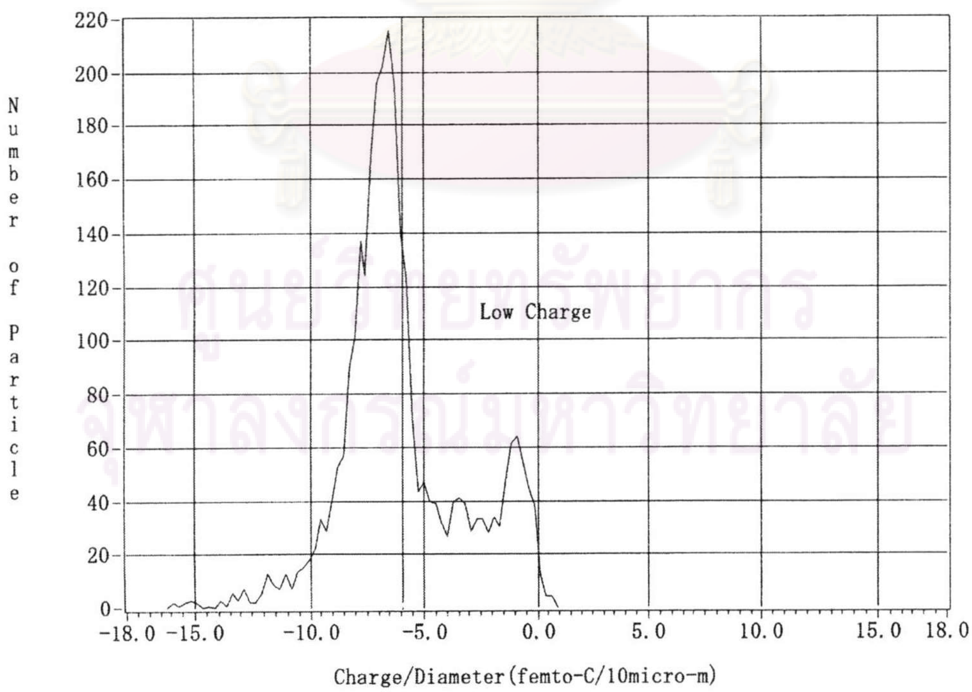


Figure 4-33 The q/d chart of black toner and TSV-200 at 1 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

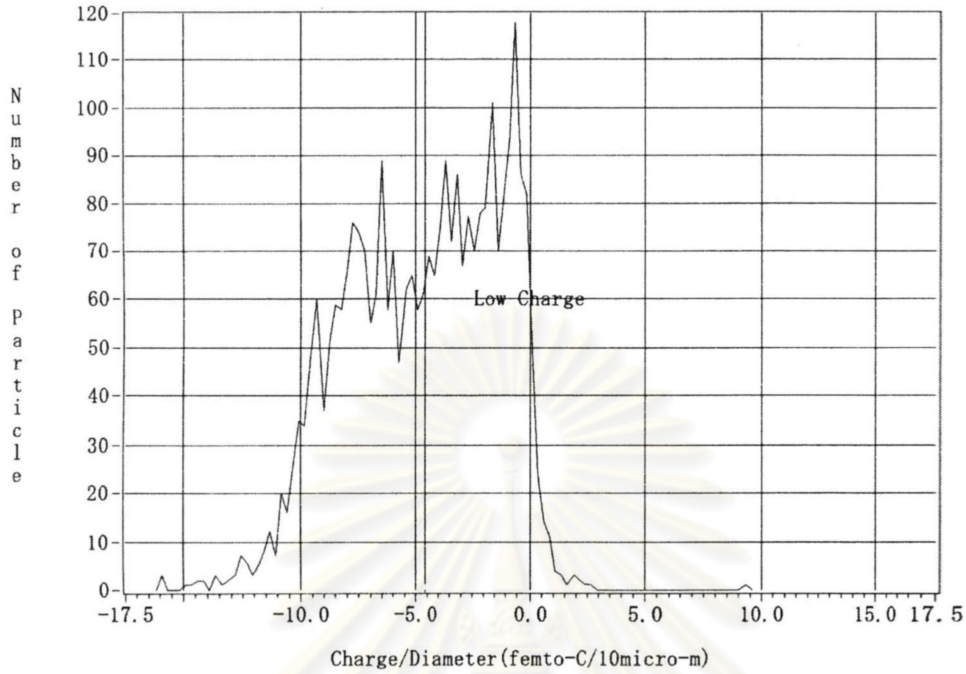


Figure 4-34 The q/d chart of black toner and TSV-200 at 3 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

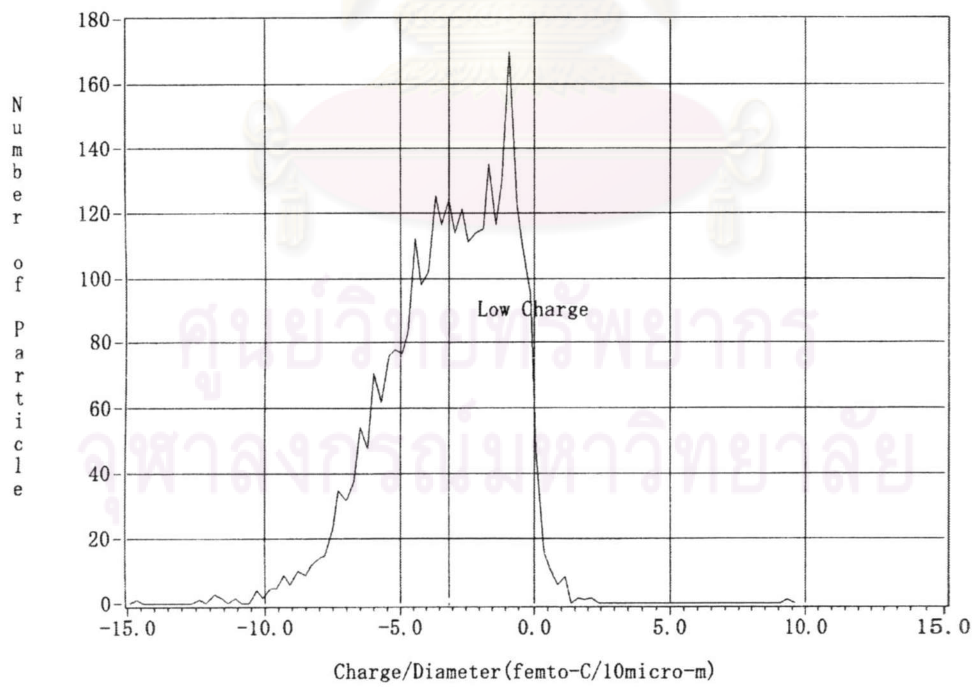


Figure 4-35 The q/d chart of black toner and TSV-200 at 5 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

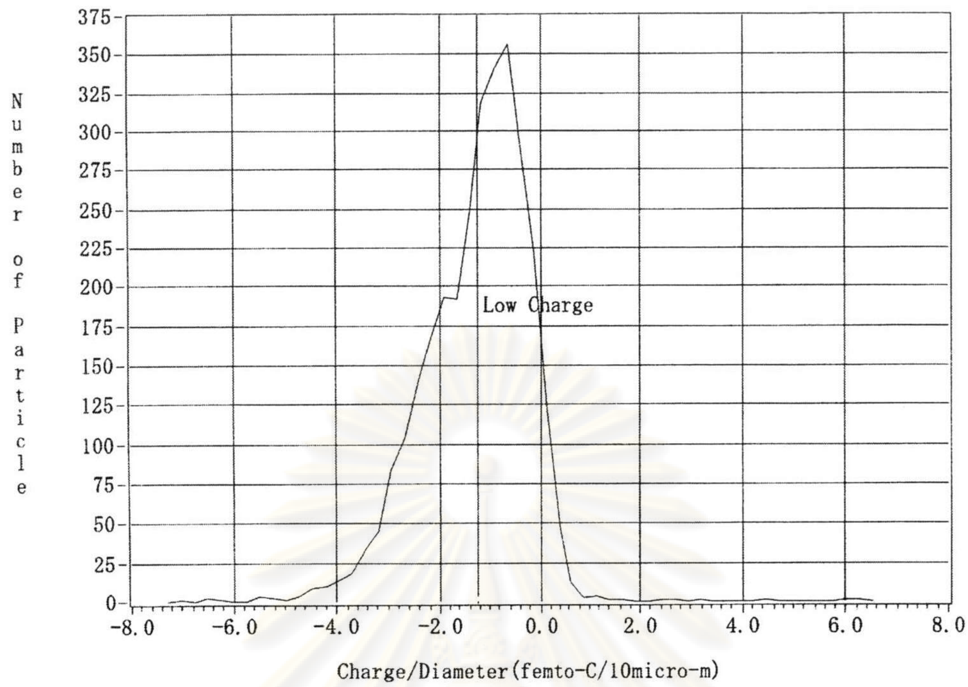


Figure 4-36 The q/d chart of black toner and TSV-200 at 7 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

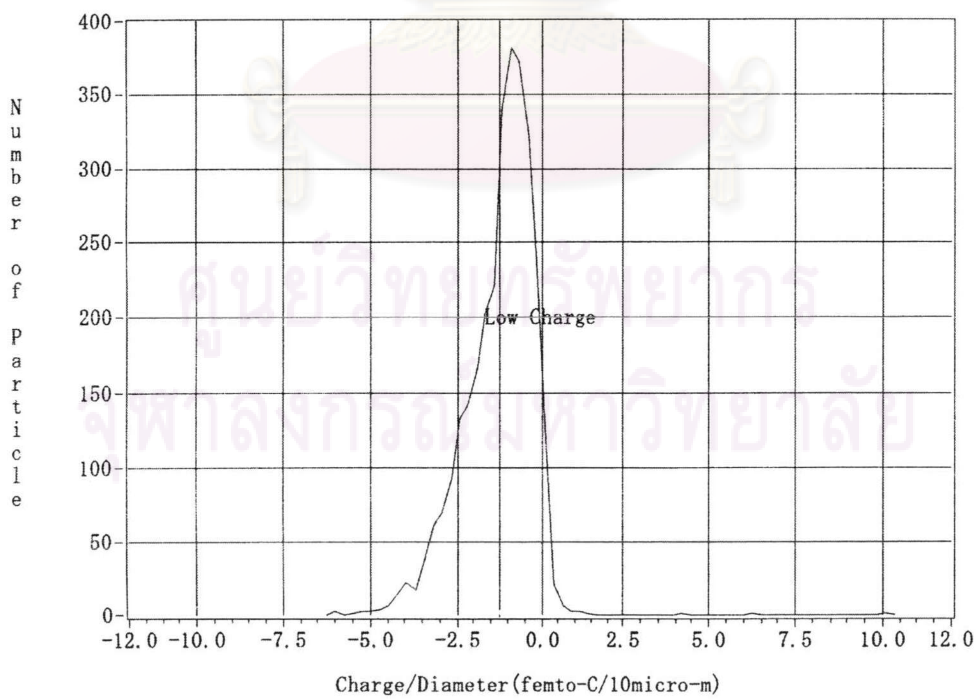


Figure 4-37 The q/d chart of black toner and TSV-200 at 10 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

4.3.2 Toner charge dependence on carrier types

Table 4-4 Effect of carrier type on toner charging

Mixing method	Carrier					
	F-150		TSV-200		Z-250	
	q/m	Std dev.	q/m	Std dev.	q/m	Std dev.
Vertical mixing*	9.20	6.92	16.96	15.65	18.99	16.22
Horizontal mixing**	9.20	6.36	19.90	15.50	24.99	14.71

* The rotating speed of 800 rpm for 4 minutes

** The rotating speed of 120 rpm for 10 minutes

Table 4-4 shows the dependence of q/m on carrier types under the condition as mentioned above. The q/m value of Z-250 is the highest but that of the F-150 carrier is the lowest for both rotating speeds. Its result can be explained similarly as those mentioned in Section 4.2.2

Tables 4-5 and 4-6 give q/d values of the developers having three types of carrier mixed at the rotating speed of 800 and 120 rpm, respectively. The charges of all three developers are negative similar to those of q/m values. Regardless of the mixing speed, the q/d value resulting from the carrier Z-250 is the highest whereas that of the carrier F-150 is the lowest.

Table 4-5 The q/d values of the developer with various carriers mixed vertically at the rotating speed of 800 rpm in a Minishaker for 4 minutes (240 seconds)

Number of measurement	Carrier type					
	F-150		TSV-200		Z-250	
	q/d	std dev	q/d	std dev	q/d	std dev
1	-1.62	1.06	-3.73	2.80	-3.71	2.77
2	-1.64	1.07	-2.44	2.47	-3.32	2.85
3	-1.70	1.01	-3.27	2.83	-3.73	2.70
average	-1.65	1.05	-3.15	2.70	-3.59	2.77

Table 4-6 The q/d values of the developer with various carriers mixed horizontally at the rotating speed of 120 rpm for 10 minutes (600 seconds)

Number of measurement	Carrier type					
	F-150		TSV-200		Z-250	
	q/d	std dev	q/d	std dev	q/d	std dev
1	-1.47	0.86	-3.43	2.51	-4.99	2.52
2	-1.57	1.00	-3.05	2.03	-3.99	2.33
3	-1.72	0.98	-3.14	2.25	-4.91	2.38
average	-1.59	0.94	-3.21	2.26	-4.63	2.41

Figures 4-38 to 4-43 are the q/d chart of the developer with various carriers at the rotating speed of 800 and 120 rpm, respectively. They show the toner charge values were negative charges than the positive charges to result in a total charge of negative.

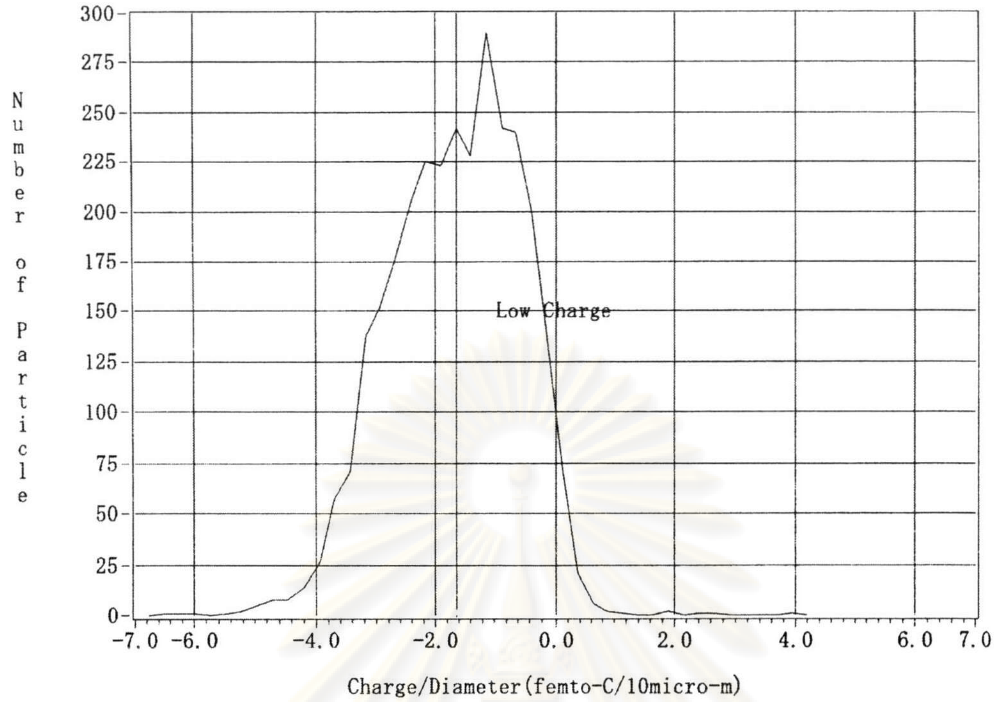


Figure 4-38 The q/d chart of black toner and F-150 at 5 wt% of toner at the rotating speed of 800 rpm in a Minishaker

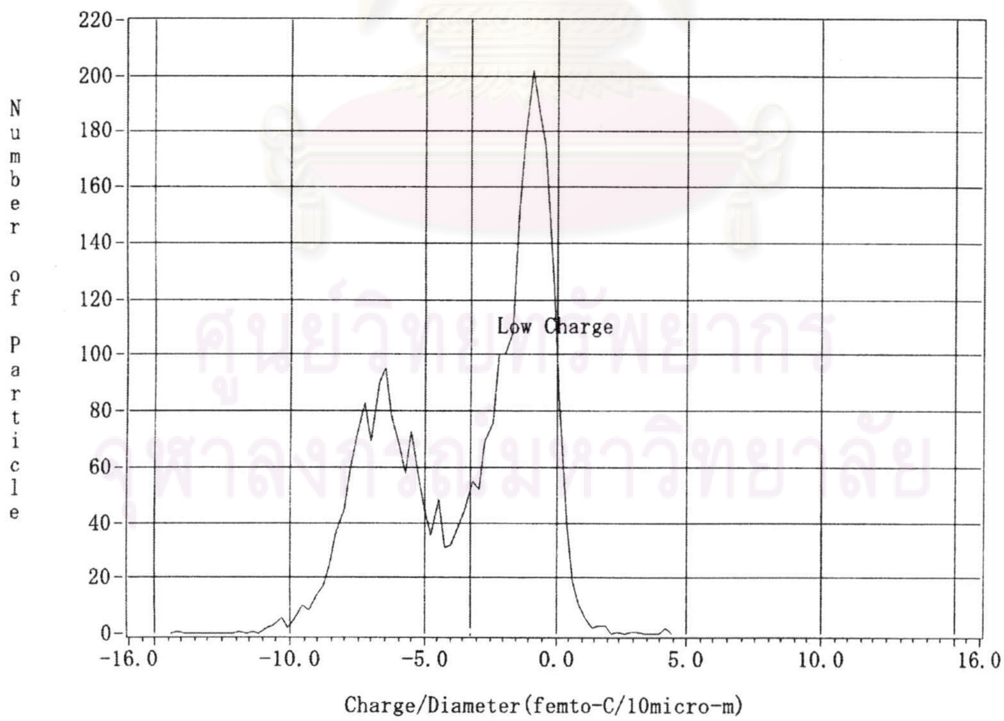


Figure 4-39 The q/d chart of black toner and TSV-200 at 5 wt% of toner at the rotating speed of 800 rpm in a Minishaker

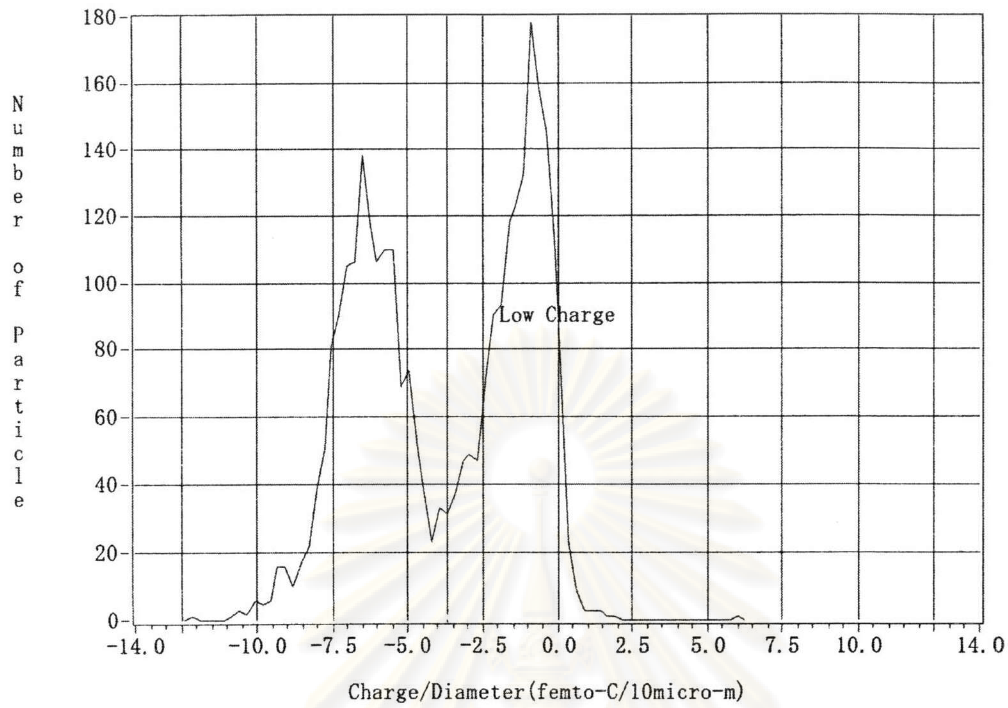


Figure 4-40 The q/d chart of black toner and Z-250 at 5 wt% of toner at the rotating speed of 800 rpm in a Minishaker

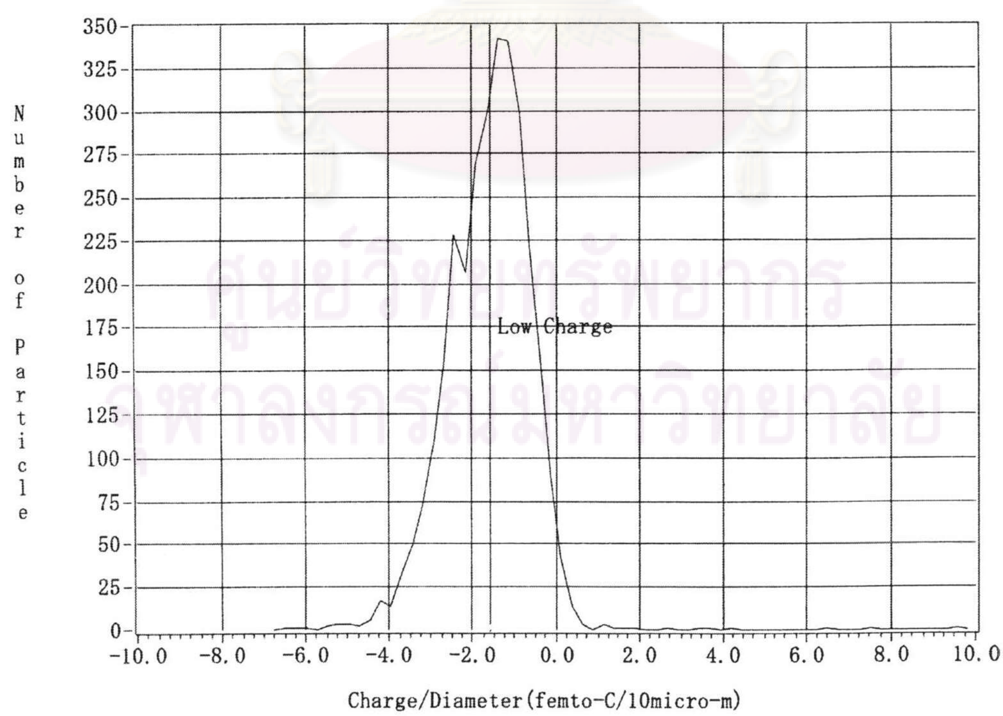


Figure 4-41 The q/d chart of black toner and F-150 at 5 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

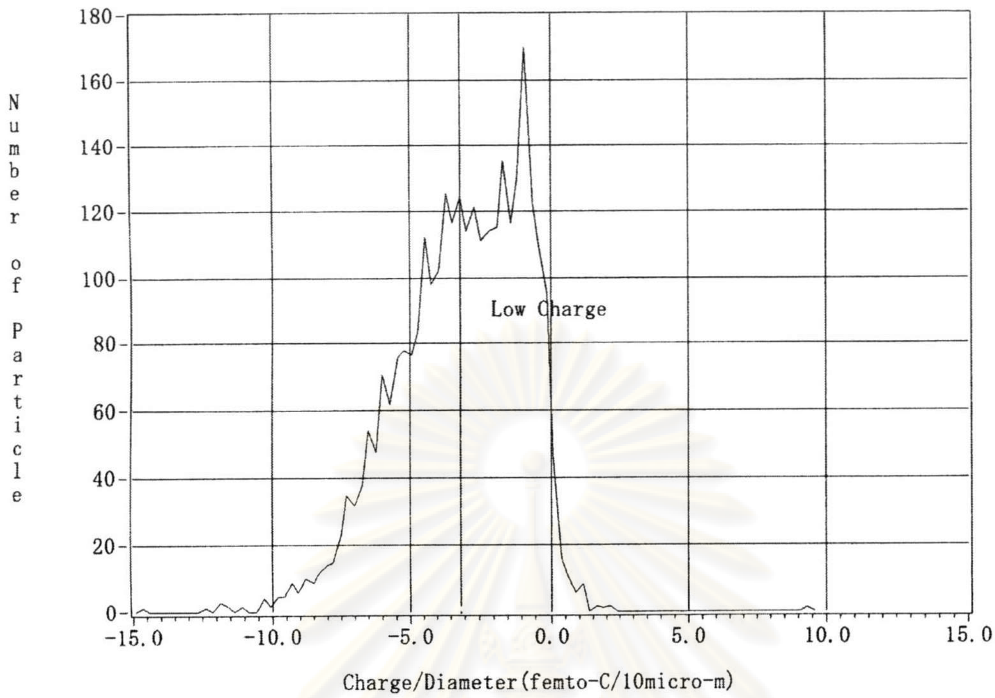


Figure 4-42 The q/d chart of black toner and TSV-200 at 5 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

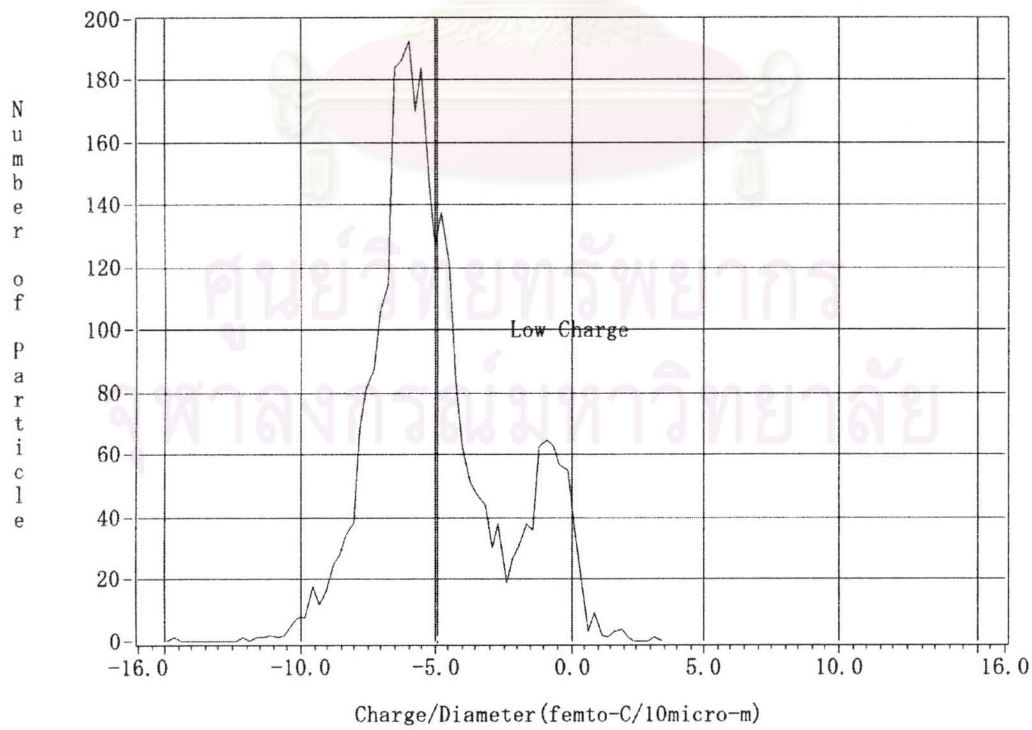


Figure 4-43 The q/d chart of black toner and Z-250 at 5 wt% of toner at the rotating speed of 120 rpm with horizontal mixing machine

4.4 Evaluation of print quality

4.4.1 Description of types of toners

All the toners of black (OKI, Japan), cyan (HP, Japan), magenta (Canon, Japan) and yellow toners (Canon, Japan) are polymerized toner. They were evaluated for their charge measurement, particle size and particle shape, and thermal property of toners. The melting points and glass temperature of the four types of toner have the nearly values as that shown in Table 4-7.

Table 4-7 Thermal property of four types of toners

Toner		Melting point (°C)	Glass transition temperature (°C)
Color	Source		
Black	OKI	71.4	93.8
Cyan	HP	73.5	NA
Magenta	Canon	73.8	NA
Yellow	HP	74.3	NA

Table 4-8 shows the wavenumber of four types of toners, analyzed using Fourier Transform Infrared Spectroscope (FTIR). The absorption bands of C-H stretching of alkene, C-H stretching of alkane, C=O stretching of ester, C=C stretching of aromatic hydrocarbon, C-C(=O)-O stretching of aromatic ester, O-C-C stretching of aromatic ester and C-H bending, suggest that all toners might be aromatic ester which also exhibits crystalline structure as seen earlier (Table 4-7). Since, the melting point and the glass transition temperature were found in the black toner, it indicates the presence of both crystalline and amorphous structures. The advantage of having low melting point is that the toner can fuse at low temperature. The low fusion toner can enhance the quality of line and alphabet and save energy. The spectrums of four types of toners are shown in Appendix D.

Table 4-8 The wavenumber of four types of toners

Type of toner	Wavenumber (cm^{-1})	Assignment
Black	3032	C-H stretching of alkene (sharp, weak)
	2919	C-H stretching of alkane (sharp, weak)
	1736	C=O stretching of ester (sharp, medium)
	1608	C=C stretching of aromatic hydrocarbon (sharp, weak)
	1495	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1454	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1157	C-C(=O)-O stretching of aromatic ester (sharp, weak)
	1034	O-C-C stretching of aromatic ester (sharp, weak)
	763	C-H bending (sharp, medium)
	702	C-H bending (sharp, strong)
Cyan	3027	C-H stretching of alkene (sharp, weak)
	2924	C-H stretching of alkane (sharp, medium)
	1731	C=O stretching of ester (sharp, medium)
	1603	C=C stretching of aromatic hydrocarbon (sharp, weak)
	1495	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1454	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1270	C-C(=O)-O stretching of aromatic ester (sharp, weak)

	1173	C-C(=O)-O stretching of aromatic ester (sharp, weak)
	1116	O-C-C stretching of aromatic ester (sharp, weak)
	1091	O-C-C stretching of aromatic ester (sharp, weak)
	758	C-H bending (sharp, medium)
	730	C-H bending (sharp, strong)
Magenta	3027	C-H stretching of alkene (sharp, weak)
	2919	C-H stretching of alkane (sharp, medium)
	1731	C=O stretching of ester (sharp, medium)
	1603	C=C stretching of aromatic hydrocarbon (sharp, weak)
	1493	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1446	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1342	C-C(=O)-O stretching of aromatic ester (sharp, weak)
	1152	C-C(=O)-O stretching of aromatic ester (sharp, weak)
	763	C-H bending (sharp, medium)
	695	C-H bending (sharp, strong)
Yellow	3032	C-H stretching of alkene (sharp, weak)
	2919	C-H stretching of alkane (sharp, medium)
	1727	C=O stretching of ester (sharp, medium)
	1516	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1493	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1454	C=C stretching of aromatic hydrocarbon (sharp, medium)
	1244	C-C(=O)-O stretching of aromatic ester (sharp, medium)
	1178	C-C(=O)-O stretching of aromatic ester (sharp, medium)
	1155	C-C(=O)-O stretching of aromatic ester (sharp, medium)
	763	C-H bending (sharp, medium)
	699	C-H bending (sharp, strong)

4.4.2 Description of printer type

All the toners of black, cyan, magenta and yellow toners were evaluated for their print qualities by a Canon printer (Canon Laser Shot LBP-2710) that uses the polymerized toner. The print-outs were compared with a Fuji printer (Fuji Xerox Color Laser Wind 3310, model) that uses the pulverized toner.

4.4.3 Solid density and tone reproduction

The solid density and tone reproduction were measured at solid area and percentage halftone area of 0-100, respectively, by a reflection densitometer (RD 915). The solid densities of Canon print-outs and Fuji print-outs are shown in Table 4-8. The solid density of Canon print-outs is lower than those printed by Fuji. In previous research [16], the polymerized toner has the higher solid density than the pulverized toner. In this case, the polymerized toner has the lower solid density than the pulverized toner, besides the polymerized toner's print-outs have the lower gloss than the pulverized toner's print-outs. The solid density depends on gloss of print-out. The print-out has the high gloss, so it has the high density. Moreover, the major attribute to different solid densities is the types of pigments and additives of the toner. We could not get technical information from these two manufacturers.

Table 4-9 The solid densities of Canon print-outs and Fuji print-outs

Type of print-out	Solid densities of toner color			
	Black	Cyan	Magenta	Yellow
Canon	1.43	0.88	1.12	1.54
Fuji	1.70	1.46	1.41	1.00

Figures 4-44 to 4-47 are the curves of tone reproduction of Canon print-outs and Fuji print-outs. Both toners produced equally the same tone reproduction of each color print-out.

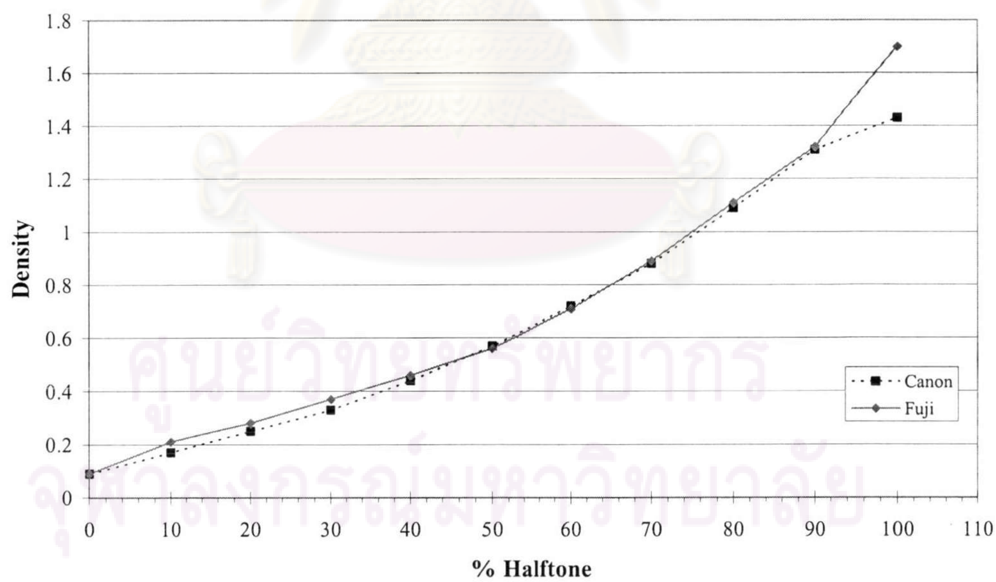


Figure 4-44 Dependence of tone reproduction for black toner

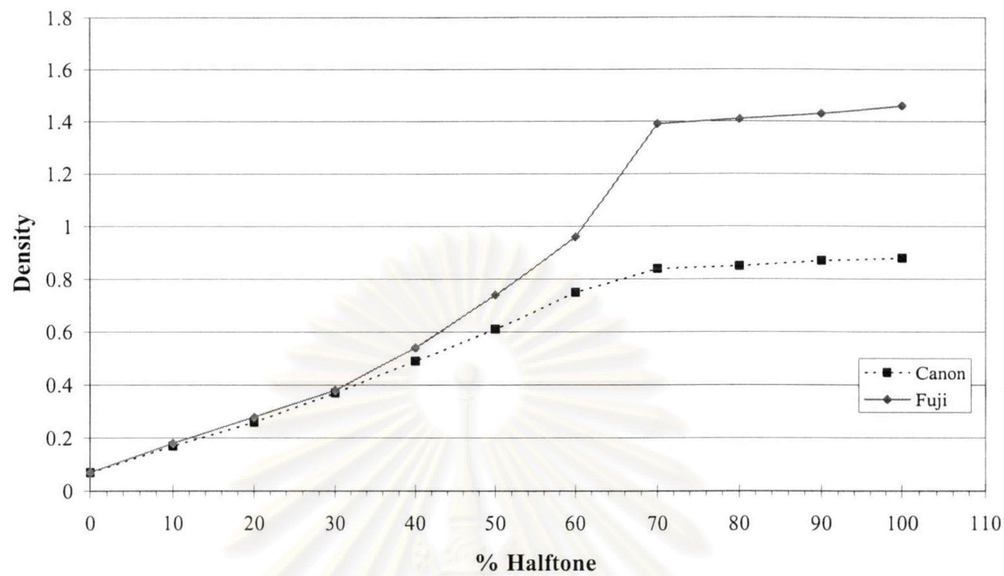


Figure 4-45 Dependence of tone reproduction for cyan toner

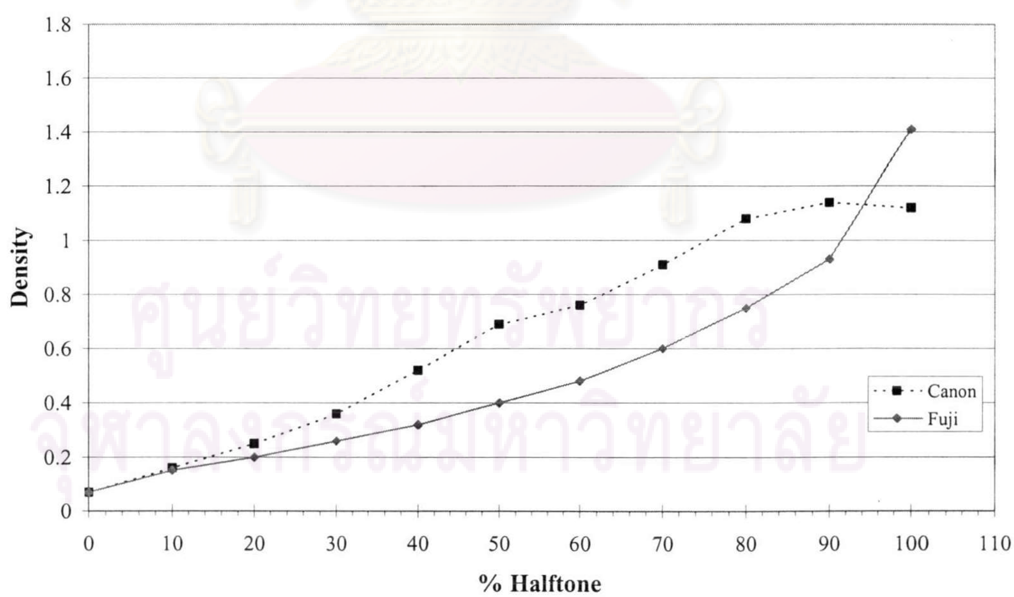


Figure 4-46 Dependence of tone reproduction for magenta toner

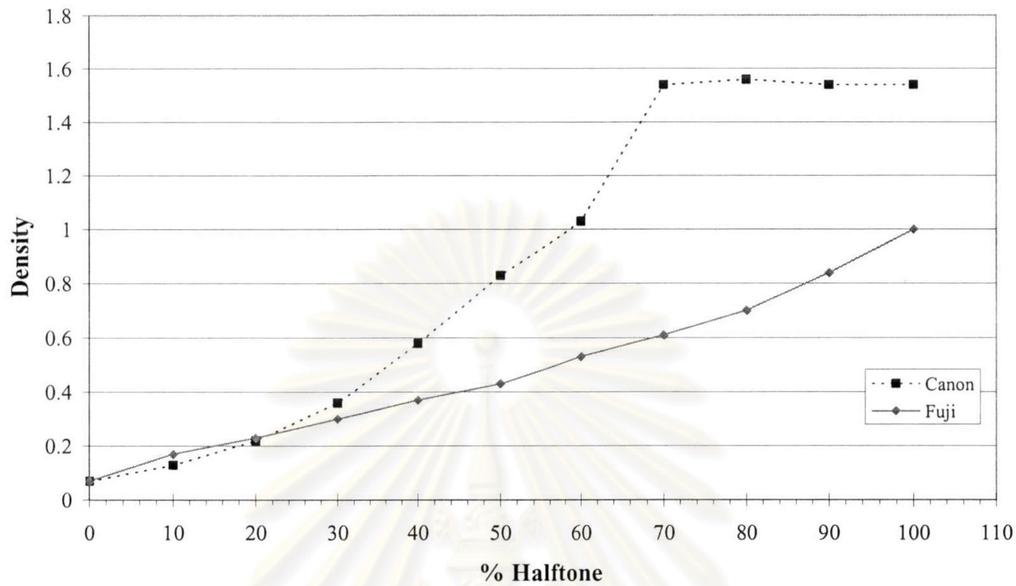
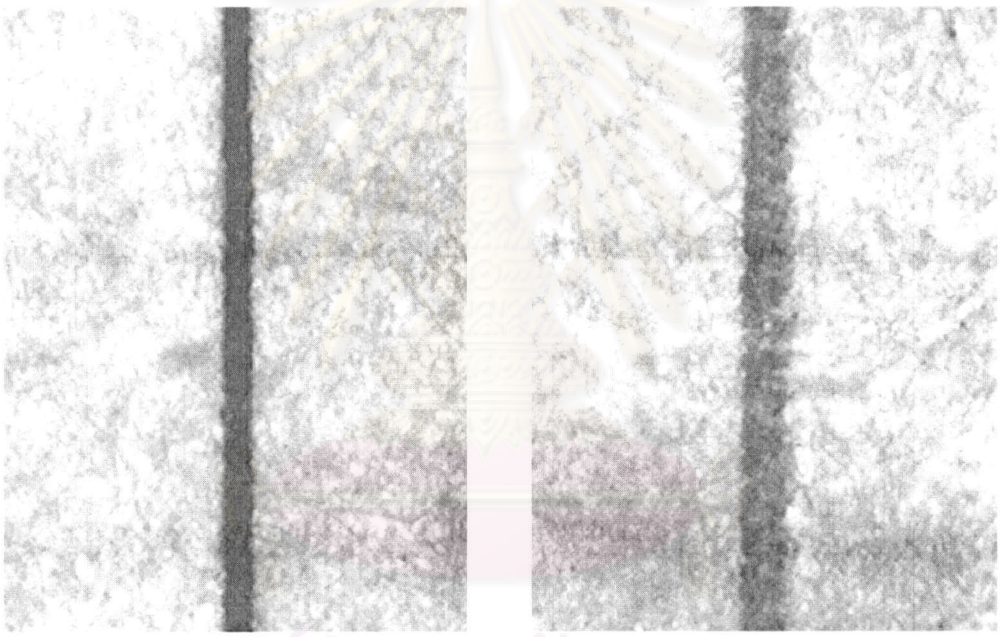


Figure 4-47 Dependence of tone reproduction for yellow toner

4.4.4 The sharpness of the alphabets and lines

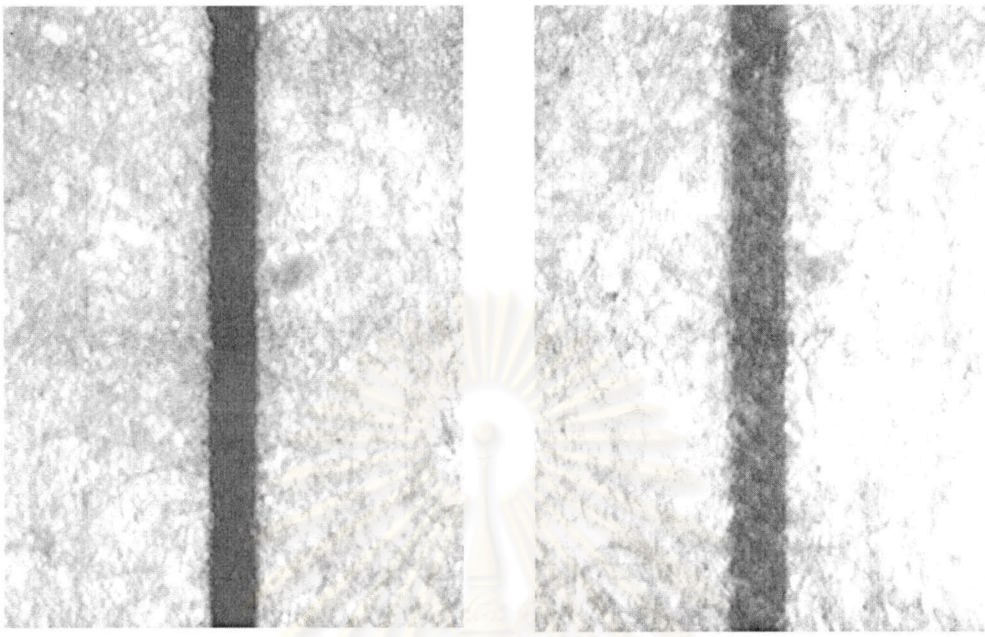
The sharpness of the alphabets and lines of Canon print-outs and Fuji print-outs, measured by the image analyzer, is shown in Figures 4-48 to 4-55, respectively. Figures 4-48 to 4-55 show the width of lines (87.75, 175.5, 263.25, 351, 702 and 1053 micrometers or 0.25, 0.5, 0.75, 1, 2 and 3 points) and the "n and I" characters of the Canon print-outs and Fuji print-outs, respectively. For the Canon print-outs, the lines and the characters have sharp edges while Fuji print-outs show ragged edges. The alphabets and lines of Canon printer were sharper and smoother than Fuji printer because the Canon print-outs were printed from polymerized toner while the Fuji print-outs were printed from pulverized toner. This result is similar to the work of Kamiyama et al. [1], Yanagida et al. [2] and Kiatkamjornwong et al. [16].

The polymerized toner has the spherical shape while the pulverized toner has the irregular shape. The spherical shaped toner is more efficiently, uniformly and triboelectrically charged than the irregular shaped toner. So, the polymerized toner had the higher charge and could be transferred more to the paper than the other, i.e. a full coverage of the toner on the printed area was obtained.



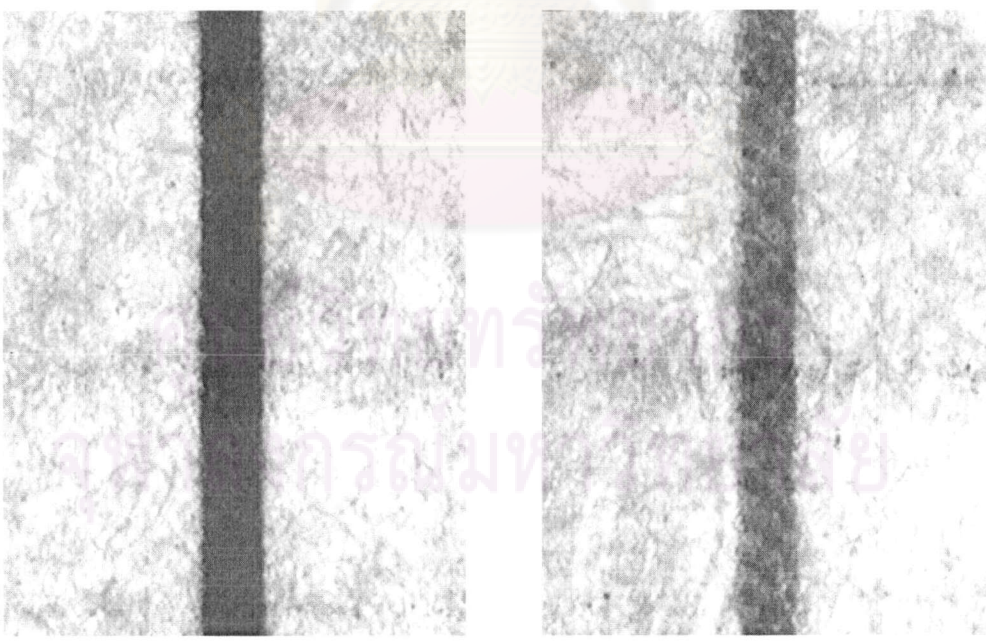
(a) (b)

Figure 4-48 The image of the lines (0.25 pt) by image analyzer: (a) Canon (b) Fuji



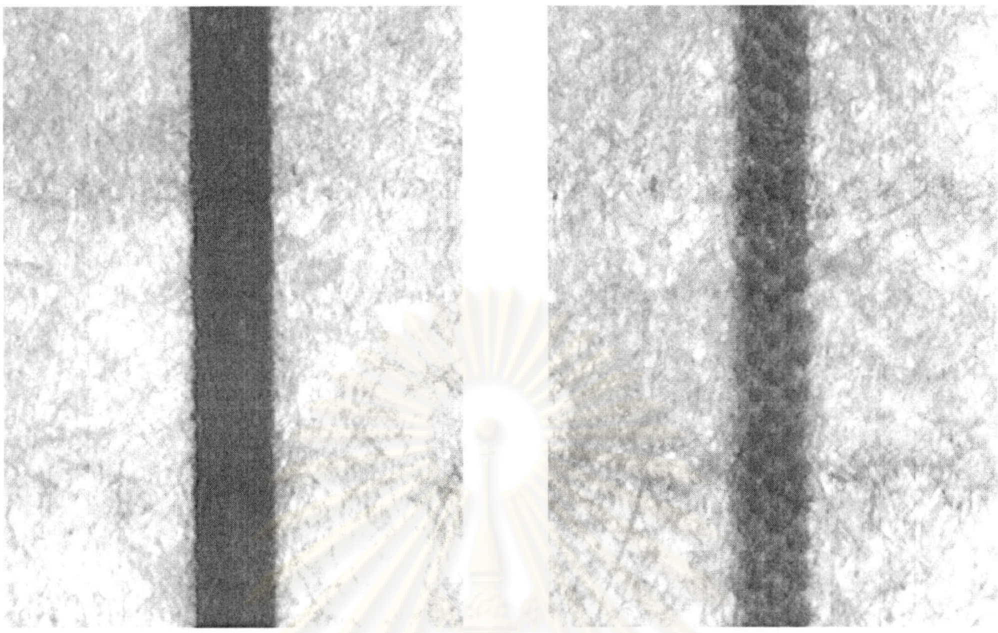
(a) (b)

Figure 4-49 The image of the lines (0.5 pt) by image analyzer: (a) Canon (b) Fuji



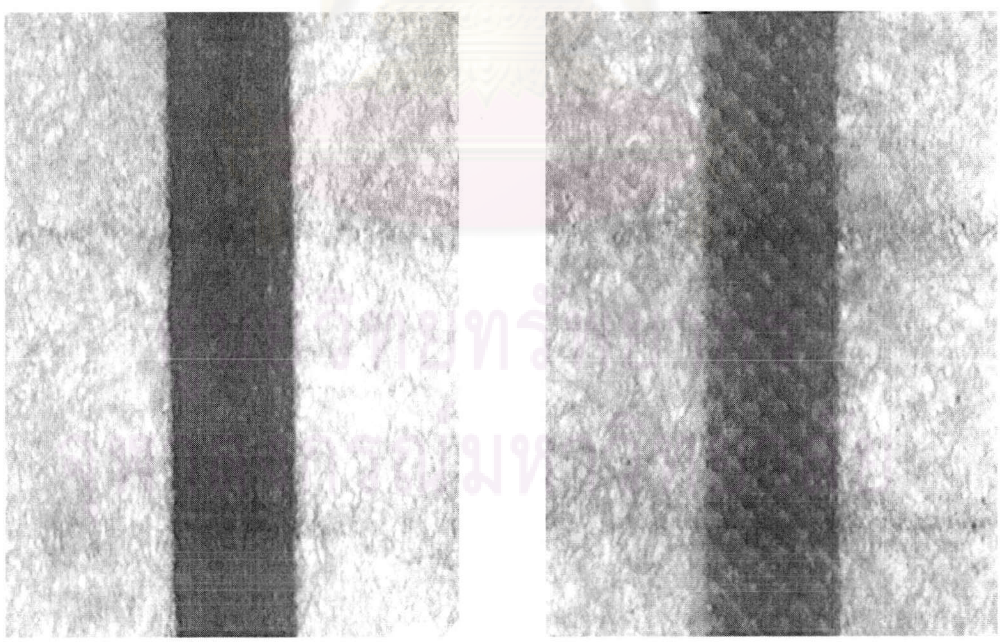
(a) (b)

Figure 4-50 The image of the lines (0.75 pt) by image analyzer: (a) Canon (b) Fuji



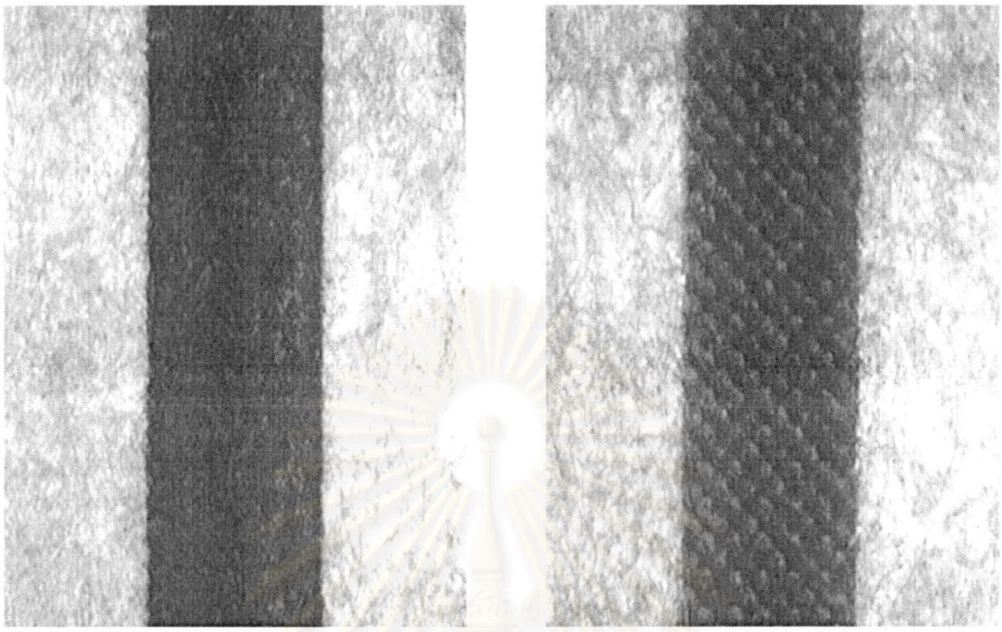
(a) (b)

Figure 4-51 The image of the lines (1 pt) by image analyzer: (a) Canon (b) Fuji



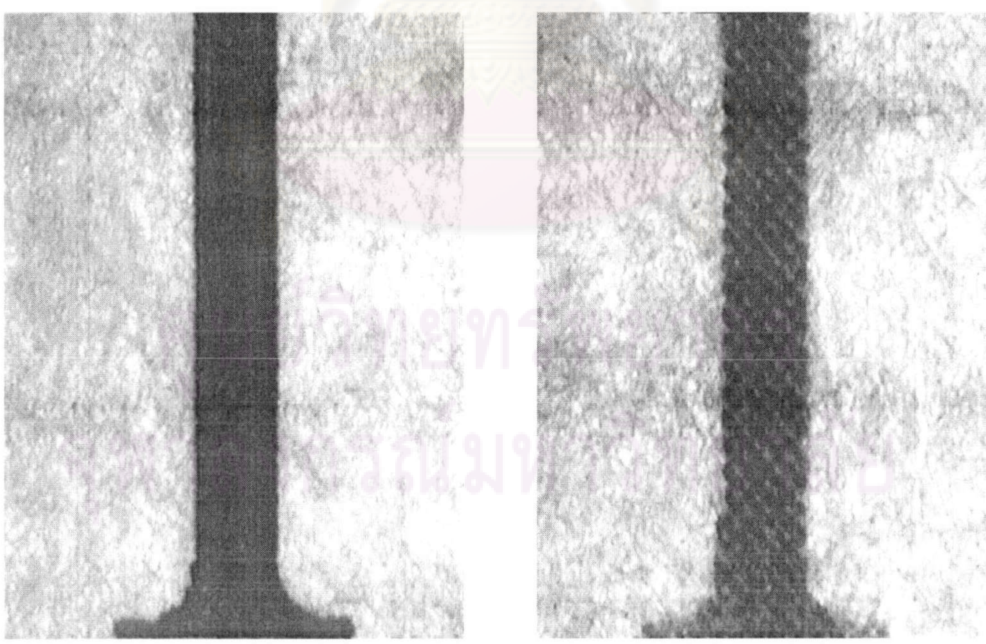
(a) (b)

Figure 4-52 The image of the lines (2 pt) by image analyzer: (a) Canon (b) Fuji



(a) (b)

Figure 4-53 The image of the lines (3 pt) by image analyzer: (a) Canon (b) Fuji



(a) (b)

Figure 4-54 The image of the "I" character by image analyzer: (a) Canon (b) Fuji

(a) (b)

Figure 4-55 The image of the "n" character by image analyzer: (a) Canon (b) Fuji

4.4.5 Color gamut and gamut volume

Color gamut and gamut volume were measured at color charts by the spectrophotometer (X-Rite SP 62), measurement geometry d/8°, Illuminants D65, CIE 1931 10° observer. The color gamut of two sets of print-outs is shown in Figures 4-56 and 4-57. Figure 4-56 is the relationship between chroma (C_{ab}*) and lightness (L*). It is shown that the color gamut of Canon print-outs, using polymerized toner is wider than the color gamut of Fuji print-outs, using pulverized toner and it is shown clearly at the higher 50 L* value. Figure 4-57 exhibits the relationship between a* and b*. It is shown that the color gamut of Canon print-outs is wider than the color gamut of Fuji print-outs in the ranges of redness-yellowness and yellowness-greenness.

However, the color gamut of Canon print-outs is narrower than the color gamut of Fuji print-outs in the ranges of greenness-blueness and blueness-redness.

For gamut volume, the values of Canon print-outs and Fuji print-outs equal to 11294 and 7986, respectively. Besides, the two sets of data in Appendix F that are the L*, a* and b* values of two sets of print-outs by the spectrophotometer.

These results could be explained similarly as the sharpness of the alphabets and lines that the polymerized toner (Canon's toner) has the spherical shape while the pulverized toner (Fuji's toner) has the irregular shape. The spherical shaped toner is more efficiently, uniformly and triboelectrically charged than the irregular shaped toner. So, the polymerized toner had the higher charge and could be transferred more to the paper than the other [1, 2 and 16], i.e. a full coverage of the toner on the printed area was obtained. For this reason, the polymerized toner could produce the wider color gamut and gamut volume than the other.

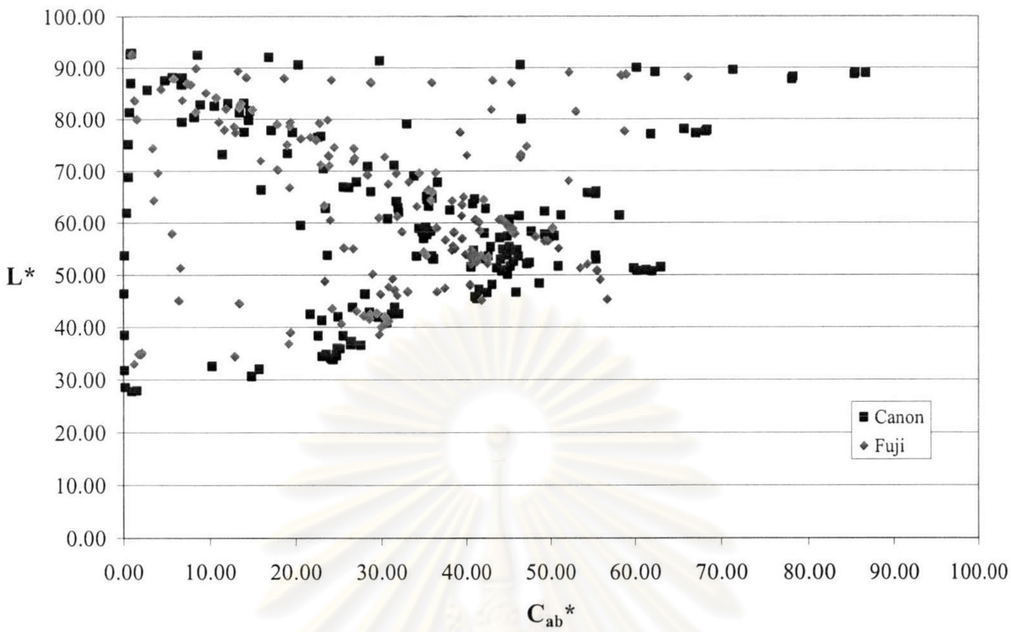


Figure 4-56 The relationship between chroma and lightness (C_{ab^*} and L*) of Canon print-outs and Fuji print-outs, measurement geometry d/8°, Illuminants D65, CIE 1931 10° observer

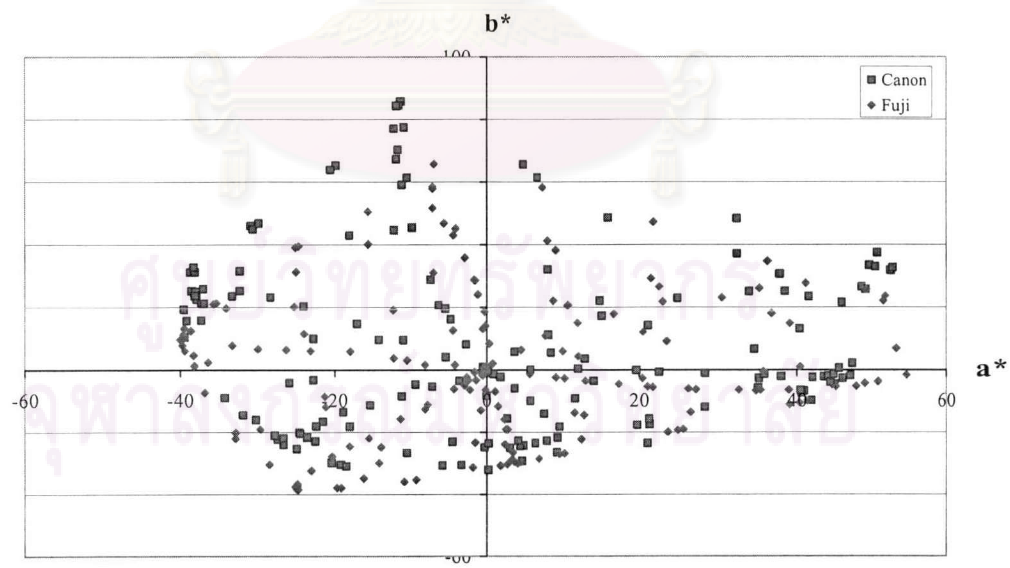


Figure 4-57 Diagram CIE L*a*b* of Canon print-outs and Fuji print-outs, measurement geometry d/8°, Illuminants D65, CIE 1931 10° observer