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TONER CLOUD GENERATION AND ITS SUPPLY OVER THE WIDTH OF PRINTING AREA

Mr. Chayanont Chansorn

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for the Degree of Master of Science in Imaging Technology

Department of Photographic Science and Printing Technology

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การสร้างหมอกหมึกผงและการควบคุมการเคลื่อนที่ของหมอกหมึกผงเป็นปัจจัยหนึ่งที่สำคัญในการพัฒนาระบบการพิมพ์ดิจิทัลด้วยเทคนิคการกำเนิดกลุ่มหมอกหมึกผง การทดลองเพื่อสร้างหมอกหมึกผงนี้ประกอบด้วยแผ่นอิเล็กโทรด 2 แผ่น โรยหมึกผงชนิดนำไฟฟ้าตรงกลางอิเล็กโทรดแผ่นล่างที่มีลักษณะโค้งเว้าและกว้าง อิเล็กโทรดแผ่นบนวางเรียงขนานกันโดยมีแผ่นฉนวนขั้นระหว่างแผ่นอิเล็กโทรดให้เป็นช่องว่าง ให้สนามไฟฟ้าระหว่างอิเล็กโทรดทั้งสอง พบว่าหมึกผงเริ่มเคลื่อนที่ขึ้นและลงระหว่างแผ่นอิเล็กโทรดทั้งสองด้วยแรงทางไฟฟ้าสถิต มีลักษณะเป็นกลุ่มหมอกหมึกผงที่เคลื่อนที่ไปตามแนวกว้างจนสุดปลายทั้งสองด้านของแผ่นอิเล็กโทรดแผ่นล่าง งานวิจัยนี้ศึกษาภาวะในการสร้างหมอกหมึกผง โดยอิเล็กโทรดแผ่นล่างที่ใช้มีลักษณะโค้งเว้าและกว้าง พบว่าความต่างศักย์ไฟฟ้าที่ให้กับขั้วอิเล็กโทรดทั้งสองแผ่น ปริมาณของหมึกผง ความลึกของบริเวณโค้งเว้าของอิเล็กโทรดแผ่นล่าง ความลาดเอียงของอิเล็กโทรดแผ่นบน และความลาดเอียงของระบบ มีอิทธิพลต่อการสร้างหมอกหมึกผงและการเคลื่อนที่ของหมอกหมึกผง เมื่อให้ความต่างศักย์ไฟฟ้ากับขั้วอิเล็กโทรดสูงขึ้น ทำให้กลุ่มหมอกหมึกผงเคลื่อนที่ได้เร็วขึ้น เมื่อใช้หมึกผงปริมาณมาก หมอกหมึกผงจะเคลื่อนที่เต็มความกว้างได้เร็วขึ้น บริเวณโค้งเว้าของอิเล็กโทรดที่ลึกขึ้น ทำให้หมอกของหมึกผงมีการเคลื่อนที่ช้าลง ความลาดเอียงของอิเล็กโทรดแผ่นบนที่เพิ่มขึ้น ทำให้หมอกหมึกผงมีการเคลื่อนที่เร็วขึ้น ส่วนการเปลี่ยนแปลงความลาดเอียงของระบบในช่วง 0-5 องศา ไม่มีผลต่อการเคลื่อนที่ของหมอกหมึกผงอย่างมีนัยสำคัญนัก นอกจากนี้การเพิ่มความต่างศักย์ไฟฟ้าระหว่างขั้วอิเล็กโทรด ทำให้ขนาดของหมอกหมึกผงแคบลง งานวิจัยนี้ยังได้ทำการศึกษาการส่งผ่านหมึกผงสู่ระบบพิมพ์โดยใช้อิเล็กโทรดแผ่นล่างที่มีลักษณะโค้งเว้าสองวงที่เลื่อมกัน พบว่าแผ่นอิเล็กโทรดชนิดนี้สามารถใช้สำหรับการส่งผ่านหมึกผงไปสู่พื้นที่พิมพ์ได้ งานวิจัยนี้ยังได้อธิบายปรากฏการณ์ที่เป็นไปได้ของการเกิดหมอกหมึกผงและสมรรถภาพที่เกิดขึ้น

ภาควิชาวิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์ลายมือชื่อนิสิต...
สาขาวิชา เทคโนโลยีทางภาพ ลายมือชื่ออาจารย์ที่ปรึกษา...................................
ปีการศึกษา 2546 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม...........................

4472245823: MAJOR IMAGING TECHNOLOGY

KEY WORD: TONER CLOUD / CONDUCTIVE TONER / ELECTRIC FIELD / DENTED ELECTRODE

CHAYANONT CHANSORN: TONER CLOUD GENERATION AND ITS SUPPLY OVER THE WIDTH OF PRINTING AREA. THESIS ADVISOR: PROFESSOR SUDA KIATKAMJORNWONG, Ph.D. THESIS COADVISOR: PROFESSOR YASUSHI HOSHINO, Ph.D. 177 pp. ISBN 974-17-5349-7.

Toner cloud generation along with controlling its movement is one of the most important parameters in the development of digital printing by toner cloud beam technique. As for the experimental set-up for toner cloud generation, the conductive toner particles were sprayed at the center of a wide chamber shape dented electrode as the lower electrode placed parallel to the upper electrode, leaving a small gap between them using two insulating sheets. Electric field was applied between the two electrodes. The toner moved up and down between the two electrodes by electrostatic force forming the toner cloud, which propagated to both ends of the dented electrode. This research studied the toner cloud generation conditions using the wide chamber shape dented electrode. We found that the applied voltage, the toner amount, the depth of the dented electrode, the slope of the nesa glass, and the slope of the system were the influencing factors that governed the toner cloud generation and its movement. An increase in the applied voltage led to a faster toner cloud speed. When a greater amount of toner was placed into the dented electrode, a faster toner cloud movement was obtained. Contrastly, the toner cloud speed decreased when increased the depth of dented electrode. An increase of the slope of nesa glass increased the toner cloud speed. However, the toner cloud speed was not significant to the system when the slope was between 0-5 degrees. It was also found that the width of toner cloud decreased when the applied voltage increased. Furthermore, the two-overlapped cone shape dented electrode could be used for transporting the conductive toner to the printing system. This research also explained the possible phenomena for the toner cloud generation and performance.

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Field of study Imaging Technology Advisor's signature..................................

Academic year 2003 Co-advisor's signature..................................

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CHAPTER 1

INTRODUCTION

1.1. Scientific Rationale

In non-impact printing technologies, toner-based and ink-based solutions play an important role in various digital-printing industries especially in short run printing. According to ink-based solution, inkjet is a direct-to-paper technology with no intermediate image carrier and is thus a direct printing. In contrast, toner printing such as electrophotography is the technology of controlling toner powder precisely onto paper; requires a photoconductive drum or image carrier to create the toner image and then transfer it to paper. Although the electrophotographic printing is excellent in quality and speed, using photoconductor in the system induces the higher cost of printing than inkjet. This disadvantage leads to making efforts for realizing new printing technologies, which have characteristics of simpler printing mechanism, higher printing quality, higher printing speed, and/or better stability and maintainability. Array Printers AB in Sweden have developed a direct printing method using insulating toner, TonerJet®, since 1986, express purpose to be faster than inkjet and lower in manufacturing cost than electrophotography.[1] In 1999, a dot formation method using conductive toner called “Toner Cloud Beam (TCB)” has been purposed. The toner beam is extracted from toner cloud generated by electric field applied between electrodes. Then, the toner beam is projected to paper to form dots by such a simple printing mechanism. In toner cloud generation, the electrostatic force is very important for moving toner over the dented electrode. The special shape of dented electrode as same as the width of printing area has been placed in this research. This research investigates the effects of dented electrode on uniformity of toner cloud and toner motion over the width of printing area. The toner supplying method has been also studied.

1.2.Objectives of Research Work

The objectives of this research are as follows:

1.2.1 To study the shape of dented electrodes that affects toner uniform cloud over the width of printing area.

1.2.2 To study the effect of applied voltage, toner amount, Nesa-glass slope and system slope on toner motion over the width of printing area.

1.2.3 To investigate the toner supplying method.

1.3.Scope of the Research Work

This research is a part of Toner Cloud Beam printing mechanism, the special shape dented electrode used in this research is a metal plate and an ITO (Indium Tin Oxide) sputtered transparent glass. The motion of conductive toner cloud was captured by a digital camera, which measured the toner cloud speed in Quick Time Player program. Dependency of the motion of toner cloud and the toner uniform cloud on the special shape of dented electrode, applied voltage, slope of Nesa-glass, slope of the system and the toner amount were determined for the conductive toner cloud motion and uniformity. Moreover, this research also investigated the toner supplying method, which was tested in various shapes of dented electrodes.

The attainable results of this research could give some information for developments of the new dot formation mechanism over the width of printing area which can be processed with a simple mechanism, Toner Cloud Beam.

1.4.Contents of the Research Work

This thesis consists of 5 chapters including introduction, theoretical background and literature review, experimental, results and discussion, and conclusion and suggestions. Chapter 1 is an introduction of this thesis. Chapter 2 concerns a brief description of the toner-based printing systems, the electrophotographic process, toner jet process, the toner component and characterization, the toner cloud generation, the toner cloud confinement condition, the toner cloud beam, and the short literature review of some previous reports. In Chapter 3, the details about experimental materials, the experimental apparatus, and procedures of the experiment in this research are explained. Chapter 4 informs the results and discussion of the dependency of the toner cloud motion and uniformity on applied voltage, the special-shaped dented electrode, slope of the Nesa-glass, slope of the system and the toner amount. In addition, the results of the dependency of the toner supplying method on the toner amount, shape of the dented electrode and the applied voltage. The final chapter presents the conclusions of the relationship between the dependencies on the toner cloud motion, toner cloud uniformity and toner supplying method along with some suggestions.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEWS

2.1. Theoretical Background

2.1.1 Conventional printing

Lithography, letterpress, flexography, gravure and screen are the major conventional machine printing processes. Each of these processes is separate and distinct, because of the different operations of the planographic, relief, intaglio and stencil types of printing.

Conventional printing processes, whatever their individual differences, follow the same initial stages of converting the original matter, which can be of either conventional or digital original, into an image carrier such as a plate, cylinder or stencil, which produces the finished printed form.

In conventional graphic reproduction the printing elements of typematter and graphics are converted into an intermediate film stage of negatives or positives which have to be assembled and approved before image carries for each of the printing processes are produced.

Image carriers in the form of plates, cylinders or stencils can be created either by exposing the assembled films onto a light sensitive image area which is then processed, or by laser engraving, digital or chemical transfer.

All printing image carriers have two separate surfaces including an image or printing area and a non-image or non-printing area. The image or printing area accepts the ink by mechanical or chemical means but the non-image area does not accept or retain ink.[2]

2.1.2 Digital printing

Digital printing or Computer-to-Print depends on a digital front-end system that can scan originals, creating text and graphic on electronic media. The printing process, from the capture of live or still originals, proofing, and printing, can be done electronically without the need for conventional film, plate, proof or printing press. Comparison of digital printing with conventional offset printing shows the reduced number of stages involved as digital files go directly from the creator to press. By eliminating the traditional middle stages, the process is deskilled and lends itself to complete in-house production:

- Conventional offset printing

Electronic page layout → output film → color proofs → stripping → plate making → printing → finishing

- Digital printing

Electronic page layout → printing → finishing.[3]

Digital printing is any reproduction that receives electronic media such as text and graphic and use spots (or dots) for replication. Colorants employed for digital printing fall into two categories, dyes and pigments, depending upon their mode of use. Dyes may be used in inkjet, impact printers, and thermal transfer systems, whereas pigments are the basis for the colored toners used in electrophotographic printing.

Digital printing also refers to the use of a re-imagable carrier or no image carrier for the transfer of toner or inkjet ink to paper. Inkjet is a direct-to-paper technology with no intermediate image carrier. Toner-based reproduction requires a drum or belt to create the toned image and then transfer it to paper. In essence, the drum acts as an image carrier. The toner-based image carrier must create a new image for every reproduction and is thus re-imagable.

Digital printing has to a great extent created new market opportunities and niches, rather than just be a straight replacement for conventional printing processes. The important advantages of digital printing are short runs, just-in-time printing and personalization. Today, the accelerating telecommunications of data transfer through medem, ISDN (Integrated Services Digital Network) and networks influence towards them alongside faster data transfer rates speeding up the process and providing the opportunity for print-on-demand response. These technologies also lend themselves to variable data printing, which means that data can be changed on the run.

A factor of great importance is that the process is environmentally friendly. There is no silver halide film involved, with its associated disposal problems of spent developer and silver-rich fixing solutions.

Digital printing is utilized in variable printing and new presses because they save cost and time compared to conventional offset printing.[4, 6]

2.1.3 Non-impact printing

Early nonimpact printers used technologies of direct printing on specially treated paper for machine simplicity. Later, in order to reduce the operating costs for high volume users, transfer methods were developed to reuse the sensitive material and print on untreated paper similar to plain paper photocopiers. The tendency of research and development is to eliminate the complex transfer step, and print directly on plain paper. Early machines used shaped characters for reasons of technology, cost, or similarity to exist impact printers. As the cost, complexity, and resolution of matrix methods improved and user acceptance increased, the use of matrix methods became more widespread. The advantages of variable character size and shape, special fonts, and full graphics capability have driven most development undertaking in the direction of matrix character printing with resolution requirements sufficient to approach the image quality of fully formed characters.

Nonimpact printing process will be classified according to the method of imaging or temporary storage. The largest groups of nonimpact printing methods are electrostatic printing techniques. Electrostatic printing is defined as those methods, which use the interaction of electrostatically charged pigment q and an electric field E to control the deposit of colorant material on a recording substrate. The q * E interaction is a total variation, which occurs as:

$$\Delta(qE) = q\Delta E + E\Delta q \tag{2.1}$$

The first term on the right of the equation represents a process where a latent image field ΔE contains the image information that is developed by uniformly charged particle q. The second term represents a process where the latent image charge Δq contains the image information and the constant electric field E in the developer. Notice that the role of latent image and developer changes for these two general classes of printing. The latent image is that term having the variable image information. Electrostatic printing can be classified as variable field processes $q\Delta E$, and variable charge processes $E\Delta q$. Variable field processes include electrographic, electrophotographic, electrographic transfer, and electrophotographic transfer. Variable charge processes include inkjet printing, ion projection printing, induction and charged pigment process.

Nonimpact printing processes can be described using the working of conditions shown in the Figure 2-1 for electrographic printing.[7]

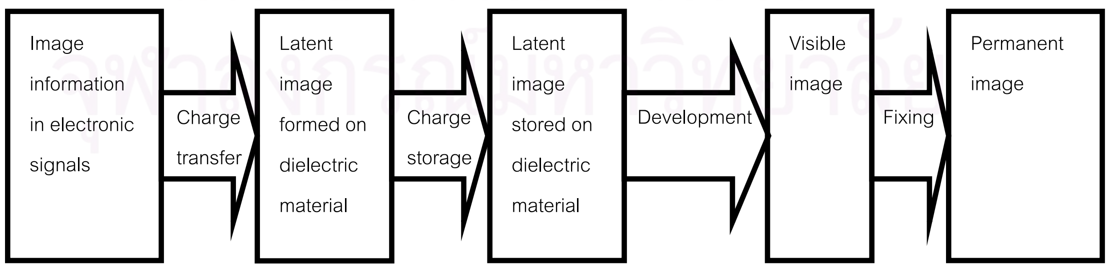


Figure 2-1 Electrography printing functional diagram

Each statement in a box represents a condition in the printing process. The names shown within the arrows are the actions leading to the next condition. Each printing process has a unique set of conditions and actions, however, many of the conditions and actions are used in many different printing processes.

2.1.4 Toner-based printing

The first forms of toners were used by Chester Carlson when he invented xerography in 1938 (Carlson, 1965), also well known as electrophotography. The basic concept consisted of ion charging and subsequently imagewise discharging a photoconductor to form an electrostatic latent image on the surface of the photoconductor. A photoconductor is a material that is an insulator in the dark and becomes a photoinduced charge generator or conductor in the light. The electrostatic latent image was developed into a real visual image by charge pigment particles that were attached to the latent image by electric fields that emerged above the surface of the photoconductor. The charged pigment particles were later called “toner” particles, since they developed or “toned” the latent image. Since then, great improvement of toner-based printing system has been accomplished.

According to the process of reproduction image, there are five main types of toner printing systems. They can all be computer driven and they use optical or electrical techniques in order to form the latent image to which toner may be attracted. These are electrophotography, ion deposition, electrostatic, magnetographic and electrophotographic. The most important and widely use is electrophotography.[3, 5] Now, toner jet has been developed with the expressed purpose to be faster than ink jet and lower in cost than electrophotographic. This research work involves electrophotographic and electrostatic aspects.

2.1.4.1 Electrophotography

Electrophotography, the technical name for photocopy and laser printing, is a technology that uses electricity to reproduce images. The process of electrophotographic printing relies on six basic steps, which includes charging, exposing, developing, transferring, fusing and cleaning. The process of electrophotography is shown in Figure 2-2 and described in following steps (1-6).

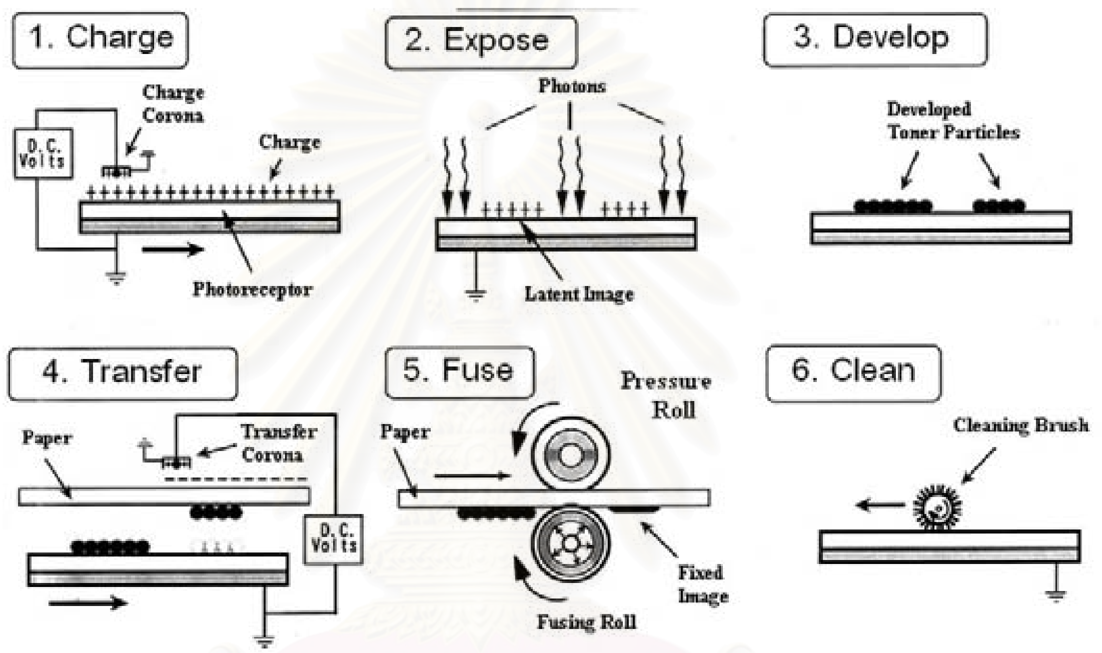


Figure 2-2 Six basic steps in electophotographic reproduction

1) In the charging step, a uniform electrostatic charge is applied to the photoconducting layer on the printing drum through the use of wire or grid bias to high voltage.

2) In the exposing step, light is projected onto the photoconducting layer in the non-image area. The photoconducting layer is sensitive to light which causes the charge in non-image area is neutralized when the light touches. This step produces a "latent electrostatic image" in the shape of the original image on the drum.

3) In the developing step, the latent image is covered in some form of toner (either dry or liquid). The toner must have the opposite charge to the non-exposed area in order to adhere to the latent image.

4) In the transferring step, a sheet of paper is inserted into the machine. The charge on the drum is reversed, which causes the toner particles to repel away from the drum and onto the paper.

5) In the fusing step, dry toners are then fused to the paper with heat or pressure. Liquid toners are fused after drying.

6) In the cleaning step, the drum is brushed to remove excess toner, and then exposed to light to remove any lingering image or charges.

2.1.4.2 TonerJet®

Toner jet is a printing technology, which was invented and developed by Array Printer AB in 1986. Toner jet is a direct print process where the image is formed directly onto the print media e.g. paper or belt. It is a process that easily achieves, extremely good and stable color registration at low manufacturing cost. The dot registration can be controlled by a feedback loop that measures the print media position. Figure 2-3 shows the schematic layout of the toner transport by the toner jet method. Toner particles are applied in the thin layer on a feeding steel roller by a brush. The brush charges the surface of the plastic particles electrostatic. Mirror forces holds the charged particles to the roller surface. A flexible printed circuit board (called FPC) is mounted in the area between the feeding roller and the print media. The FPC contains an array of apertures. The electrode that can be controlled surround each aperture is shown in Figure 2-4.

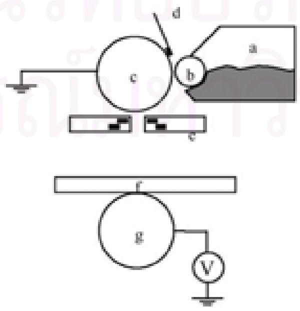


Figure 2-3 Schematic layout of the toner transports by toner jet method: a) toner container, b) brush, c) feed roller, d) FPC, e) print media, f) belt, and g) back electrode.

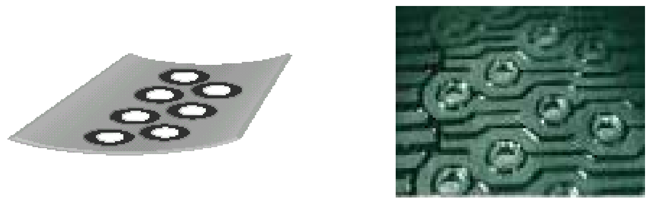


Figure 2-4 Flexible printed circuit board with two rows of apertures and ring electrodes.

The toner particles (negatively charged) are attracted to the print media by the electrostatic forces. The electrostatic forces generated by a potential difference between a toner supply sleeve and a back electrode. The back electrode is located behind the print media and has a higher potential than the toner supply sleeve. The potential difference creates the electric field that transfers the toner particles from the toner sleeve to the print media. The FPC is mounted in this electric field, which has an array of small apertures as shown in Figure 2-5.[1]

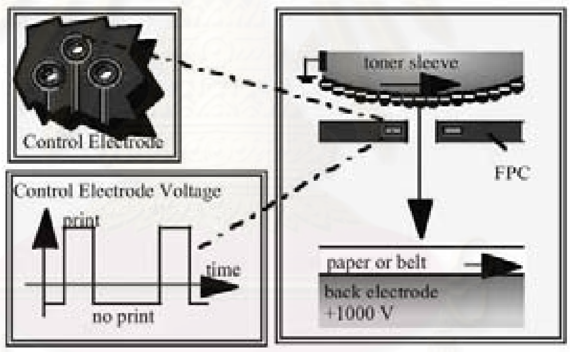


Figure 2-5 The control electrode in the flexible printed circuit

The dots on the print media created by the toners that pass through these apertures. The potential of the control electrodes controls the toner transport to the print media. So, the toner particles can pass through the aperture and form a dot using the control electrodes. Figure 2-5 shows how the control electrode potential is pulsed to a print voltage that allows toner transport to the print media.

Then, the document is fused in the same manner as in laser printers; heat and pressure cause the toner to bond to the paper. Meanwhile, the FPC is cleaned and the next page is ready to be printed.[1, 8]

Toner jet, which relies on the mono-component toner, thereby, accomplishes in three steps, whereas the laser technology needs six steps to do the same job. Toner jet thus processes a competitive advantage in this respect.

Toner Jet is now the print technology that combines color printing at a high speed, good print quality and a low manufacturing cost. The print media is paper or an intermediate image transfer belt. Figure 2-6 shows a printer model with four print heads, one for each color, using a transfer belt as print media.

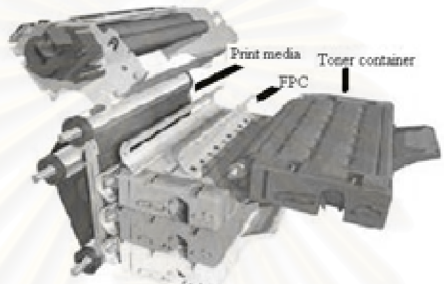


Figure 2-6 Toner jet printer with four print heads, CMYK, using a transfer belt as print media

2.1.5 Properties and Uses of Toners

The main properties of toners for use in digital printing is that the particle size must be small enough to achieve shape definition and that they flow or transport in a controlled manner to ensure uniform application.

Toners consist essentially of pigment particles dispersed in thermoplastic resin. Charge control agents (CCA) are frequently added to toners to create a desired magnitude and polarity of toner charge. Besides these essential ingredients, a particular toner design may contain surface additives, magnetic additives and other additives such as wax. There are two major groups of toners that are dry toners and liquid toners.

Dry toners are classified into two main types including dual component toners and single- or mono-component toners.

Dual component toners are made up of two distinctive parts; toner and carrier bead which help transport and bind the toner to the substrate. There are three major ways of developing dual-component toners; cascade development, magnetic development and continuous tone development. They generally also have advantage over mono-component toners in that their particle size is smaller, yielding higher resolution and brighter printed colors.

Mono-component toners differ from dual-component toners in that they do not require the use of carrier bead for development. There are several ways to charge mono-component toners: induction, contacting, corona charging, ion beam and traveling electric field. Single component developer hardware is generally simpler, smaller and lower in cost than two-component developer hardware.

Liquid toners consist of pigmented toner and carrier which is normally a liquid hydrocarbon or mineral spirit. The toner being ‘liquefied’ as it is suspended in the carrier. Liquid toner systems are generally considered to give superior printed results than dry toner systems, through brighter colors and smaller toner particle size.

Liquid toners result in printed work with features more in keeping with conventional printing inks, rather than the glazed appearance which is often associated with dry toner. More highly intense transparent colors are also possible with liquid toners.

The fusing of dry toners to produce the final printed result is mainly through radiant heat or heat pressure, where as liquid toners operate by hot transfer or hot air.[2,3,6]

2.1.6 Toner Cloud Beam

The control of toner motion is significant for evaluation of nonimpact printing. Main evaluation items of the printing process are print quality, printing speed and simplicity of printing mechanism. The print quality is controlled by the precision of position where a toner particle is attached to a paper and the controllability of an amount of attaching toner particles.

Although the printing mechanism of electrophotography is very complex but print quality and speed are excellent. So, the electrophotoghaphy is used as one of major non-impact printing technologies. In order to reduce the operating costs for printing mechanism, Toner jet is one of important attempts. Toner is selectively conveyed to paper. The printing mechanism is simplified compared with the electrophography.

In 1999, Hoshino and Hirayama proposed a new dot formation method for the toner-based digital printing system called Toner Cloud Beam (TCB).[9] This method has an advantage that the printing mechanism is simplified compared with the electrophotography and TCB differences from Toner jet in that it relies on conducting toner while Toner jet relies on insulating toner. The basic theory for the dot reproduction in TCB technology is described in the following items (a-c).

a) Toner cloud generation condition

To generate a toner cloud, the experiment for the toner jumping as shown in Figure 2-7 is setup. The system consists of two closely spaced conducting parallel plates placed across, a voltage source are connected for applying the voltage to the electrode, and an electrometer for the current measurement. Firstly, conducting toner particles are deposited on the top surface of the bottom electrode. Next the dc voltage is applied to the electrodes. The voltage is ramped from zero to a maximum voltage at a constant rate. In this procedure, the toner particles are charged. When the electrostatic force of detachment exceeds the forces of adhesion between the toners and substrate, the toner particles jump from the lower electrode to the upper electrode and these cause an increase of current between the two parallel plates. After reaching the upper electrode, the initial induced charge is neutralized and the particles acquire electrostatic charge of the opposite polarity, and then move toward the lower plate. These fallen particles are charged again and repeat same behavior until the applied voltage is stopped or they move out of the system.

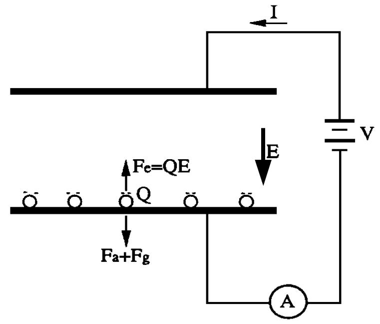


Figure 2-7 Schematic diagram of the experimental set-up for the toner jumping

When one of the toner particles begins jumping from the lower electrode to the upper electrode, the following relationship is valid:

$$\vec{F}_e = \vec{F}_a + \vec{F}_g \tag{2.2}$$

where $\vec{F}_e$ is the electric force, $\vec{F}_a$ is the adhesion force and $\vec{F}_g$ is the gravitational force. The electric force worked on the toner $\vec{F}_e$ is estimated as equation (2.3), when the toner is conductive.

$$\begin{aligned}\vec{F}_e &= Q\vec{E} \\ &= (\varepsilon ES)E \\ &= \varepsilon SE^2\end{aligned} \tag{2.3}$$

when Q is the induced toner charge, $\vec{E}$ is the electric field applied between electrodes, ε is the dielectric constant of air, and S is the effective area of the toner, which means the cross section of an electric flux reaches the toner as shown in Figure 2.8. When the shape of the toner is spherical, the area S becomes $1.65 \times 4\pi R^2$, where R is the radius of the toner.

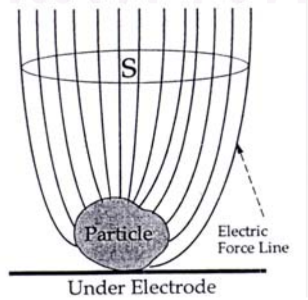


Figure 2-8 Relationship between the toner shape and the area S.

The adhesion force between the toner particles and the substrate, $\vec{F}_a$, has two components that are electrostatic image force and the van der Waals force. When the electric force overcomes sum of the adhesion force and gravitational force, the toner particles jump from the lower electrode to the upper electrode and cause an increasing in total current as shown in Figure 2-9. The voltage value at which the toner jumping occurs is called the threshold voltage, V_{th}.[10-11]

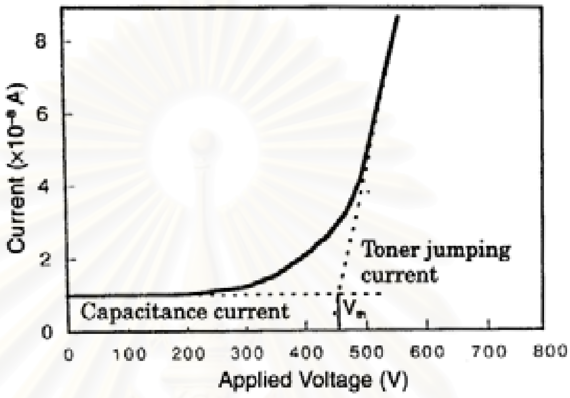


Figure 2-9 Determination of the threshold voltage for toner jumping across the parallel plates.

According to Hosino and his co-workers[9], the total current can be written as follows:

$$I = I_c + I_t \tag{2.4}$$

where I_c is the current component of charging capacitance given by:

$$I_c = C\frac{dV}{dt} \tag{2.5}$$

where C is capacitance between the electrodes and $\frac{dV}{dt}$ is the rate of a voltage increment. I_t is the current component of charged toner jumping up and down between the two parallel plates.

b) Toner cloud confinement condition

In the experiment for the toner jumping, when the voltage applied to the electrodes increases from zero until it reaches the threshold voltage, the toner particles start to move up and down between the electrodes and these cause an increase in the measured current. The current waveform versus the ramp voltage applied between two electrodes is shown in the Figure 2-10 (a). Obviously, the current waveform drops down rapidly as a result of a moving out of toner particles.

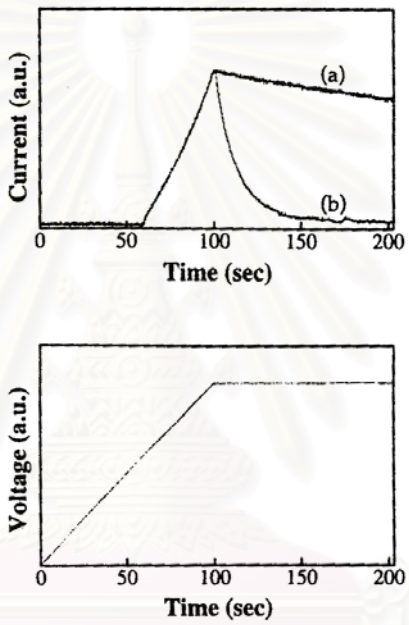


Figure 2-10 The current waveform versus the ramp voltage applied between the electrodes. The current waveforms (a) and (b) correspond to the dented electrode and the flat electrode, respectively.

To confine toner cloud, Hoshino and his co-worker[12, 13] replaced the flat lower electrode by the electrode that is dented to a thin lens shape as shown in Figure 2-11, and repeated the experiment. The current waveform versus the ramp voltage applied between two electrodes is shown in the Figure 2-10 (b). The amplitude of the current waveform has a linear relationship to the amount of jumping toner in the condition of the same applied voltage. This shows that the conductive toner is confined between the electrodes at the dented area. The confinement is confirmed by observing the toner motion through the upper transparent electrode, which is covered by a thin layer of indium tin oxide (ITO) glass. When the toner start jumping, the toner on the electrode goes out of sight and becomes like a black cloud in the dented area. The phenomenon is explained that the electric force lines have the direction toward the center axis as shown in Figure 2-12.

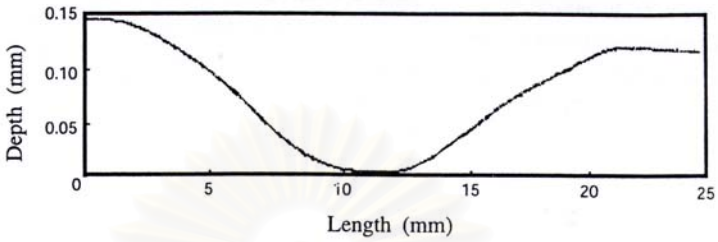


Figure 2-11 Cross section of the dented shape electrode

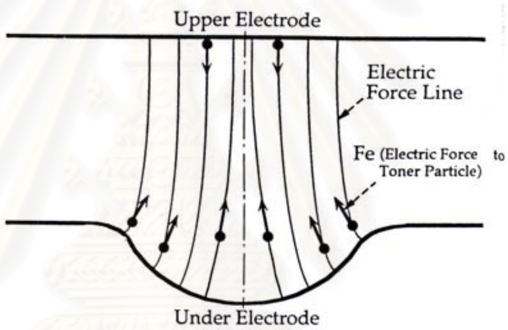


Figure 2-12 Schematic demonstration of the toner motion in the case of dented electrode, ▬ · ▬ · ▬ means the center axis.

Figure 2-13 shows the typical relationship between the current and the applied voltage. The current begins to increase at a certain voltage and drops at another certain voltage. Figure 2-13 also shows the method of obtaining the voltages, at which the toner begins jumping and stops jumping. There are slight differences between these voltages. such differences are caused by the disparity between the adhesion force, which sometime has elapsed and sometime the adhesion force is just enough to adhere. Jumping conductive toners are confined between electrodes, one of which is dented to a thin lens shape. So, the start and stop toner jumping characteristics are then measured by the increasing and decreasing ramp voltages.[13]

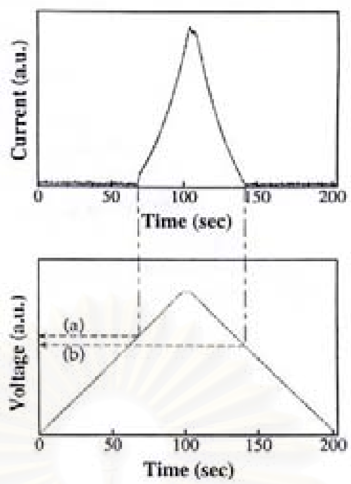
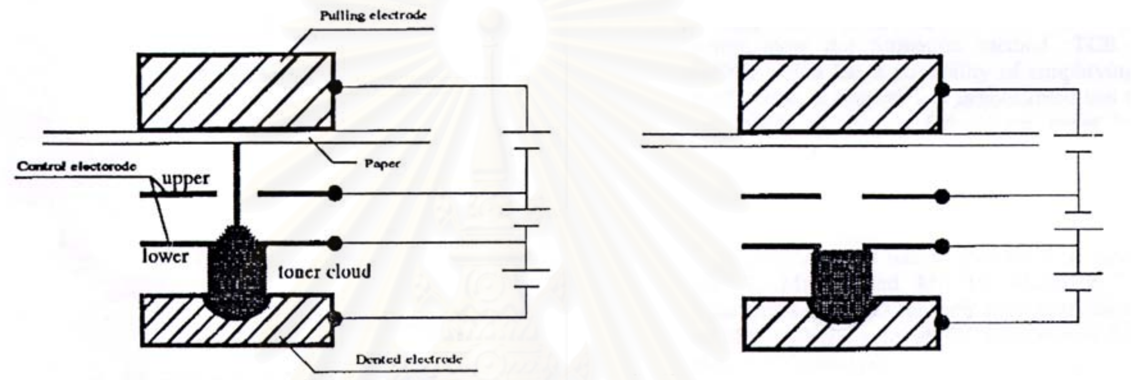


Figure 2-13 Current versus voltage, when the voltage waveform is trapezoid. The marks (a) and (b) mean the voltage of jump at begin and at stop, respectively.

c) Control condition of Toner Cloud Beam

The experimental setup for Toner Cloud Beam (TCB) is shown in Figure 2-14 which (a) shows the toner beam at the “on”, state and Figure 2-14 (b) shows the toner beam at the “off” state.[9] In the system, a dented electrode, lower control electrode, upper control electrode and pulling electrode are placed parallel in the horizontal line, respectively, leaving a certain distance between them using insulating sheets. The dented electrode and the pulling electrode are used to generate toner cloud and confine toner cloud at the dented area. The toner movement is controlled by a switch of the electric field polarity between two control electrodes. By applying an extracting electric field to the toner cloud, the toner beam is extracted from the toner cloud and is project to paper. These procedures produce a toner dot on the paper.

The toner beam is controlled as shown in Figure 2-14. For the on state case, the voltage applied to the upper control electrode is higher than the voltage applied to the lower control electrode and results in the negatively charged toner moves upward passing through the control electrode. In an opposite way, the off state means the voltage of the upper electrodes is less than the lower electrode. The toner cannot pass the control electrode because the direction of electric field in the aperture of control electrodes becomes blocking.



(a) “on” state (b) “off” state

Figure 2-14 Toner beam control mechanism

2.2.Literature Reviews

In early research, the toner jumping property in electric field is investigated to understand the movement of electrostatically charged toner particles, which occur during the development, transfer, and cleaning step in copying machines and laser printers. Subsequently, this property became useful for invention of a new direct printing process called Toner Cloud Beam, TCB.

The measurement of van der Waals force of toner adhesion between various substrates and different particle sizes of toner, which involves the measurement of the detachment force by toner jumping between the parallel plates. This method was proposed by Hoshino et al.[10] In their experiment, three difference sizes of toner including small, medium and large size were used. There are three types of substrates used including stainless steel, silicon wafer and PPC paper. According to the experiment, conducting toners were first sprayed on the lower plate, then applied the ramped voltage to the plates at a constant rate. When the electrostatic force of detachment exceeded the force of adhesion between toners and substrate, there was a significant increase of current between the two parallel plates. The particles jumped from the lower plate and reach the upper plate. Then the threshold voltage was determined and the van der Waals force between the toner and test substrates was estimated. They found that the threshold voltage, for detachment of toners from the substrate, decreases with increasing particle size. The threshold voltage for toner jumping remains essentially the same for both stainless and silicon wafers. They found that the threshold voltage had to be significantly higher for toner jumping to start when the moist papers were used. Moreover, by changing the rate of increase of the voltage, it indicated that the charging time constant was less than the time required for electric field to reach its threshold value start from zero.

In the experiment of Kiatkamjornwong et al,[14] they applied the toner jumping method to estimate toner adhesion force by electric field activated toner jumping, by which various substrates and toner particle size were used. Four conductive toner sizes were studied including large-to-large size (14.6 μm), large-to-medium size (12.5 μm), medium-to-large (9.43 μm) and medium-to-medium size (7.7 μm). The lower electrodes used were a crystalline silicon wafer, Organic Photoconductor (OPC), ITO coated glass and stainless steel. In addition, several toner application methods were tried including free falling, wipe-on using Kim-wipe and magnetic brush. Toner was first sprayed on one of a pair of electrodes. Voltage increase at a constant rate was applied to the electrodes. From the toner jumping voltage, the adhesion force was estimated. The conductive glass shows significantly different jumping voltage of the toner whereas the amorphous silicon film was inactive to the voltage applied and toners cannot jump. Using magnetic brushing technique, the threshold voltage is higher than Kim-wipe rubbing and free falling, respectively when the same type of lower electrode was used. Kiatkamjornwong et al. results confirmed Hoshino et al. work, the smaller the toner size, the higher the toner jumping voltage.

The influence of electrostatic and van der Waals forces to toner adhesion was further discussed by Fukuchi and Takeuchi[11, 17], by comparing results of toner jumping method and centrifugal method. To measure the toner adhesion forces by the toner jumping method, a toner was spattered over on the lower electrode. The dc voltage applied to the electrodes was increased at a constant rate, and the occurrence of the toner jumping was observed by measuring the current flowing between the electrodes. The toner adhesion force was then estimated from the voltage at the occurrence of the toner jumping. The numbers of toner particles, which have a certain adhesion force, were estimated. In this research, low resistivity toners were used. The toner adhesion forces were distributed from 10^{-11} to 10^{-7} N. Fukuchi and Takeuchi concluded that the results of the toner adhesion force measurements by the toner jumping method agree well with those by the centrifugal method.

The control of conductive powder cloud by applying the toner jumping method, using the dented electrode was proposed and developed by Hoshino et al.[12, 13] The conductive cloud generation and its cloud confinement between the electrodes using the electrode, dented to a thin lens shape were found. There are three different sizes of the conductive toners of 8.5, 10.71, and 12.85 μm were used. When the conductive toner was charged and controlled by the capacitance of the lower electrode and the conductivity of substrate to the toner for a period corresponding to the toner relaxation time. The toner jumping current between the electrodes is measured. The amplitude of current has a linear relation to the amount of jumping toner at the same electric field. The confinement of toner cloud was confirmed by observing the toner motion through the upper transparent electrode, which is covered by a thin layer of ITO. The confining technique is expected to be useful in such application as Toner Cloud Beam (TCB), which is a new dot formation method.

Toner Cloud Beam (TCB) was also invented by Hoshino et al.[9] The experimental setup for this new dot formation method includes a dented electrode, lower control electrode, upper control electrode and pulling electrode, which are placed parallel, respectively, leaving a certain distance between them using insulating sheets. When the voltage is applied, a number of electrodes modulate the electric field, which makes the charged toner particles move from the dented electrode pass through the aperture of control electrodes and reach the paper beneath the pulling electrode to generate a toner dot.

The effect of toner jumping parameters on toner dot size in electronic digital printing was discussed by Tanyong et al.[15] Toner Cloud Beam using the conductive toner was investigated. The conductive toners were charged by the electric field applied between the electrodes and moved through the control electrodes until reaching the pulling electrode. The paper beneath the pulling electrode recorded this amount of toner and generated a toner dot. The size of the toner dot also depends on the amount of the toner particles that can pass through the control electrode. From the simplified calculation model, they found that when the voltage applied to the upper control electrode increases, the toner dot size increases. The toner dots could be obtained on various potentials applied to the upper control electrode. The results agree with the simplified model calculation in “on” condition. When the voltage applied to the upper control electrode increases, the toner dot size increases. This is because the toner passing area of aperture cross sectional increases. So the toner amount increases when the voltage increases. In a highly “off” condition, a dot is formed. This is considered that the negative toner charge is recharged at the lower control electrode and reaches the upper control electrode. The toner dots are obtained using two different sizes of aperture of the control electrode. When the bigger aperture was used, the area of toner dot is much larger than when the smaller aperture was applied. The behavior of toner powder in the presence of electric field was investigated through the electric field analysis and the simulation of toner trajectory.

Sripho et al. have studied about toner confinement condition for various toner resistivity and electrode shapes.[16] They achieved the conductive toner cloud confinement technique for toner transport mechanism measured in terms of toner jumping current. The upper electrode is ITO glass, which is transparent, and lower electrode is dented to give a cone shape. When a certain value of the electric field was applied between the electrodes, the conductive toner motion was observed through the ITO glass. At the toner cloud state, the conductive toner on the dented electrode is out of sight and becomes like a black cloud that the electric force carries the toner component toward the central axis of the dented electrode. Investigation of the dependence of the toner cloud extent on the toner amount, at three values of the toner characteristic resistivity was carried out. It was found that the increase in the toner amount leads to the larger toner cloud extent by the lower resistivity toner. On the other hand, the smaller the toner cloud extent was found in the high resistivity toner. The toner cloud extent decreases with increasing applied voltage. For the depth of the cone-shaped dented electrode, the smaller toner cloud extent, the larger the depth of the dented electrode. It was also found that the toner jumping current depends on the toner amount. When the toner amount increased, the toner jumping current also increased. Likewise, the applied voltage to the electrodes was higher, the toner jumping current was also increased. The deeper the dented electrode, the greater the toner jumping current. Moreover, the toner characteristic resistivity is another parameter in the toner jumping current. The lower resistivity toner gives the higher toner jumping current. The ELFIN software is additionally used to simulate the toner trajectory in the electric field. The simulated results show that the deeper the dented electrode and/or the higher the applied voltage, the smaller the toner cloud extent. Further, they found that the simulated results are in good agreement with the experimental results.

CHAPTER 3

EXPERIMENTAL

3.1. Materials

- Conductive toner (made in Japan)
    - Mean particle size: 11.25 μm
    - Resistivity: 1.55×10^{10} Ω-cm
    - The specific gravity: 1.9 g/cm^3
- Pulling electrode: Nasa-glass (Indium Tin Oxide; ITO) 100 mm×100 mm×1 mm
- Dented electrodes:
    - Stainless steel plate 100 mm×100 mm×1 mm; Dented area: wide chamber shape with 70 mm×10 mm and 0.2 mm in depth.
    - Stainless steel plate 100 mm×100 mm×1 mm; Dented area: wide chamber shape with 70 mm×10 mm and 0.5 mm in depth.
    - Brass plate 100 mm×100 mm×1 mm; Dented area: two-overlapped cone shape: diameter 5 mm, center distance 5 mm
- Teflon sheet: 0.50 mm in depth (made in Japan)
- Jump wire: 50 mm and 200 mm
- Soldering iron and solder
- Resistors

3.2. Apparatus

- Toner Cloud Beam Control unit (home made) comprising three important units:
    - Electrode: dented electrode and pulling electrode
    - Regulated DC power supply: Model SPD~905s AD-DC SPECTRUM ADAPTOR 5 A., CCE Chatchawan electronics Co., Ltd., Thailand; input AC 200 V 50-60 Hz., output DC 4.5-12 V
    - DC High Voltage Source: UHV 2KP/24 (made in Japan) Model: MHV 12 – 2.0 k, 1000 p Input: + 10.8 ~ + 16.5 V Output: 0 ~ + 2000 V, 1000 μA
- Digital Camera: Casio QV-2300UX, Effective Pixel 1.92 Million, Movie Clips 16 sec.
- Camera stand
- Meter Pro's Kit® 903-150N-B and Meter Sunwa YX-360TRD for voltage measurement
- Digital VDO file viewer software for toner cloud motion analyzing: Program QuickTime Player version 4.0 for windows 95/NT/98
- Scanning Electron Microscope (SEM): JSM-5410LV (manufactured by JEOL Co., Ltd, Akishima, Japan)
- Personal Computer: Pentium MMX, 166 MHz

3.3. Procedure

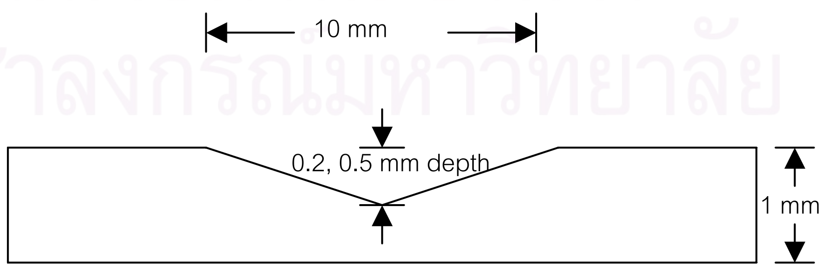
3.3.1 Experiment setup

3.3.1.1 Preparation of electrodes

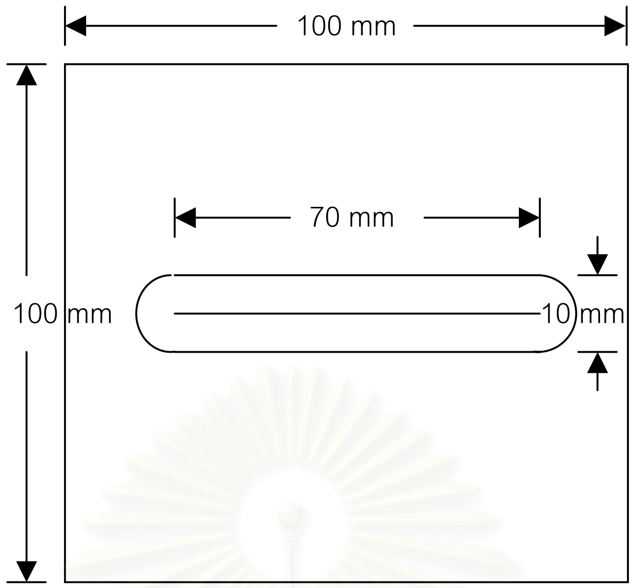
The electrodes used in the experiments are made of a stainless steel and an ITO (Indium Tin Oxide) sputtered transparent glass. The ITO glass is used for observing the toner motion. The ITO glass is flat and the stainless steel electrode is dented into wide chamber shape in which both ends are round shapes. The configurations of the dented electrodes used in this study are given in Table 3-1. Figure 3-1 shows the shape of the dented electrode including the cross section of the dented shape electrode and the top view of the dented electrode.

Table 3-1 The configurations of the dented electrodes.

Shape of Dented Electrode	Length (mm)	Depth (mm)	Width (mm)
wide chamber shape with both round ends	70	0.2 0.5	10



a) Cross section of the dented electrode



b) Top view of the dented electrode

Figure 3-1 The shape of dented electrode; a) Cross section and b) Top view

3.3.1.2 Preparation of Toner Cloud Beam control unit (TCB)

Toner Cloud Beam control unit was prepared as shown in Figure 3-2. The basic circuit for the TCB unit requires a dc voltage source that generates high output voltage for applying to each electrode. In this work, two electrodes are arranged in parallel. The upper electrode is an ITO glass and the lower electrode is dented and named "the dented electrode". The spacing of the two parallel electrodes is set to be 0.50 mm by a Teflon sheet, which is inserted to avoid short circuit.

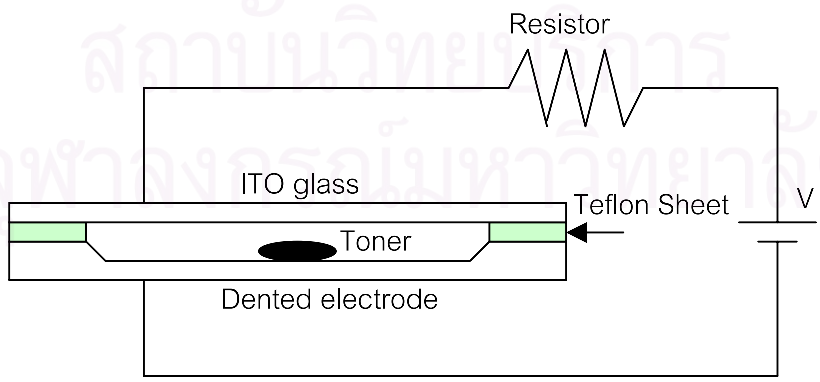


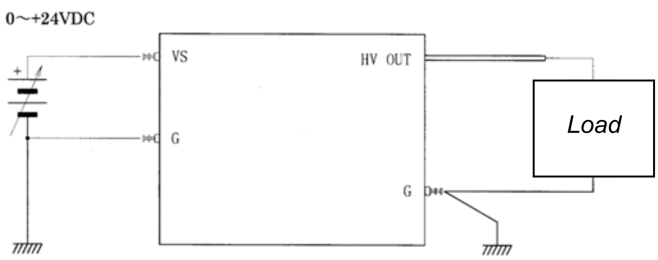
Figure 3-2 Schematic diagram of the TCB unit.

The cell symbol in Figure 3-2 refers to a source of DC electrical power, which provides the high voltage for applying to the circuit. In the experimental set-up, the DC voltage source consists of an AC-DC switching power supply and a HIGH-VOLTAGE DC power supply. The AC-DC power switching supply of SPD~905s manufactured by CCE electronics is shown in Figure 3-3. The SPD~905s converts the AC current into DC and supplies the DC voltage to the HV DC power supply. The input range of this switching power supply is 220 VAC while the output voltage is rated at 12 VDC maximum.

Figure 3-3 AC/DC switching power supply, SPD~905s

In order to generate high voltage, the HIGH-VOLTAGE DC power supply, UHV-2KP/24 as shown in Figure 3-4 (a) is used. The input/output of the UHV-2KP/24 is a non-isolated type as shown in Figure 3-4 (b).

(a)



(b)

Figure 3-4 HIGH-VOLTAGE DC power supply, UHV 2KP/24

The output voltage of the UHV-2KP/24 power supply is directly proportional to the input voltage. The power supply will start with an input voltage as low as 2 volts and will not be damaged by the input voltage as high as 24 volts. The output range of this power supply is 0 ~ 2kV.[14]

The experimental set up for toner cloud generation is illustrated in Figure 3-5.

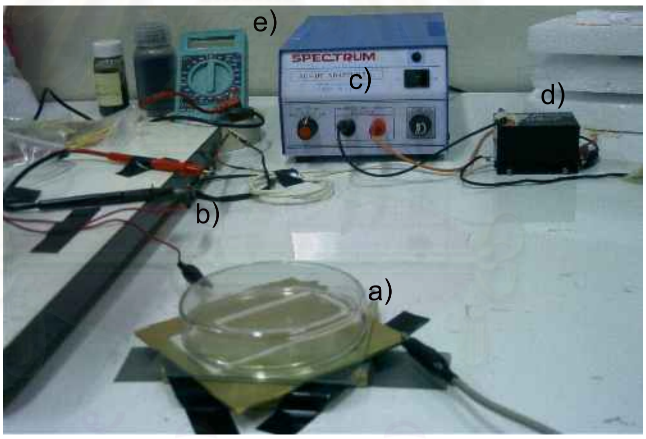


Figure 3-5 Toner Cloud Beam Unit; a) electrode setup, b) resister, c) AC/DC switching power supply, SPD~905s, d) HIGH-VOLTAGE DC power supply, UHV 2KP/24 and e) Meter Pro's Kit® 903-150N-B for voltage measurement

3.3.2 Experimental Procedure

3.3.2.1 Dependence of toner cloud movement on the applied voltage and the toner amount

Table 3-2 Voltage and the amount of the conductive toner.

Depth of dented electrode (mm)	Amount of conductive toner (mg)	Voltage (V)	Slope of Nesa glass (degree)
0.5 0.2	3 4 6	521 757 961 1202 1678	Parallel 0.64 0.95

a) Conductive toner weighed approximately 3 mg was put into the dented electrode at the center of the chamber. The width and depth of the dented electrode are 70 mm and 0.5 mm, respectively. The voltages applied to the electrode were 521, 757, 961, 1202, and 1678V to generate toner cloud. A digital camera (Casio QV-2300UX) was used to take movie clips of the toner cloud movement through ITO glass at real time. Two replicas were taken for each experiment.

b) The amount of toner was varied to 4 mg and 6 mg then the step a) was repeated.

c) The position of applying toner was changed from the center of the chamber to the one end of the width of the dented electrode and the steps a) and b) were the repeated.

d) Toner cloud movement was captured from the start of applying voltage. After that, the traveled distance of the front toner cloud was measured basically by using software QuickTime 4.0. Next, the traveled distance and the derivative velocity of the front toner cloud was calculated and plotted in a graph to indicate the relationship between the toner cloud movement and its applied voltage. This method gives the dependency of the toner cloud velocity on the applied voltage. Furthermore, the traveled distance of the front toner cloud and the toner amount was plotted to find the relationship between the toner cloud movement and the toner amount. Such a plot exhibits the dependency of the velocity of the toner cloud on the toner amount.

3.3.2.2 Dependence of toner cloud movement on the slope of Nesa glass

The slope set-up of ITO glass over the dented electrode is shown in Figure 3-6. The slope of ITO glass was varied at about 0.64 and 0.95 degree. Then, the step 3.2.2.1 was repeated.

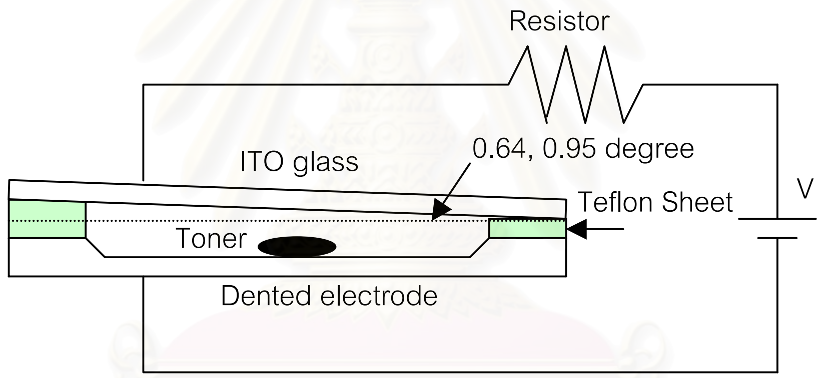


Figure 3-6 The set-up slope of ITO glass over the dented electrode

3.3.2.3 Dependence of toner cloud movement on the slope of the system

The dependence of the toner movement on the applied voltage was studied using the wide chamber shape of the dented electrode with the depths of 0.5 and 0.2 mm. The wide chamber shape of the dented electrode was applied at one electrode end with the conductive toner. The amounts of conductive toner are 3, 4, and 6 mg the same as the previous step used. The applied voltages used are 521, 757, 961, 1202, and 1678 V and the spacing between the electrodes is 0.50 mm. The system was set on the slope, which was inclined at 2.86, and 5.31 degrees. After the applied voltages have been set, the experimental procedures of step 3.2.2.1 were repeated except applying toner at the center.

3.3.2.4 Dependence of toner cloud movement on the depth of electrode

From the data of the steps 3.3.2.1, 3.3.2.2 and 3.3.2.3, the dented electrode with the depth of 0.5 mm and 0.2 mm was compared to study the effect of the depth of the dented electrode on the front toner cloud movement. Again, the traveled distance of the front toner cloud and the toner amount were plotted to get the relationship between the front toner cloud movement and the depth of dented electrode. Such a plot gives the dependency of the traveled distance of the front toner cloud on the depth of electrode.

3.3.3 Determination of toner supplying

The two-overlapped cone shape dented electrode as shown in Figure 3-7 was replaced to determine the supplying toner method. The dependence of the toner transfer speed on the applied voltage was studied using three pieces of the two-overlapped cone shape dented electrode with the input toner amount 3 mg. The configuration of three pieces of the two-overlapped cone shape dented electrode is shown in Table 3.3. The applied voltages used are 521, 961 and 1202 V and the spacing between the electrodes is 0.50 mm.

Figure 3-7 The OLDE_01 dented electrode for toner supplying

Table 3-3 Configuration of the two-overlapped cone shape dented electrode.

NAME	Diameter of two cones (mm)	Center distance of two cones (mm)
OLDE_01	3 and 5	5
OLDE_02	5 and 5	5
OLDE_03	4.5 and 5	5

3.3.4 Determination of toner particle morphology

The highly conductive toners were analyzed for the morphology in terms of particle shape and size by SEM technique.

CHAPTER 4

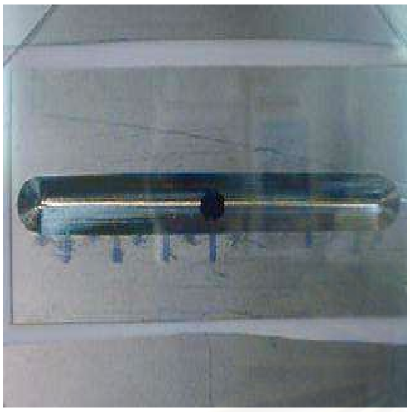
RESULTS AND DISCUSSION

4.1.Toner Cloud Motion Condition

It is known that printing technology such as electrophotography is the technology of controlling toner precisely onto paper. The control of the conductive toner motion is very important in most applications. As mentioned in Chapter 2, the toner cloud confinement condition was studied using an electrode dented to a cone shape. The conductive toner was sprayed freely on the dented electrode. When more than a certain value of electric field had been applied between the electrodes, the conductive toner started to move up and down between the electrodes by electrostatic force. The conductive toner was confined between the electrodes in the dented area.

As stated in Chapter 3, the electrodes used in the experiments are made of a stainless steel plate and the second one, the ITO sputted transparent glass. The ITO glass was used for observing the toner motion. The stainless steel plate was dented to a wide chamber shape that is round at both ends.

4.1.1 Dependence of toner cloud motion on applied voltage



a) toner before the cloud state

b) toner cloud at the cloud state (~2 sec.)

c) toner cloud at the steady state

d) toner after the cloud state

Figure 4-1 The photographs of the conductive toner observed through the ITO glass, a) toner before the cloud state, b) toner cloud at the cloud state, c) toner cloud at the steady state and d) toner after the cloud state

Figure 4-1 displays the photographs of the toner before the cloud state, the toner motion at the cloud state, the toner cloud at the steady state and the toner after the cloud state. After the voltage had been applied to the electrodes, the conductive toner started to move up and down between the electrodes by the electric force. Dispersion or scattering of the conductive toner on the dented electrode governed the cloud to propagate to both ends. The conductive toner on the electrode became like a black cloud and moved toward both ends as shown in Figure 4-1 b). After the toner cloud reached both ends, it became a steady state as shown in Figure 4-1 c). When the applied voltage was stopped, the conductive toner moved down to the dented electrode. It was confined on the dented electrode as shown in Figure 4-1 d). The movement of the toner cloud was captured in a video file using a digital camera whereas the displacement of front toner cloud was basically measured using a software called QuickTime 4.0. The fundamental data of the displacement of front toner cloud on the 0.5 mm depth dented electrode are shown in Tables 4-1 to 4-9 and the 0.2 mm depth dented in Tables 4-10 to 4-18 in the case of toner input on the center of dented electrode and the nesa glass was set parallel, 0.64, and 0.95 degrees to the dented electrode.

Table 4-1 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, input toner 3 mg at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of				
	521	757	961	1202	1678
0.33	0.0060	0.0084	0.0102	0.0137	0.0187
0.67	0.0070	0.0102	0.0120	0.0159	0.0216
1.00	0.0083	0.0119	0.0136	0.0178	0.0237
2.00	0.0101	0.0177	0.0215	0.0238	0.0312
3.00	0.0130	0.0212	0.0263	0.0296	0.0338
4.00	0.0145	0.0251	0.0303	0.0339	0.0350
5.00	0.0161	0.0288	0.0333	0.0347	0.0350
6.00	0.0178	0.0312	0.0346	0.0350	0.0350
7.00	0.0192	0.0329	0.0349	0.0350	0.0350
8.00	0.0204	0.0342	0.0350	0.0350	0.0350
9.00	0.0214	0.0347	0.0350	0.0350	0.0350
10.00	0.0223	0.0349	0.0350	0.0350	0.0350
11.00	0.0231	0.0350	0.0350	0.0350	0.0350
12.00	0.0244	0.0350	0.0350	0.0350	0.0350
13.00	0.0263	0.0350	0.0350	0.0350	0.0350
14.00	0.0283	0.0350	0.0350	0.0350	0.0350
15.00	0.0296	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-2 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 3 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0110	0.0131	0.0157	0.0174
0.67	0.0121	0.0144	0.0185	0.0230
1.00	0.0133	0.0161	0.0212	0.0286
1.33	NA	NA	0.0245	0.0344
1.67	NA	NA	0.0278	0.0350
2.00	0.0164	0.0194	0.0311	0.0350
2.33	NA	NA	0.0345	0.0350
2.67	NA	NA	0.0350	0.0350
3.00	0.0192	0.0278	0.0350	0.0350
4.00	0.0214	0.0344	0.0350	0.0350
5.00	0.0265	0.0350	0.0350	0.0350
6.00	0.0316	0.0350	0.0350	0.0350
7.00	0.0347	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-3 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 3 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0081	0.0120	0.0152	0.0210
0.67	0.0094	0.0152	0.0196	0.0309
1.00	0.0107	0.0183	0.0234	0.0350
1.33	NA	0.0214	0.0304	0.0350
1.67	NA	0.0256	0.0347	0.0350
2.00	0.0138	0.0298	0.0350	0.0350
2.33	NA	NA	0.0350	0.0350
2.67	NA	NA	0.0350	0.0350
3.00	0.0162	0.0350	0.0350	0.0350
4.00	0.0190	0.0350	0.0350	0.0350
5.00	0.0222	0.0350	0.0350	0.0350
6.00	0.0256	0.0350	0.0350	0.0350
7.00	0.0290	0.0350	0.0350	0.0350
8.00	0.0313	0.0350	0.0350	0.0350
9.00	0.0334	0.0350	0.0350	0.0350
10.00	0.0342	0.0350	0.0350	0.0350
11.00	0.0347	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-4 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 4 mg put at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of				
	521	757	961	1202	1678
0.33	0.0073	0.0095	0.0125	0.0165	0.0205
0.67	0.0084	0.0112	0.0147	0.0187	0.0231
1.00	0.0091	0.0126	0.0166	0.0211	0.0256
2.00	0.0125	0.0188	0.0227	0.0272	0.0312
3.00	0.0148	0.0259	0.0298	0.0323	0.0338
4.00	0.0160	0.0299	0.0334	0.0338	0.0349
5.00	0.0176	0.0323	0.0347	0.0345	0.0350
6.00	0.0186	0.0333	0.0350	0.0349	0.0350
7.00	0.0200	0.0339	0.0350	0.0350	0.0350
8.00	0.0215	0.0345	0.0350	0.0350	0.0350
9.00	0.0235	0.0347	0.0350	0.0350	0.0350
10.00	0.0255	0.0350	0.0350	0.0350	0.0350
11.00	0.0269	0.0350	0.0350	0.0350	0.0350
12.00	0.0278	0.0350	0.0350	0.0350	0.0350
13.00	0.0287	0.0350	0.0350	0.0350	0.0350
14.00	0.0296	0.0350	0.0350	0.0350	0.0350
15.00	0.0302	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-5 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 4 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0114	0.0125	0.0157	0.0195
0.67	0.0126	0.0150	0.0195	0.0255
1.00	0.0141	0.0169	0.0228	0.0312
1.33	NA	NA	0.0274	0.0339
1.67	NA	NA	0.0320	0.0350
2.00	0.0175	0.0236	0.0339	0.0350
3.00	0.0218	0.0319	0.0350	0.0350
4.00	0.0264	0.0342	0.0350	0.0350
5.00	0.0332	0.0350	0.0350	0.0350
6.00	0.0341	0.0350	0.0350	0.0350
7.00	0.0347	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-6 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 4 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0100	0.0139	0.0161	0.0192
0.67	0.0111	0.0167	0.0209	0.0342
1.00	0.0124	0.0185	0.0287	0.0350
1.33	NA	0.0223	0.0345	0.0350
1.67	NA	0.0243	0.0350	0.0350
2.00	0.0154	0.0312	0.0350	0.0350
3.00	0.0173	0.0347	0.0350	0.0350
4.00	0.0191	0.0350	0.0350	0.0350
5.00	0.0224	0.0350	0.0350	0.0350
6.00	0.0255	0.0350	0.0350	0.0350
7.00	0.0301	0.0350	0.0350	0.0350
8.00	0.0324	0.0350	0.0350	0.0350
9.00	0.0342	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-7 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 6 mg put at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of				
	521	757	961	1202	1678
0.33	0.0085	0.0117	0.0148	0.0173	0.0229
0.67	0.0097	0.0137	0.0169	0.0196	0.0251
1.00	0.0110	0.0154	0.0189	0.0219	0.0273
2.00	0.0133	0.0204	0.0242	0.0288	0.0318
3.00	0.0159	0.0272	0.0298	0.0316	0.0340
4.00	0.0176	0.0309	0.0326	0.0328	0.0348
5.00	0.0187	0.0321	0.0335	0.0336	0.0350
6.00	0.0199	0.0333	0.0342	0.0346	0.0350
7.00	0.0215	0.0339	0.0349	0.0349	0.0350
8.00	0.0224	0.0343	0.0350	0.0350	0.0350
9.00	0.0237	0.0347	0.0350	0.0350	0.0350
10.00	0.0246	0.0349	0.0350	0.0350	0.0350
11.00	0.0254	0.0350	0.0350	0.0350	0.0350
12.00	0.0265	0.0350	0.0350	0.0350	0.0350
13.00	0.0281	0.0350	0.0350	0.0350	0.0350
14.00	0.0291	0.0350	0.0350	0.0350	0.0350
15.00	0.0298	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-8 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 6 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0126	0.0139	0.0175	0.0189
0.67	0.0146	0.0161	0.0208	0.0258
1.00	0.0165	0.0186	0.0235	0.0325
1.33	NA	NA	0.0263	0.0350
1.67	NA	NA	0.0301	0.0350
2.00	0.0202	0.0269	0.0345	0.0350
3.00	0.0247	0.0336	0.0350	0.0350
4.00	0.0314	0.0347	0.0350	0.0350
5.00	0.0347	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-9 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 6 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0127	0.0154	0.0161	0.0256
0.67	0.0146	0.0191	0.0240	0.0344
1.00	0.0168	0.0229	0.0280	0.0350
1.33	NA	NA	0.0323	0.0350
1.67	NA	NA	0.0342	0.0350
2.00	0.0218	0.0316	0.0350	0.0350
3.00	0.0265	0.0340	0.0350	0.0350
4.00	0.0309	0.0347	0.0350	0.0350
5.00	0.0336	0.0350	0.0350	0.0350
6.00	0.0342	0.0350	0.0350	0.0350
7.00	0.0347	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-10 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 3 mg put at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0123	0.0144	0.0162	0.0191
0.67	0.0174	0.0197	0.0215	0.0288
1.00	0.0225	0.0241	0.0274	0.0338
1.33	0.0252	0.0298	0.0325	0.0350
1.67	0.0291	0.0336	0.0346	0.0350
2.00	0.0324	0.0350	0.0350	0.0350
2.33	0.0344	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-11 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 3 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0106	0.0128	0.0174	0.0205
0.67	0.0149	0.0200	0.0271	0.0347
1.00	0.0182	0.0281	0.0347	0.0350
1.33	0.0233	0.0342	0.0350	0.0350
1.67	0.0269	0.0350	0.0350	0.0350
2.00	0.0312	0.0350	0.0350	0.0350
2.33	0.0339	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-12 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 3 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0091	0.0106	0.0141	0.0219
0.67	0.0121	0.0163	0.0225	0.0349
1.00	0.0148	0.0205	0.0347	0.0350
1.33	0.0166	0.0253	0.0350	0.0350
1.67	0.0187	0.0333	0.0350	0.0350
2.00	0.0203	0.0350	0.0350	0.0350
2.33	0.0233	0.0350	0.0350	0.0350
2.67	0.0253	0.0350	0.0350	0.0350
3.00	0.0275	0.0350	0.0350	0.0350
4.00	0.0341	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-13 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 4 mg put at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0137	0.0160	0.0171	0.0208
0.67	0.0184	0.0219	0.0246	0.0304
1.00	0.0231	0.0274	0.0310	0.0341
1.33	0.0269	0.0300	0.0335	0.0350
1.67	0.0299	0.0325	0.0348	0.0350
2.00	0.0321	0.0338	0.0350	0.0350
2.33	0.0335	0.0345	0.0350	0.0350
2.67	0.0343	0.0348	0.0350	0.0350
3.00	0.0348	0.0349	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-14 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 4 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0139	0.0160	0.0193	0.0254
0.67	0.0182	0.0229	0.0284	0.0350
1.00	0.0230	0.0295	0.0350	0.0350
1.33	0.0276	0.0345	0.0350	0.0350
1.67	0.0319	0.0350	0.0350	0.0350
2.00	0.0341	0.0350	0.0350	0.0350
2.33	0.0350	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-15 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 4 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0114	0.0139	0.0181	0.0244
0.67	0.0167	0.0217	0.0317	0.0350
1.00	0.0211	0.0292	0.0347	0.0350
1.33	0.0247	0.0347	0.0350	0.0350
1.67	0.0289	0.0350	0.0350	0.0350
2.00	0.0325	0.0350	0.0350	0.0350
2.33	0.0336	0.0350	0.0350	0.0350
2.67	0.0347	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-16 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 6 mg put at the center, and the nesa glass was set parallel to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0140	0.0164	0.0170	0.0208
0.67	0.0190	0.0225	0.0236	0.0317
1.00	0.0225	0.0275	0.0304	0.0344
1.33	0.0250	0.0316	0.0343	0.0349
1.67	0.0299	0.0338	0.0350	0.0350
2.00	0.0330	0.0349	0.0350	0.0350
2.33	0.0346	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

Table 4-17 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 6 mg put at the center, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0122	0.0155	0.0196	0.0256
0.67	0.0190	0.0240	0.0320	0.0350
1.00	0.0247	0.0326	0.0350	0.0350
1.33	0.0290	0.0350	0.0350	0.0350
1.67	0.0323	0.0350	0.0350	0.0350
2.00	0.0347	0.0350	0.0350	0.0350
2.33	0.0350	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

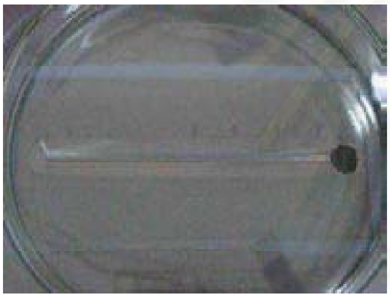
The average displacement was obtained from 3 measurements (m)

Table 4-18 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 6 mg put at the center, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

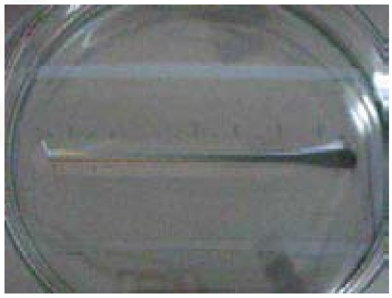
Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0119	0.0160	0.0200	0.0274
0.67	0.0176	0.0241	0.0328	0.0350
1.00	0.0231	0.0331	0.0350	0.0350
1.33	0.0269	0.0350	0.0350	0.0350
1.67	0.0309	0.0350	0.0350	0.0350
2.00	0.0336	0.0350	0.0350	0.0350
2.33	0.0350	0.0350	0.0350	0.0350
2.67	0.0350	0.0350	0.0350	0.0350
3.00	0.0350	0.0350	0.0350	0.0350
4.00	0.0350	0.0350	0.0350	0.0350
5.00	0.0350	0.0350	0.0350	0.0350
6.00	0.0350	0.0350	0.0350	0.0350
7.00	0.0350	0.0350	0.0350	0.0350
8.00	0.0350	0.0350	0.0350	0.0350
9.00	0.0350	0.0350	0.0350	0.0350
10.00	0.0350	0.0350	0.0350	0.0350
11.00	0.0350	0.0350	0.0350	0.0350
12.00	0.0350	0.0350	0.0350	0.0350
13.00	0.0350	0.0350	0.0350	0.0350
14.00	0.0350	0.0350	0.0350	0.0350
15.00	0.0350	0.0350	0.0350	0.0350

The average displacement was obtained from 3 measurements (m)

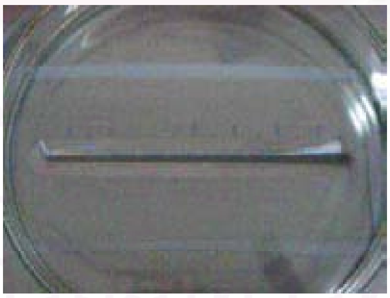
The experiment was reset up again in case of the toner input at one end of the dented electrode in which the nesa glass was tilted to the dented electrode to follow precisely the toner cloud motion under the same condition. Figure 4-2 displays photographs of the conductive toner amount of 6 mg, on one side of the dented electrode at the 0.5 mm depth and observed by the ITO glass which was set to tilt at 0.64 degree to the dented electrode; the applied voltage was 1678 V for a) toner before the cloud state, b) toner cloud at 1 sec after applying voltage, and c) toner cloud at 8 sec after applying voltage. After the voltage had been applied to the electrode, the toner cloud propagated to the opposite side. The influence of applied voltage on the dispersion or scattering of the conductive toner on the dented electrode is shown in Tables 4-19 to 4-30 as the fundamental results of the front toner cloud displacement.



a) toner before the cloud state



b) toner cloud at 1 sec after applying the voltage



c) toner cloud at 8 sec after applying the voltage

Figure 4-2 The photographs of the conductive toner (6 mg) on one side of the dented electrode (0.5 mm depth) observed through the ITO glass (0.64 degree tilted to the dented electrode) and the applied voltage of 1678 V for a) toner before the cloud state, b) toner cloud motion at 1 sec and c) toner cloud at 8 sec.

Table 4-19 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 3 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0132	0.0147	0.0161	0.0192
0.67	0.0151	0.0174	0.0211	0.0244
1.00	0.0165	0.0199	0.0244	0.0306
1.33	NA	NA	0.0286	0.0383
1.67	NA	NA	0.0344	0.0450
2.00	0.0252	0.0285	0.0397	0.0497
2.33	NA	NA	0.0442	0.0556
2.67	NA	NA	0.0483	0.0644
3.00	0.0288	0.0349	0.0517	0.0697
4.00	0.0330	0.0459	0.0661	0.0700
5.00	0.0403	0.0531	0.0700	0.0700
6.00	0.0453	0.0614	0.0700	0.0700
7.00	0.0512	0.0675	0.0700	0.0700
8.00	0.0588	0.0700	0.0700	0.0700
9.00	0.0633	0.0700	0.0700	0.0700
10.00	0.0664	0.0700	0.0700	0.0700
11.00	0.0689	0.0700	0.0700	0.0700
12.00	0.0697	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-20 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 3 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0167	0.0174	0.0189	0.0247
0.67	0.0191	0.0240	0.0291	0.0357
1.00	0.0209	0.0301	0.0409	0.0475
1.33	NA	0.0380	0.0477	0.0611
1.67	NA	0.0444	0.0535	0.0692
2.00	0.0294	0.0481	0.0611	0.0700
2.33	NA	0.0523	0.0682	0.0700
2.67	NA	0.0557	0.0700	0.0700
3.00	0.0361	0.0575	0.0700	0.0700
4.00	0.0424	0.0654	0.0700	0.0700
5.00	0.0461	0.0679	0.0700	0.0700
6.00	0.0498	0.0700	0.0700	0.0700
7.00	0.0554	0.0700	0.0700	0.0700
8.00	0.0594	0.0700	0.0700	0.0700
9.00	0.0666	0.0700	0.0700	0.0700
10.00	0.0684	0.0700	0.0700	0.0700
11.00	0.0695	0.0700	0.0700	0.0700
12.00	0.0697	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-21 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 4 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0131	0.0171	0.0176	0.0212
0.67	0.0149	0.0200	0.0236	0.0281
1.00	0.0170	0.0227	0.0278	0.0344
1.33	NA	NA	0.0338	0.0401
1.67	NA	NA	0.0389	0.0467
2.00	0.0232	0.0323	0.0422	0.0521
2.33	NA	NA	0.0491	0.0586
2.67	NA	NA	0.0535	0.0661
3.00	0.0310	0.0401	0.0586	0.0697
4.00	0.0363	0.0464	0.0670	0.0700
5.00	0.0429	0.0535	0.0700	0.0700
6.00	0.0470	0.0640	0.0700	0.0700
7.00	0.0500	0.0685	0.0700	0.0700
8.00	0.0533	0.0697	0.0700	0.0700
9.00	0.0566	0.0700	0.0700	0.0700
10.00	0.0596	0.0700	0.0700	0.0700
11.00	0.0628	0.0700	0.0700	0.0700
12.00	0.0643	0.0700	0.0700	0.0700
13.00	0.0655	0.0700	0.0700	0.0700
14.00	0.0661	0.0700	0.0700	0.0700
15.00	0.0661	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-22 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 4 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0164	0.0244	0.0209	0.0233
0.67	0.0189	0.0281	0.0296	0.0369
1.00	0.0203	0.0315	0.0350	0.0497
1.33	NA	NA	0.0460	0.0628
1.67	NA	NA	0.0557	0.0697
2.00	0.0294	0.0434	0.0666	0.0700
2.33	NA	NA	0.0700	0.0700
2.67	NA	NA	0.0700	0.0700
3.00	0.0384	0.0569	0.0700	0.0700
4.00	0.0440	0.0652	0.0700	0.0700
5.00	0.0489	0.0687	0.0700	0.0700
6.00	0.0586	0.0700	0.0700	0.0700
7.00	0.0654	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-23 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 6 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0154	0.0188	0.0183	0.0228
0.67	0.0167	0.0215	0.0243	0.0289
1.00	0.0184	0.0242	0.0308	0.0367
1.33	NA	NA	0.0347	0.0422
1.67	NA	NA	0.0395	0.0471
2.00	0.0247	0.0313	0.0443	0.0528
2.33	NA	NA	0.0497	0.0625
2.67	NA	NA	0.0539	0.0697
3.00	0.0296	0.0419	0.0593	0.0700
4.00	0.0343	0.0482	0.0700	0.0700
5.00	0.0409	0.0580	0.0700	0.0700
6.00	0.0458	0.0662	0.0700	0.0700
7.00	0.0500	0.0697	0.0700	0.0700
8.00	0.0549	0.0700	0.0700	0.0700
9.00	0.0601	0.0700	0.0700	0.0700
10.00	0.0640	0.0700	0.0700	0.0700
11.00	0.0670	0.0700	0.0700	0.0700
12.00	0.0692	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-24 The average displacement of the front toner cloud (dented electrode 0.5 mm depth, toner 6 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0175	0.0254	0.0216	0.0283
0.67	0.0204	0.0292	0.0330	0.0440
1.00	0.0230	0.0335	0.0388	0.0595
1.33	NA	NA	0.0475	0.0700
1.67	NA	NA	0.0598	0.0700
2.00	0.0318	0.0461	0.0674	0.0700
2.33	NA	NA	0.0700	0.0700
2.67	NA	NA	0.0700	0.0700
3.00	0.0373	0.0592	0.0700	0.0700
4.00	0.0435	0.0700	0.0700	0.0700
5.00	0.0490	0.0700	0.0700	0.0700
6.00	0.0618	0.0700	0.0700	0.0700
7.00	0.0688	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

NA = not available data due to unshaped toner image

The average displacement was obtained from 3 measurements (m)

Table 4-25 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 3 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0147	0.0179	0.0201	0.0281
0.67	0.0221	0.0284	0.0339	0.0441
1.00	0.0266	0.0364	0.0419	0.0633
1.33	0.0319	0.0428	0.0511	0.0700
1.67	0.0370	0.0499	0.0636	0.0700
2.00	0.0416	0.0566	0.0690	0.0700
2.33	0.0474	0.0639	0.0700	0.0700
2.67	0.0508	0.0687	0.0700	0.0700
3.00	0.0572	0.0700	0.0700	0.0700
4.00	0.0694	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

Table 4-26 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 3 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0161	0.0218	0.0246	0.0336
0.67	0.0248	0.0335	0.0373	0.0572
1.00	0.0310	0.0415	0.0510	0.0700
1.33	0.0356	0.0503	0.0622	0.0700
1.67	0.0429	0.0553	0.0700	0.0700
2.00	0.0474	0.0608	0.0700	0.0700
2.33	0.0511	0.0663	0.0700	0.0700
2.67	0.0544	0.0700	0.0700	0.0700
3.00	0.0587	0.0700	0.0700	0.0700
4.00	0.0694	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

Table 4-27 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 4 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0162	0.0204	0.0222	0.0283
0.67	0.0233	0.0289	0.0333	0.0452
1.00	0.0296	0.0368	0.0423	0.0633
1.33	0.0347	0.0438	0.0537	0.0700
1.67	0.0404	0.0502	0.0653	0.0700
2.00	0.0452	0.0583	0.0697	0.0700
2.33	0.0509	0.0636	0.0700	0.0700
2.67	0.0559	0.0691	0.0700	0.0700
3.00	0.0607	0.0700	0.0700	0.0700
4.00	0.0700	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

Table 4-28 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 4 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0188	0.0233	0.0270	0.0349
0.67	0.0261	0.0337	0.0424	0.0585
1.00	0.0329	0.0441	0.0548	0.0700
1.33	0.0388	0.0523	0.0680	0.0700
1.67	0.0439	0.0596	0.0700	0.0700
2.00	0.0486	0.0663	0.0700	0.0700
2.33	0.0543	0.0700	0.0700	0.0700
2.67	0.0582	0.0700	0.0700	0.0700
3.00	0.0633	0.0700	0.0700	0.0700
4.00	0.0700	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

Table 4-29 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 6 mg put at the electrode end, and the nesa glass was set to tilt at 0.64 degree to the dented electrode)

Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0182	0.0211	0.0230	0.0302
0.67	0.0248	0.0306	0.0367	0.0475
1.00	0.0323	0.0383	0.0475	0.0689
1.33	0.0374	0.0457	0.0603	0.0700
1.67	0.0428	0.0529	0.0677	0.0700
2.00	0.0476	0.0632	0.0700	0.0700
2.33	0.0521	0.0675	0.0700	0.0700
2.67	0.0571	0.0700	0.0700	0.0700
3.00	0.0625	0.0700	0.0700	0.0700
4.00	0.0697	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

Table 4-30 The average displacement of the front toner cloud (dented electrode 0.2 mm depth, toner 6 mg put at the electrode end, and the nesa glass was set to tilt at 0.95 degree to the dented electrode)

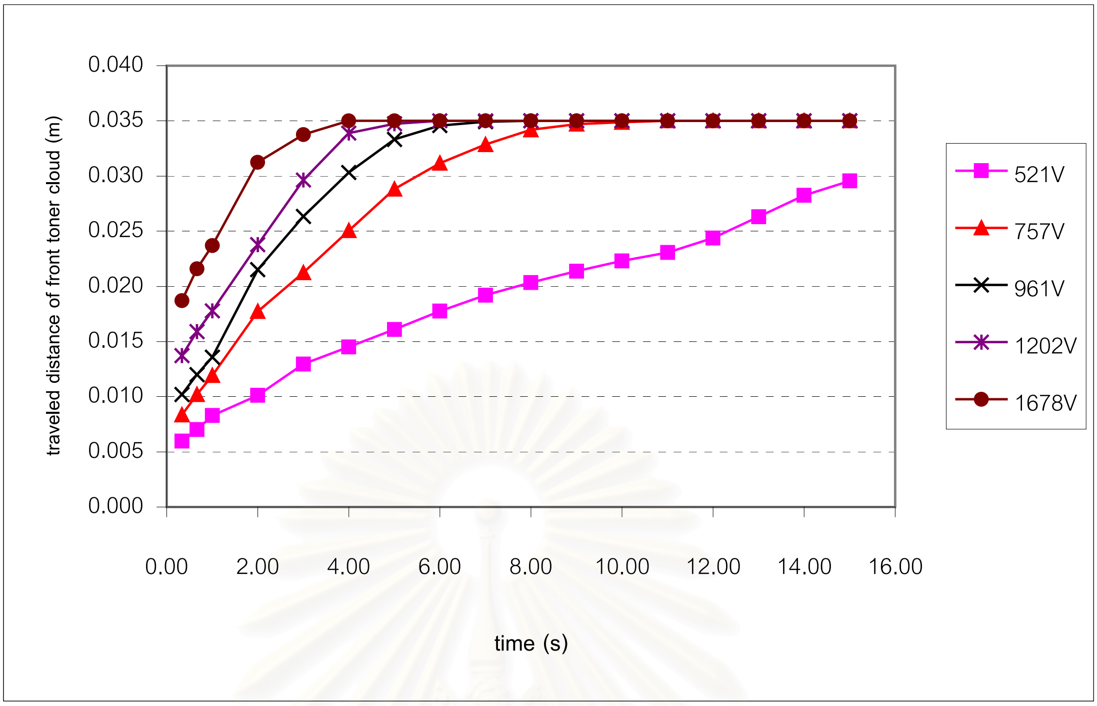
Time (s)	Average displacement when the applied voltage, V of			
	757	961	1202	1678
0.33	0.0198	0.0242	0.0281	0.0373
0.67	0.0266	0.0343	0.0444	0.0596
1.00	0.0340	0.0439	0.0576	0.0700
1.33	0.0404	0.0535	0.0692	0.0700
1.67	0.0445	0.0590	0.0700	0.0700
2.00	0.0497	0.0670	0.0700	0.0700
2.33	0.0544	0.0700	0.0700	0.0700
2.67	0.0585	0.0700	0.0700	0.0700
3.00	0.0626	0.0700	0.0700	0.0700
4.00	0.0700	0.0700	0.0700	0.0700
5.00	0.0700	0.0700	0.0700	0.0700
6.00	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700
15.00	0.0700	0.0700	0.0700	0.0700

The average displacement was obtained from 3 measurements (m)

The dependence of the toner cloud speed on the applied voltage was also studied at various conditions using the wide chamber shape dented electrode. The conditions can be summarized in order as follows:

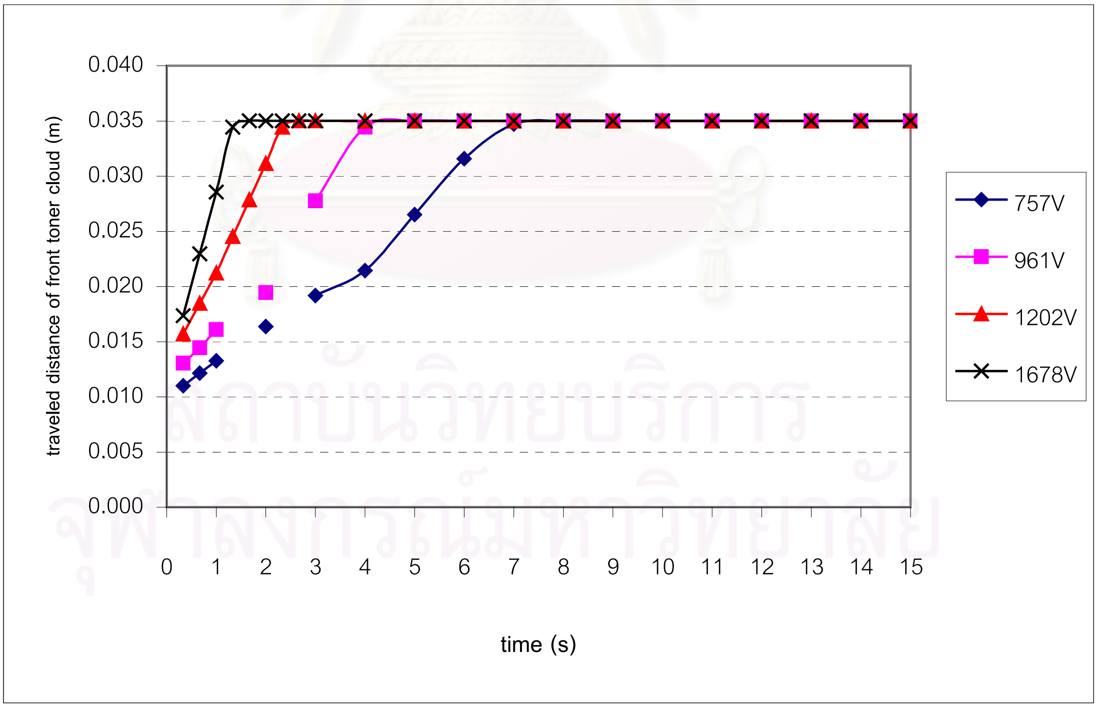
1. Applied voltage dependence
   - 521 V, 757 V, 961 V, 1202 V and 1678 V
2. Toner amount dependence
   - 3 mg, 4 mg and 6 mg
3. The depth of dented electrode dependence
   - 0.2 mm depth and 0.5 mm depth
4. The slope of nesa glass over the dented electrode dependence
   - 0.64 degree and 0.95 degree
5. The slope of the system dependence
   - 2.86 degrees and 5.31 degrees

Figures 4-3 to 4-14 show the relationship between the displacement of the front toner cloud and the applied voltage from the fundamental data in Tables 4-1 to 4-30. The higher applied voltage produces the faster speed of the toner cloud during toner jumping, resulting from the greater speed and higher frequency of the up and down movements of the toner particles on the dented electrode.



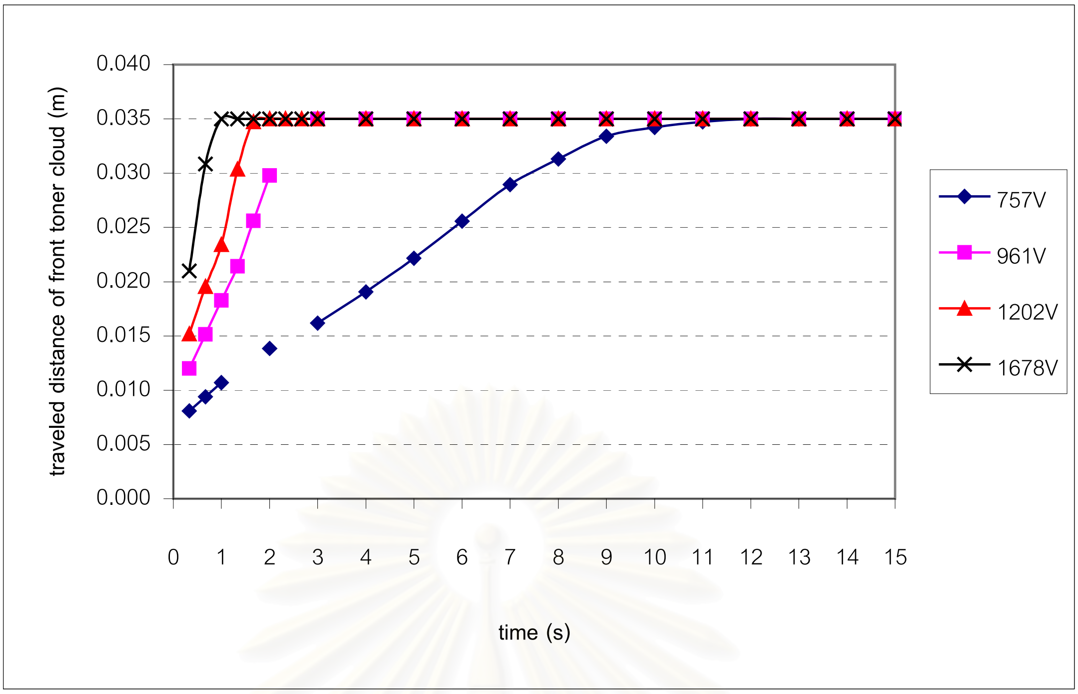
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
time (s)
521V
757V
961V
1202V
1678V

a)



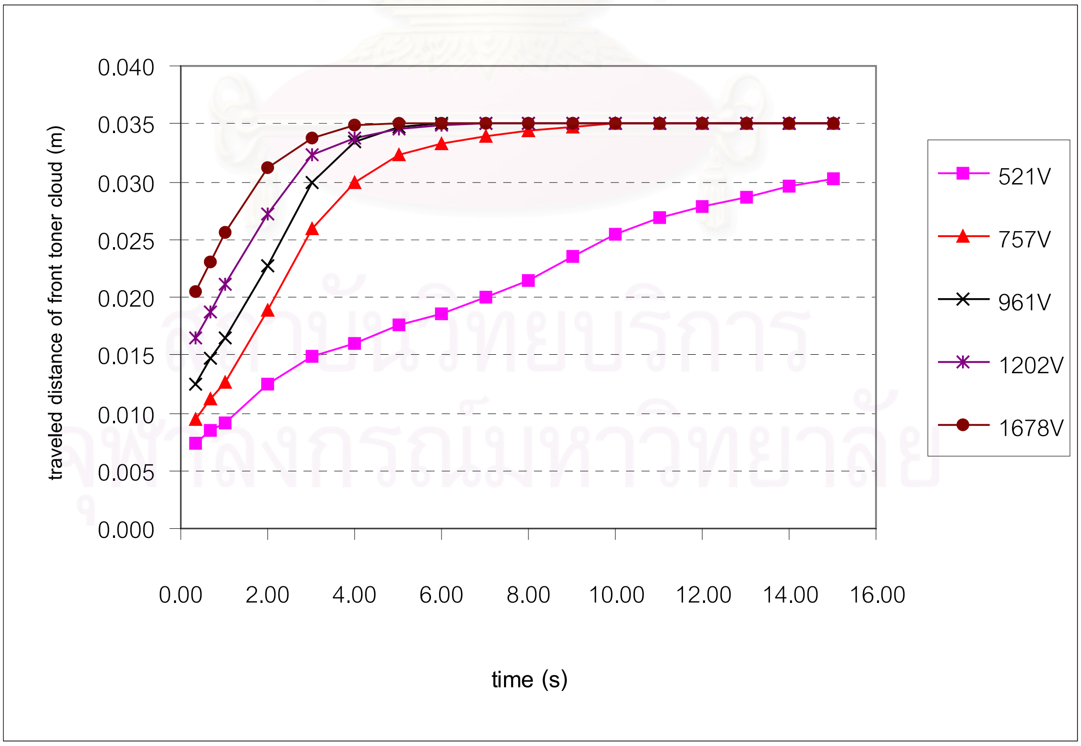
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
time (s)
757V
961V
1202V
1678V

b)

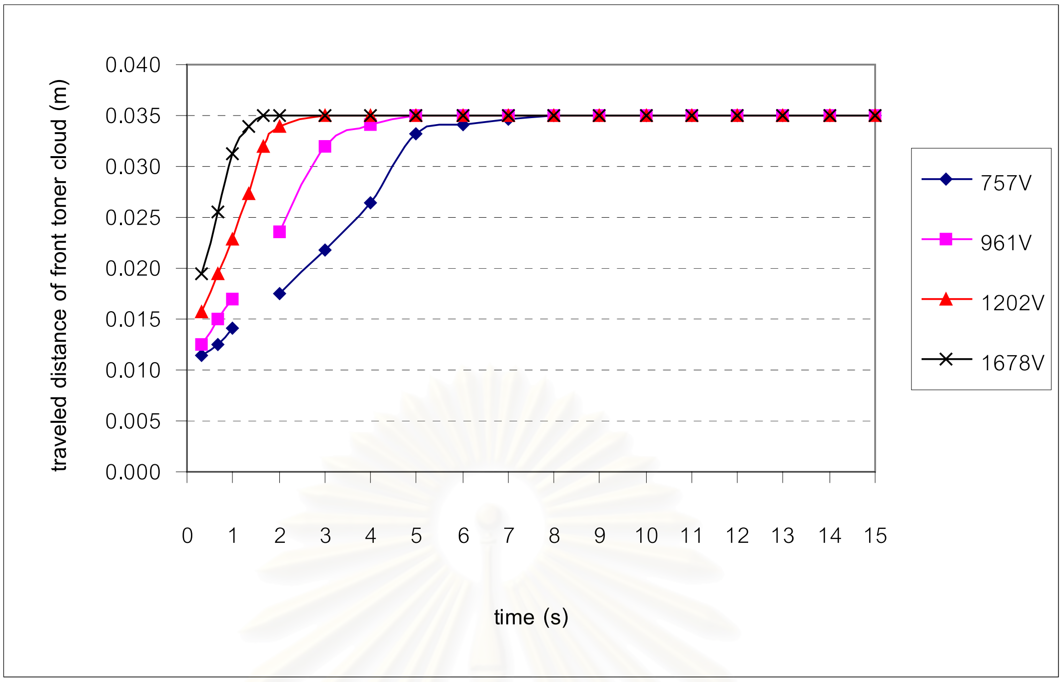


c)

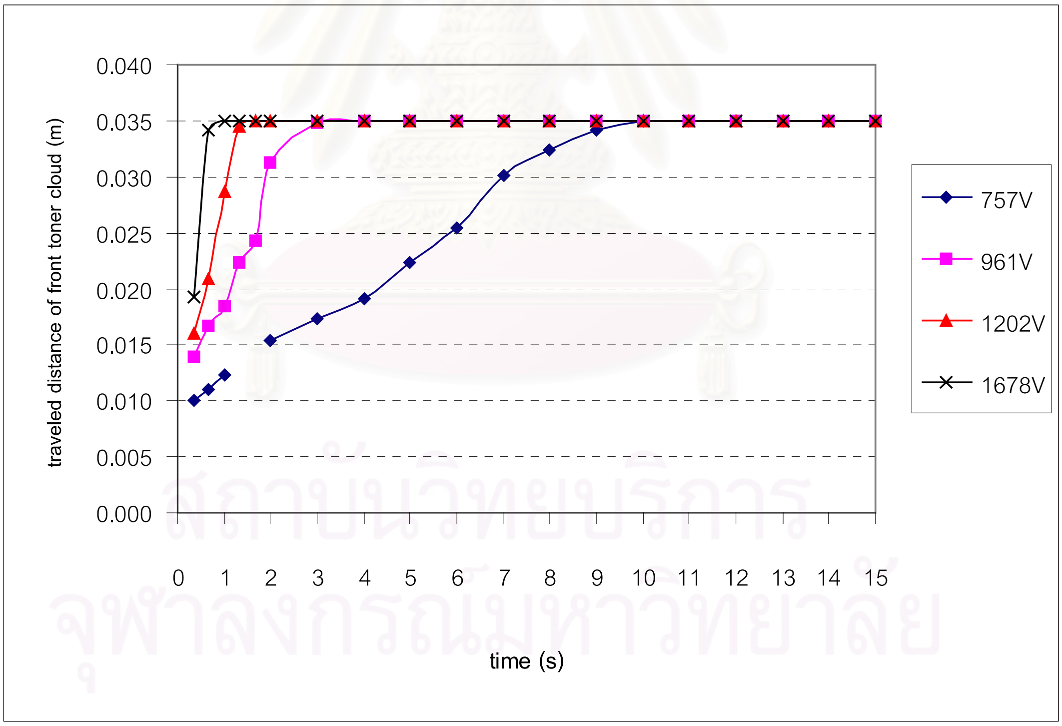
Figure 4-3 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 3 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.



a)

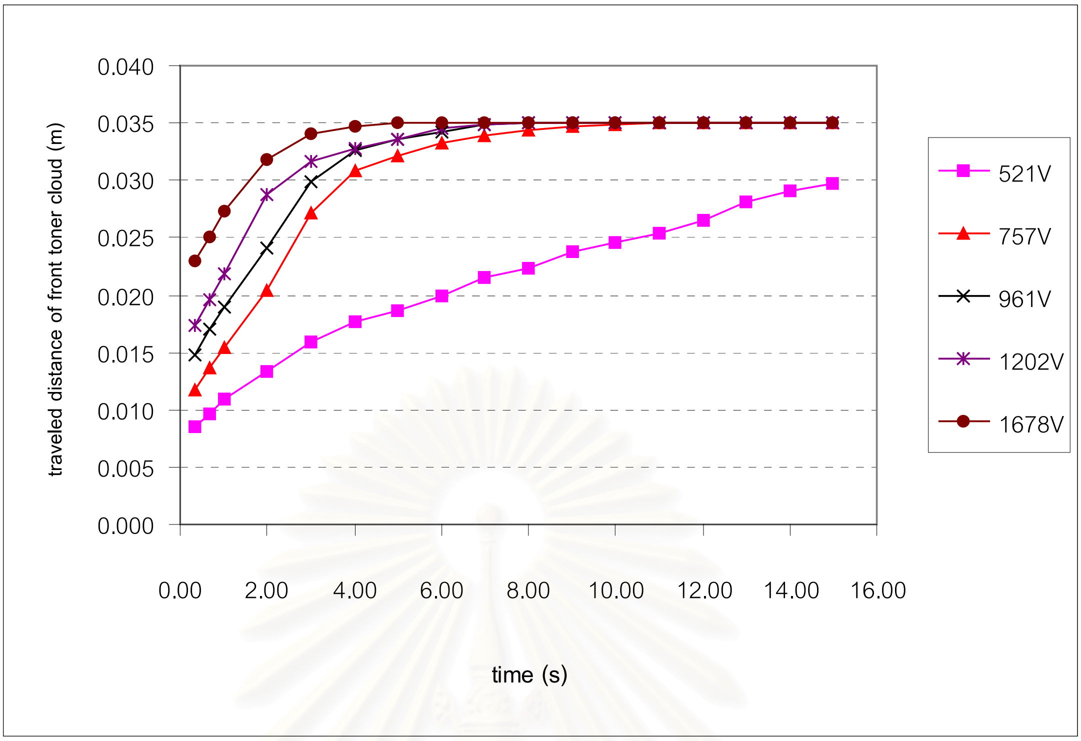


b)

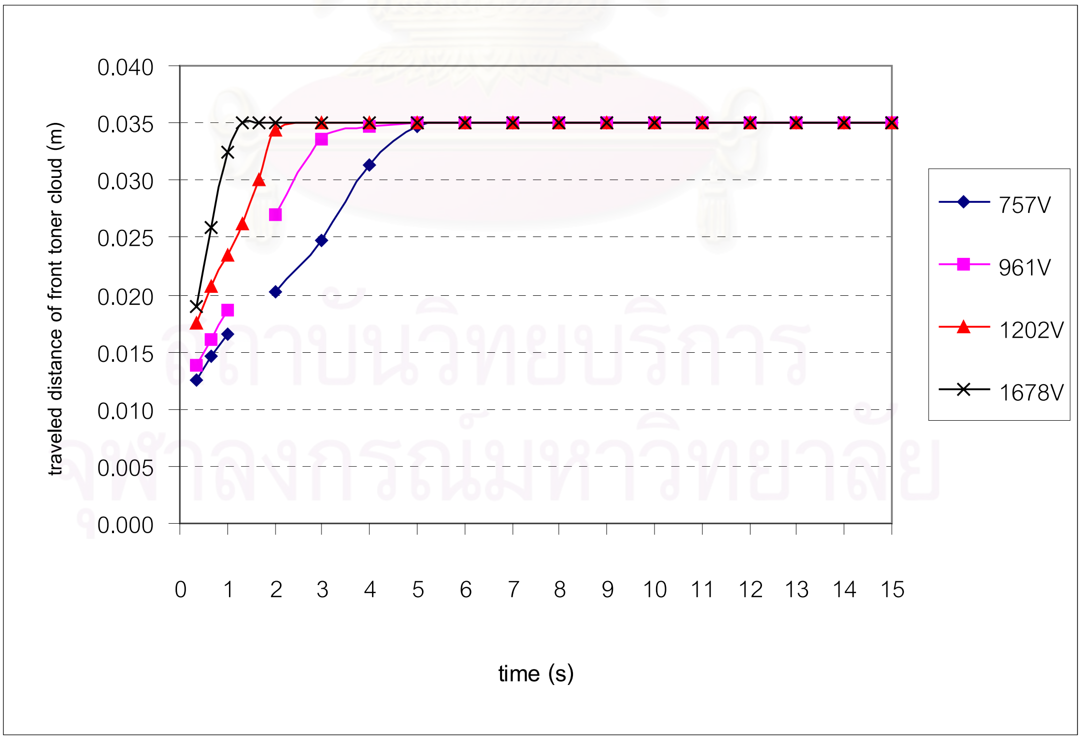


c)

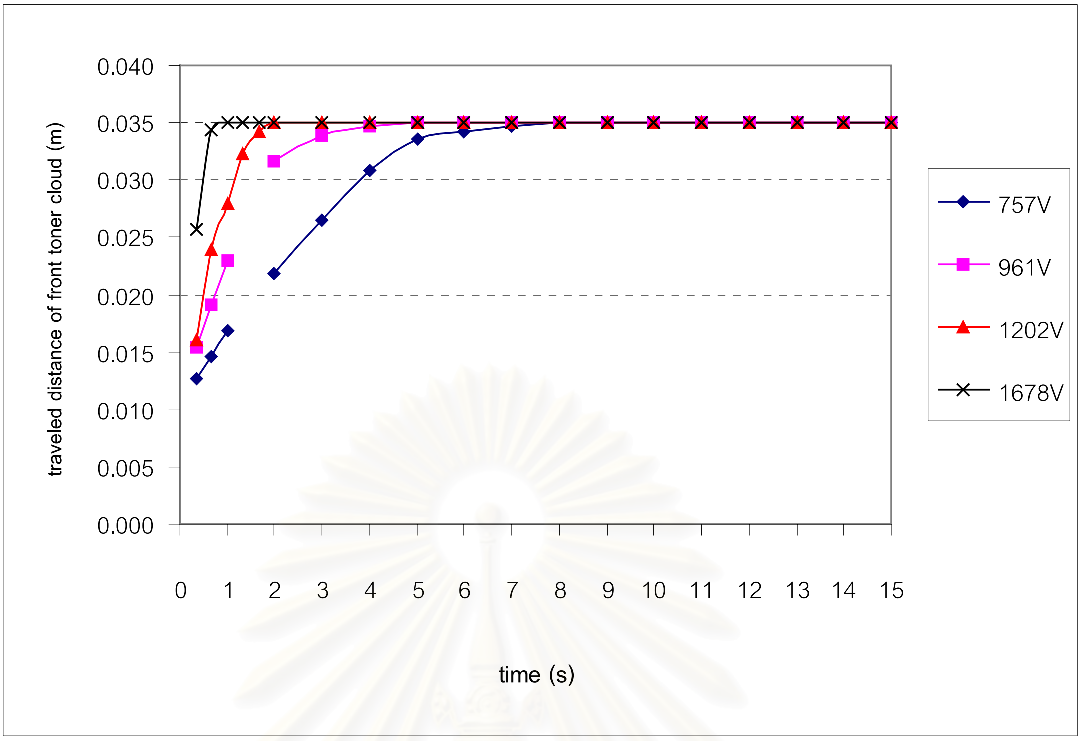
Figure 4-4 Dependence of the cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 4 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.


0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
time (s)
521V
757V
961V
1202V
1678V

a)

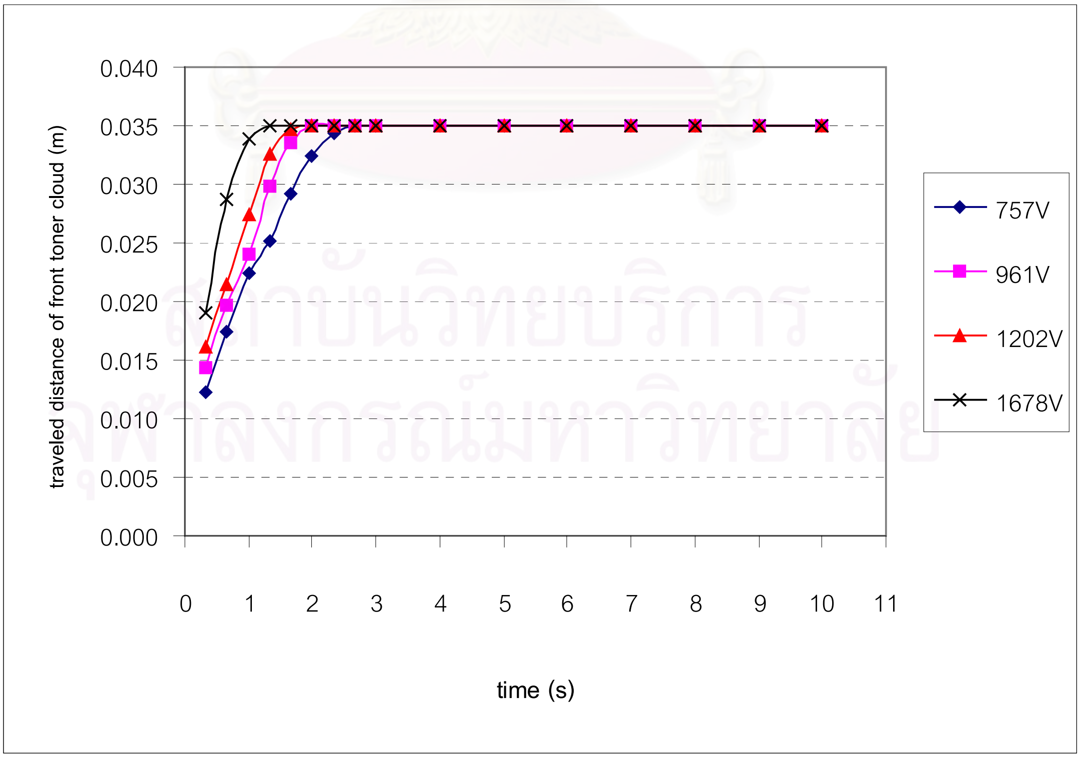

0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
time (s)
757V
961V
1202V
1678V

b)

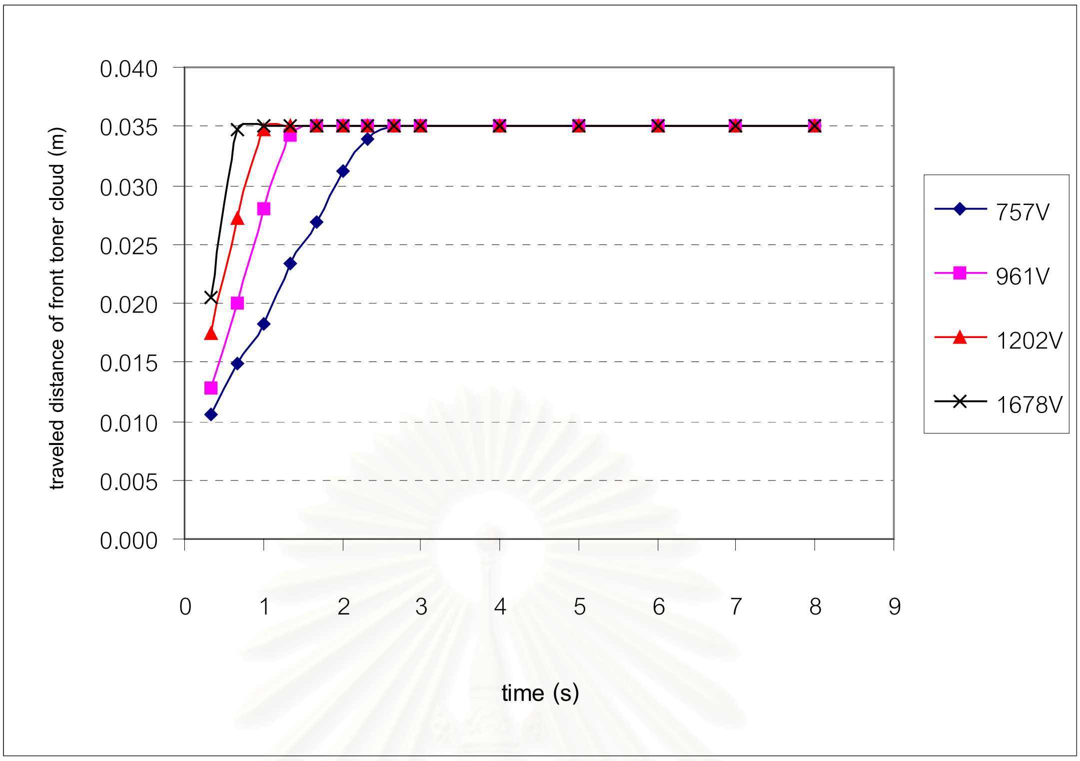


c)

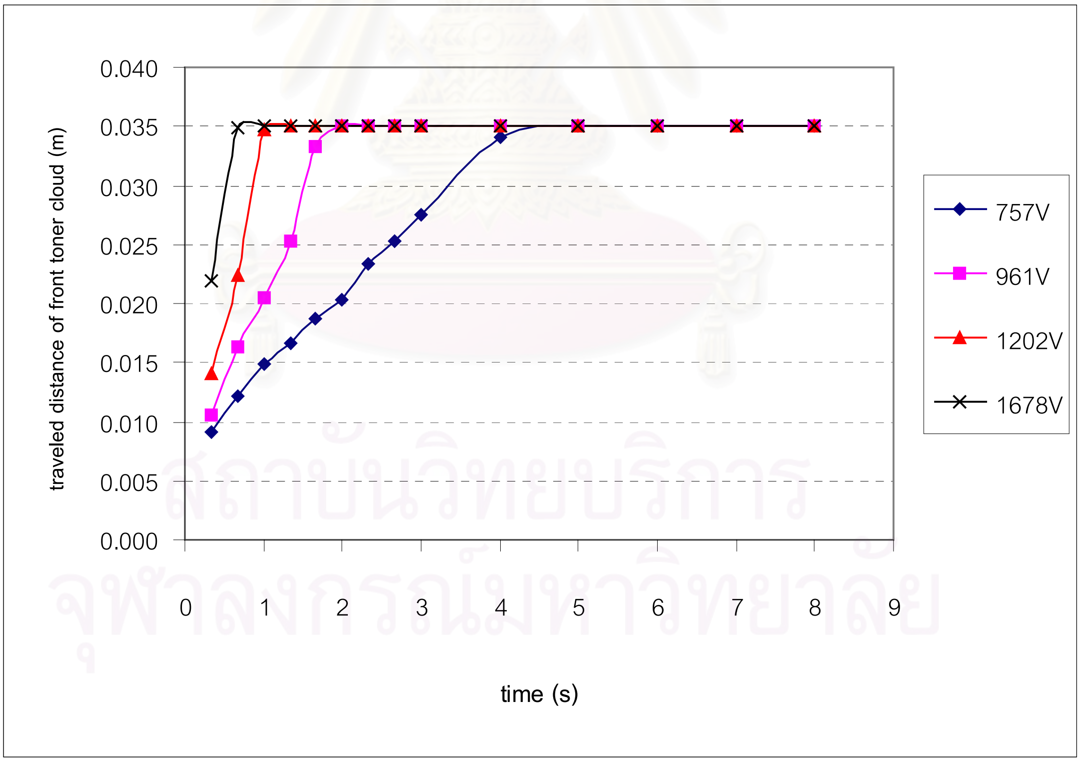
Figure 4-5 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 6 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.



a)

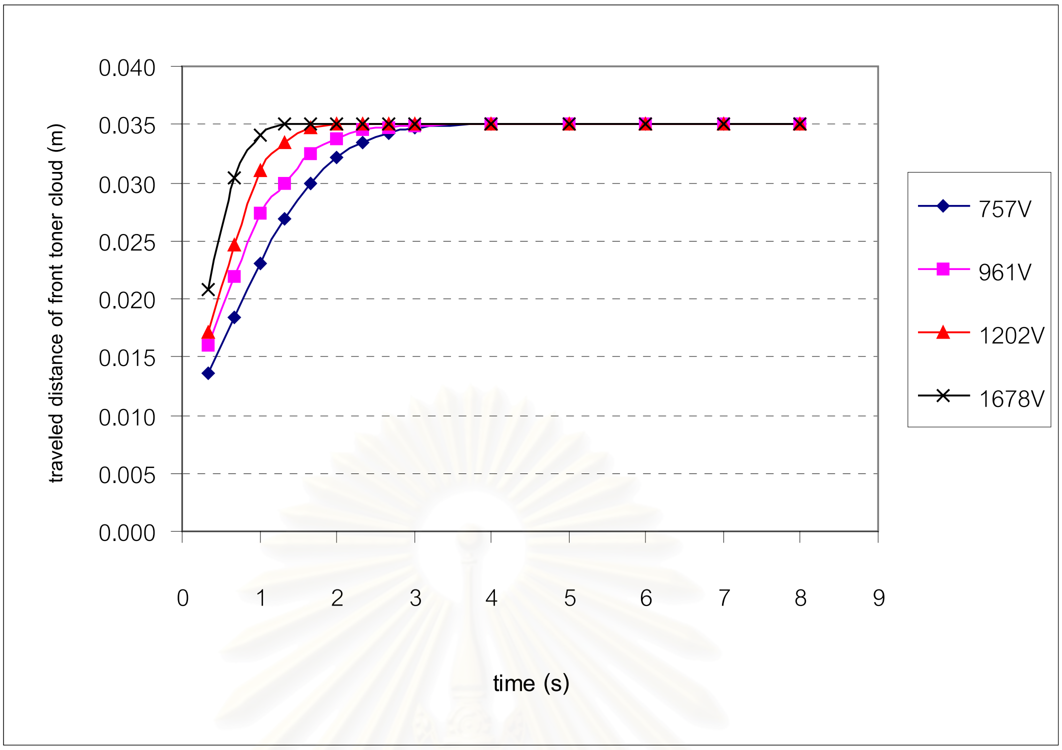


b)

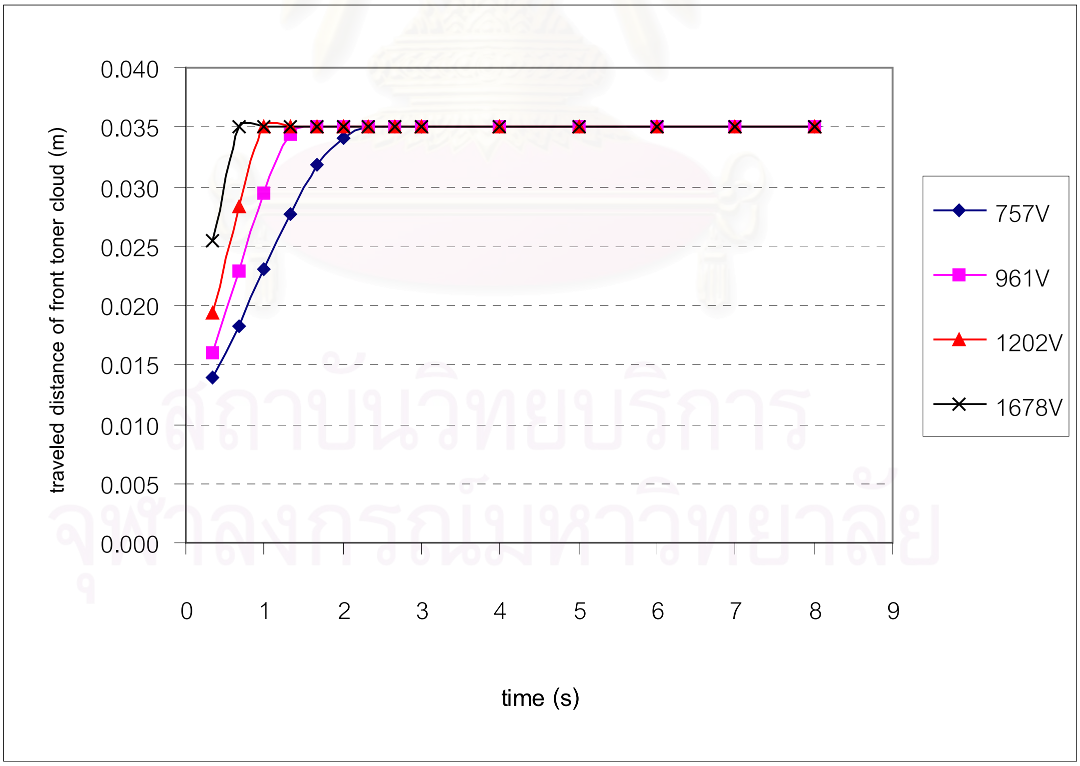


c)

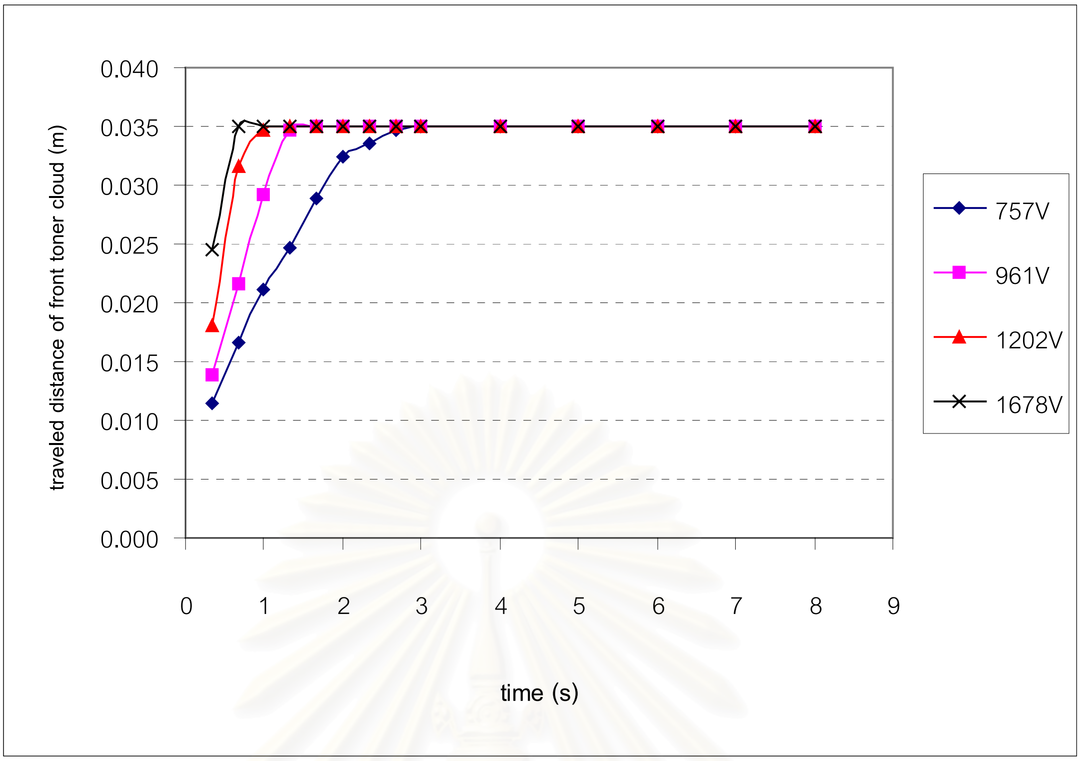
Figure 4-6 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 3 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.


0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0
1
2
3
4
5
6
7
8
9
time (s)
757V
961V
1202V
1678V

a)

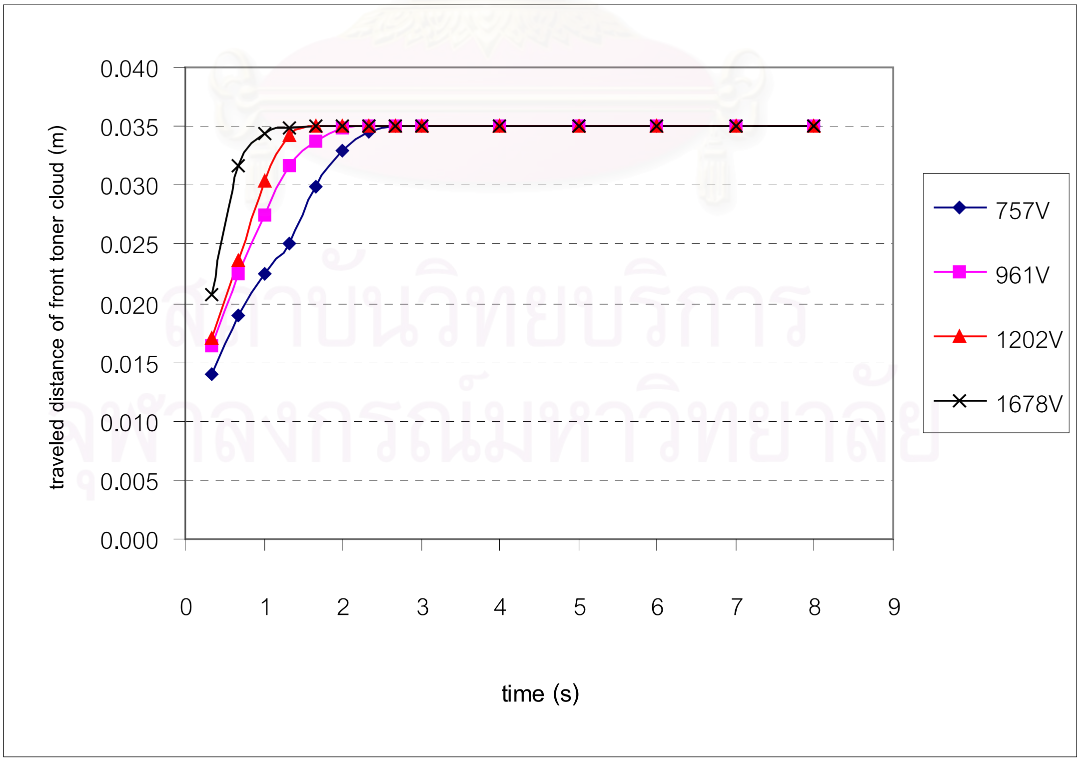

0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0
1
2
3
4
5
6
7
8
9
time (s)
757V
961V
1202V
1678V

b)

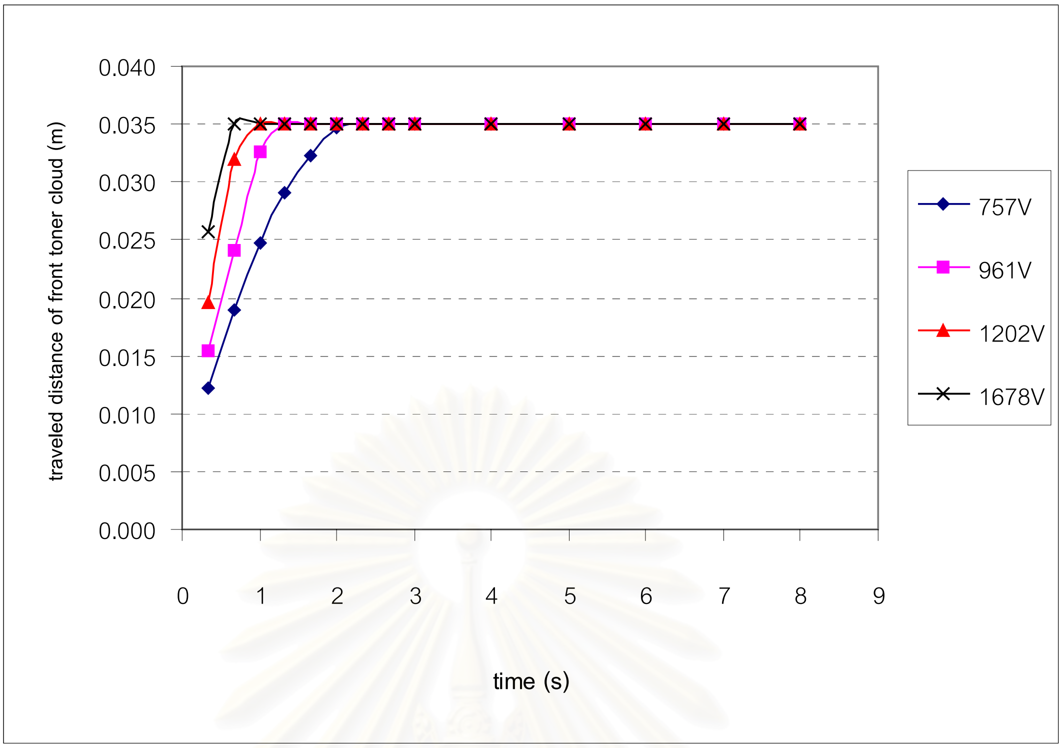


c)

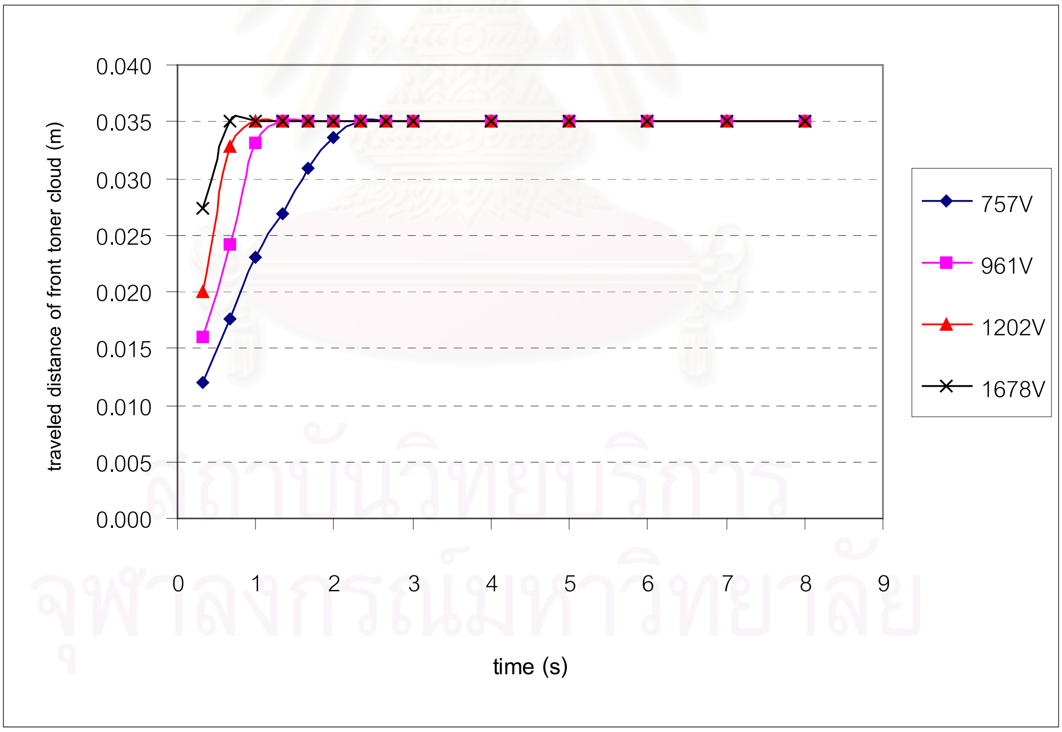
Figure 4-7 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 4 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.



a)

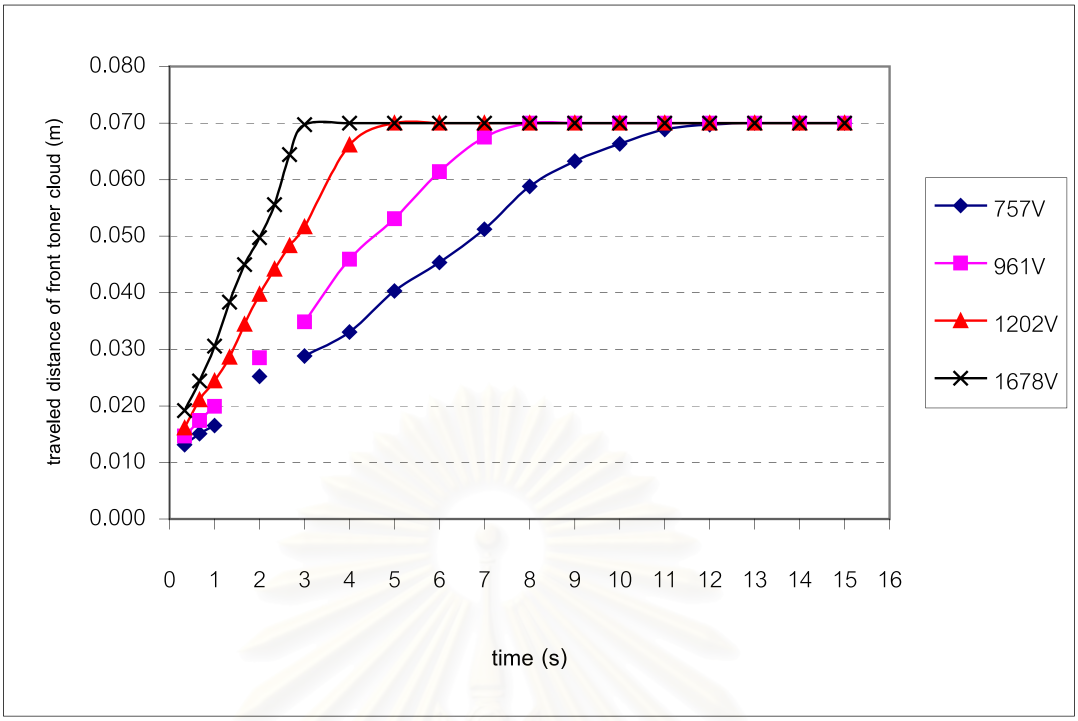


b)

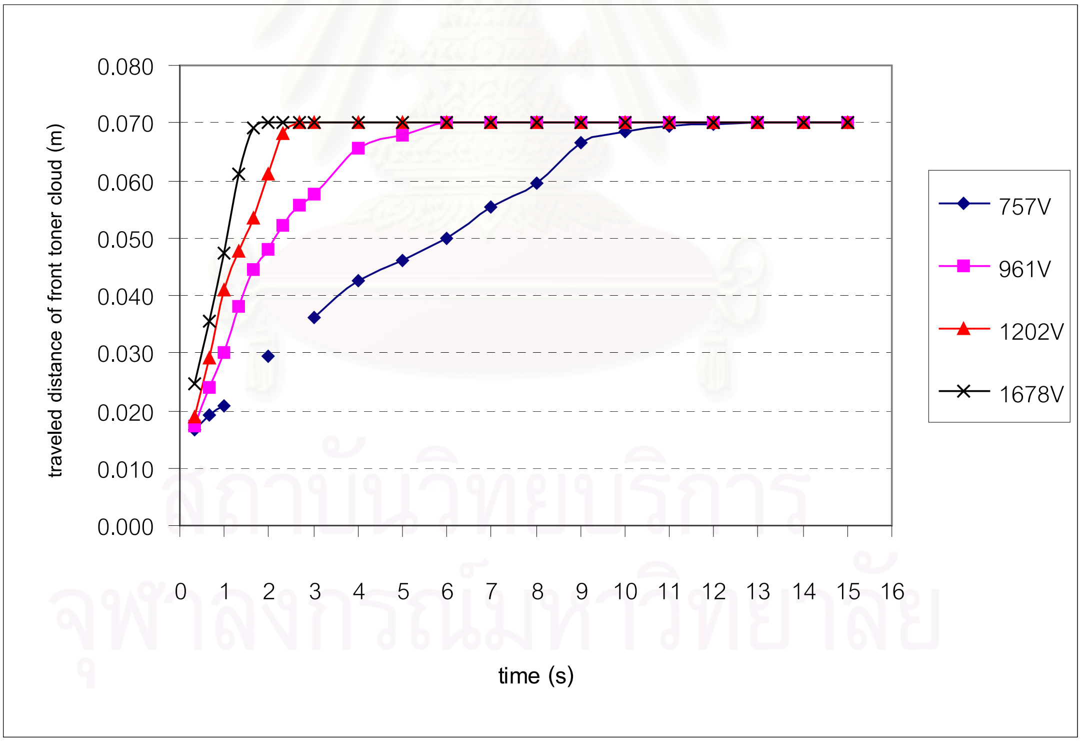


c)

Figure 4-8 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 6 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree, and c) 0.95 degree.

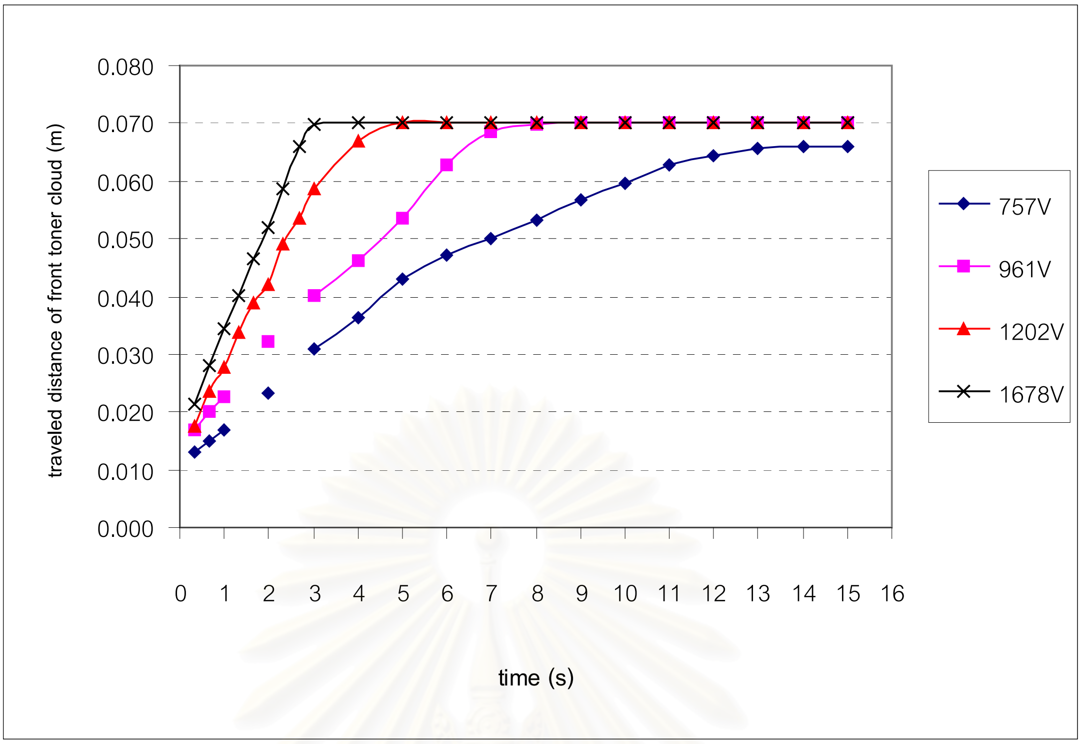


a)

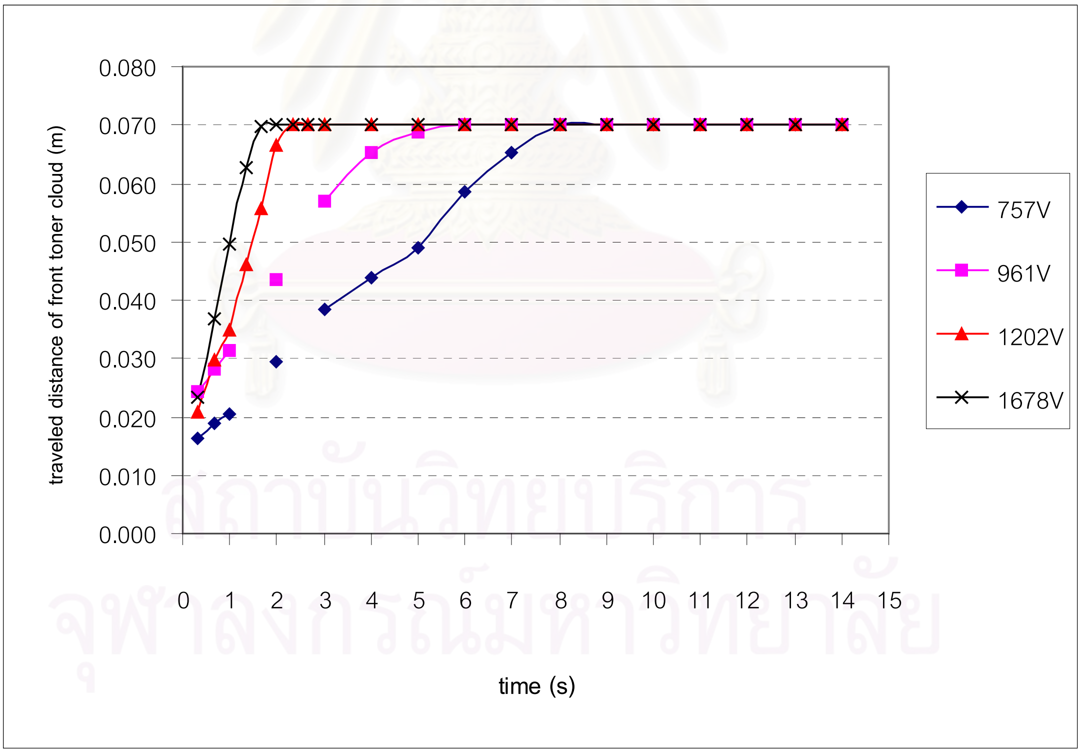


b)

Figure 4-9 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 3 mg put at the end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

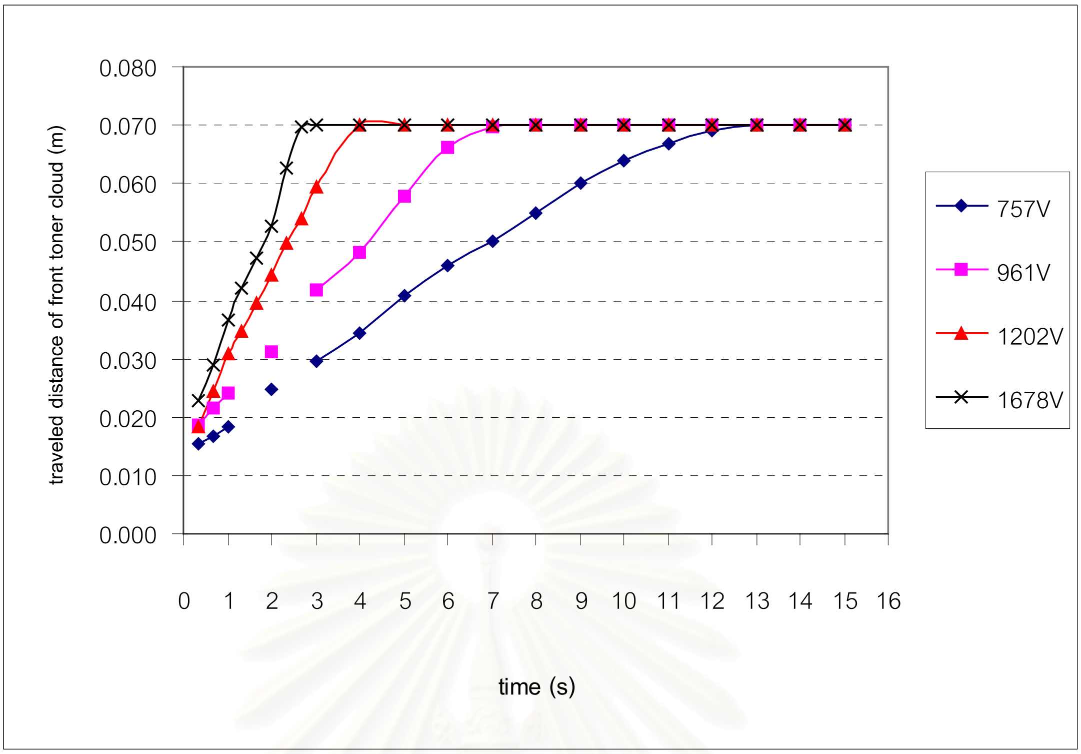


a)

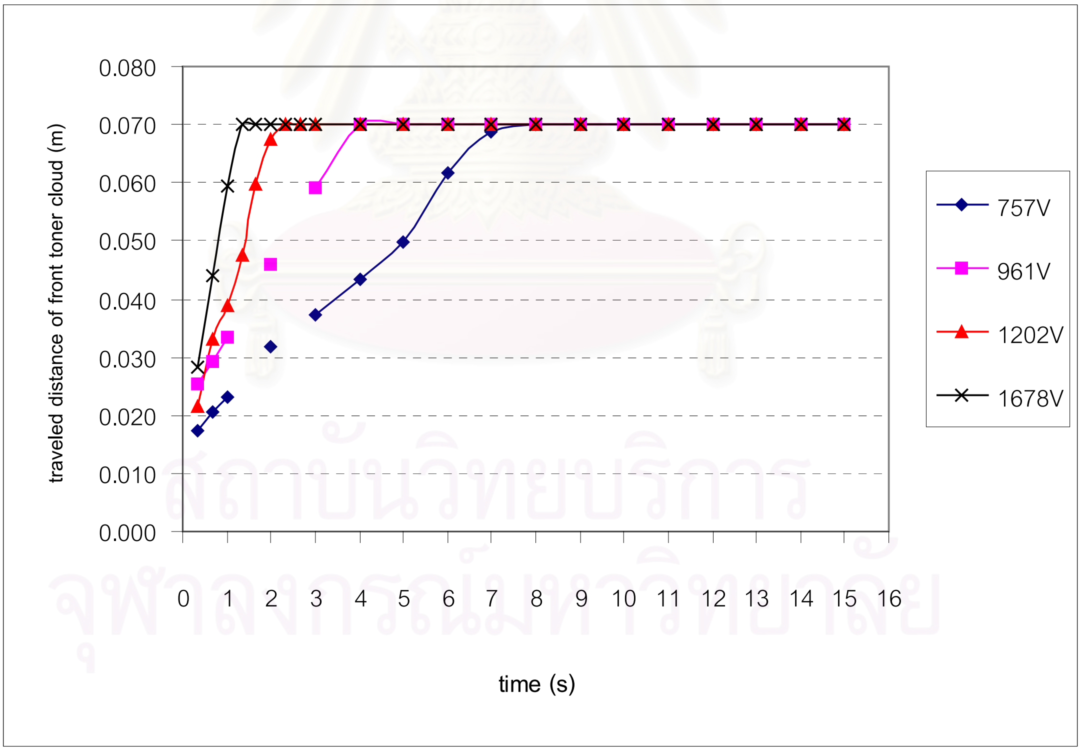


b)

Figure 4-10 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 4 mg put at end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

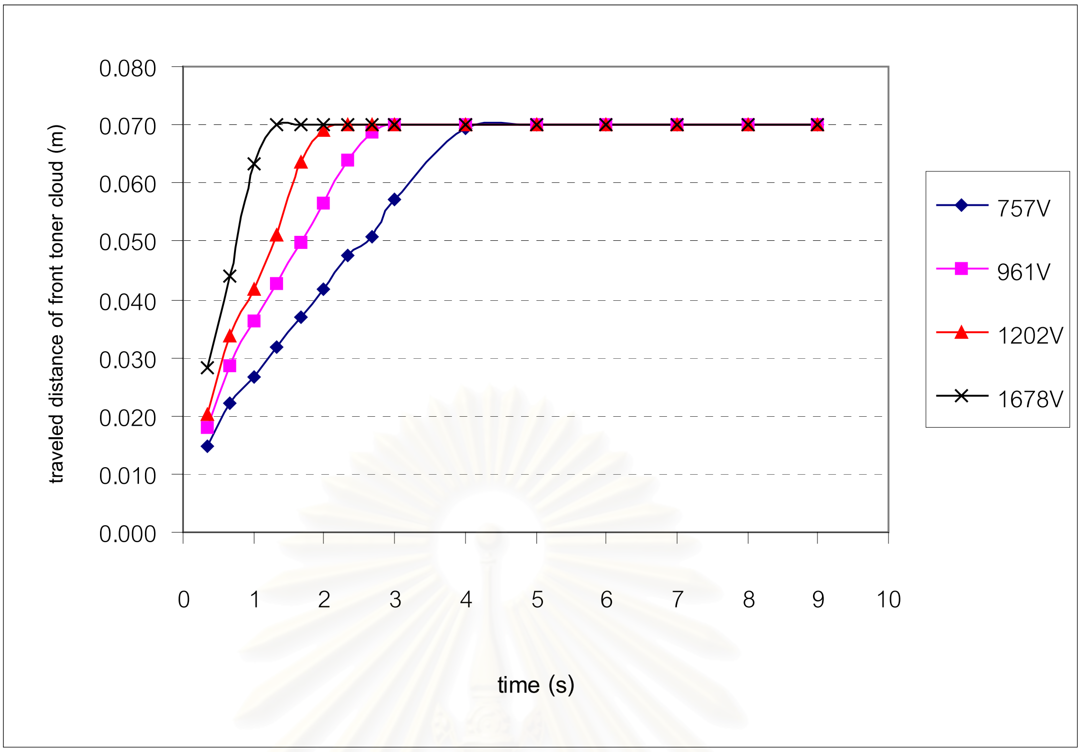


a)

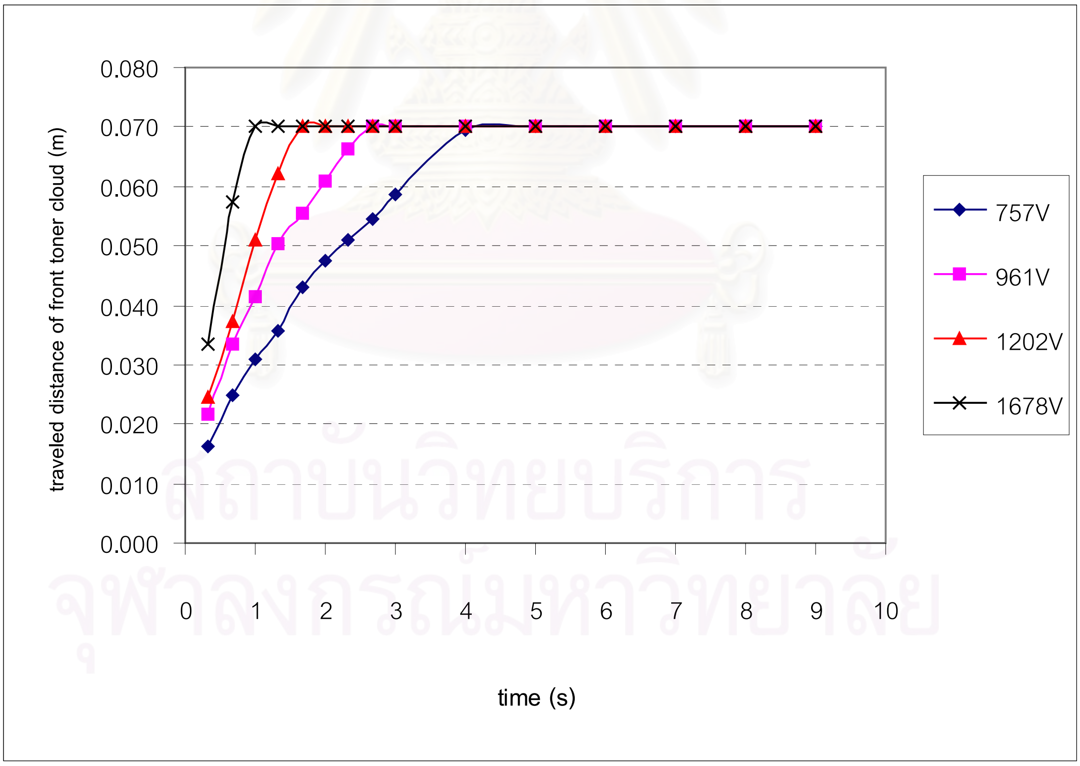


b)

Figure 4-11 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 6 mg put at end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

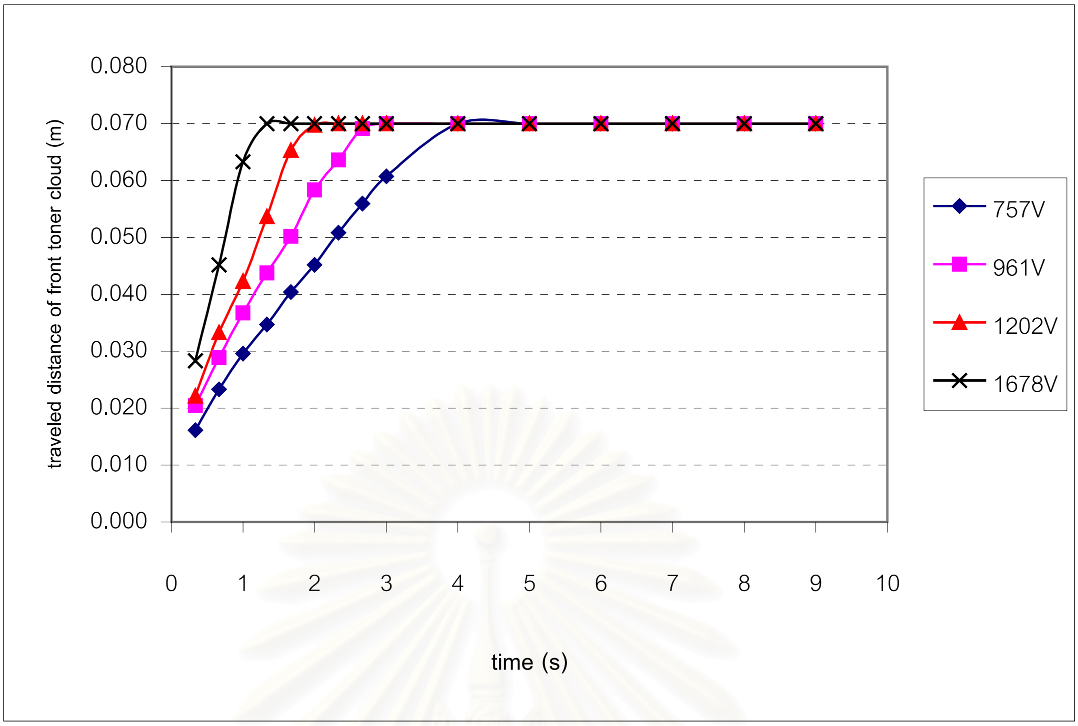


a)

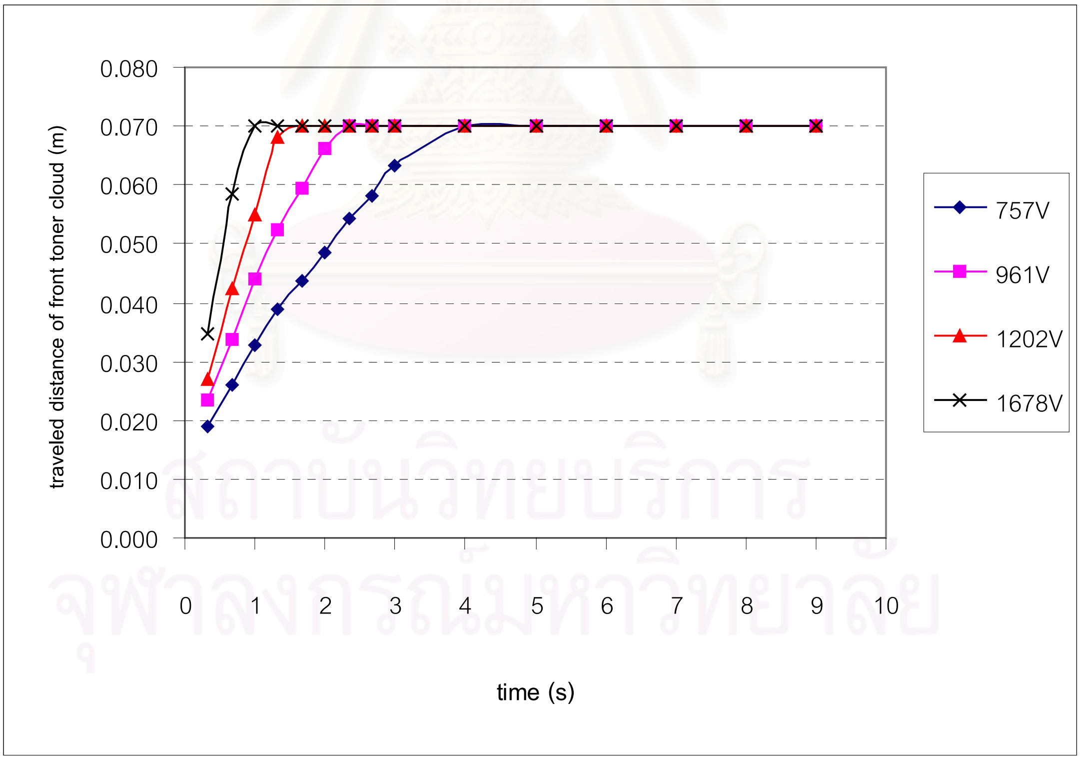


b)

Figure 4-12 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 3 mg put at end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

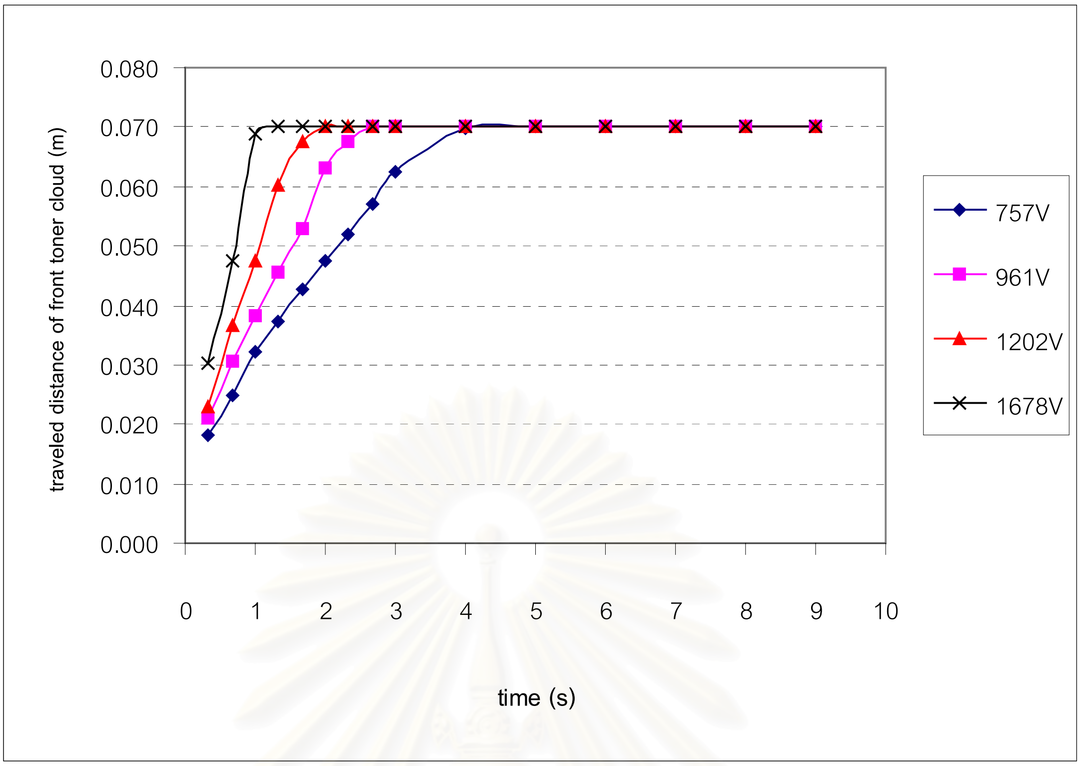


a)

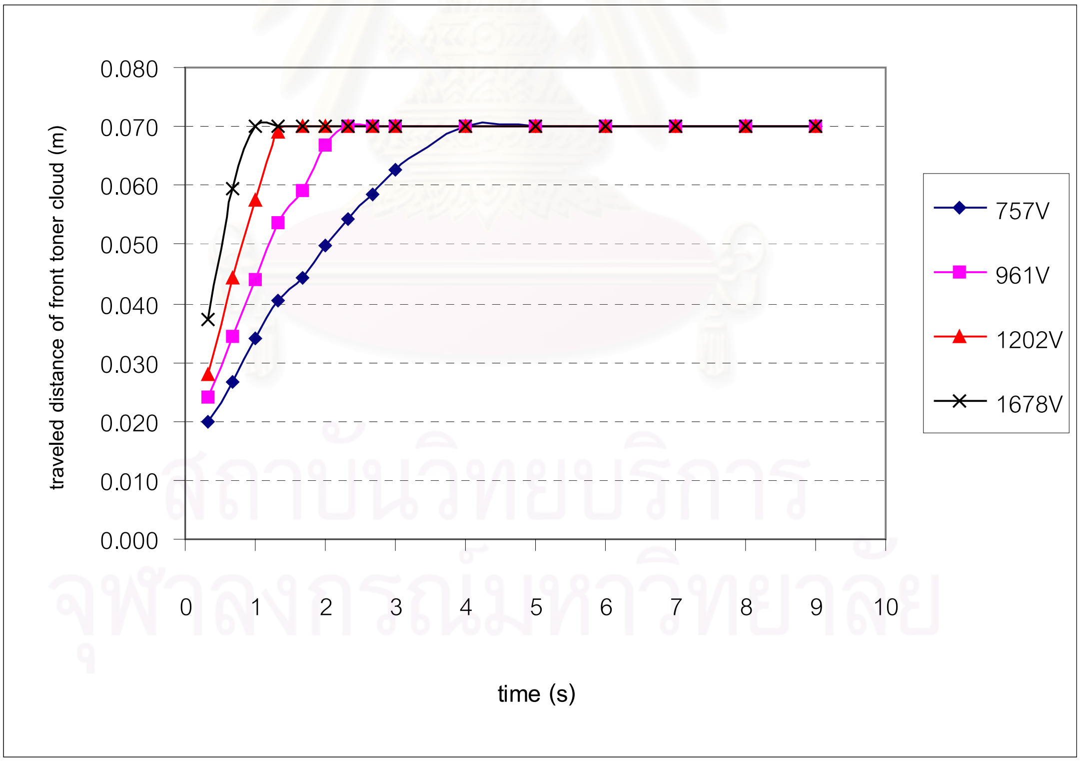


b)

Figure 4-13 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 4 mg put at end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.



a)



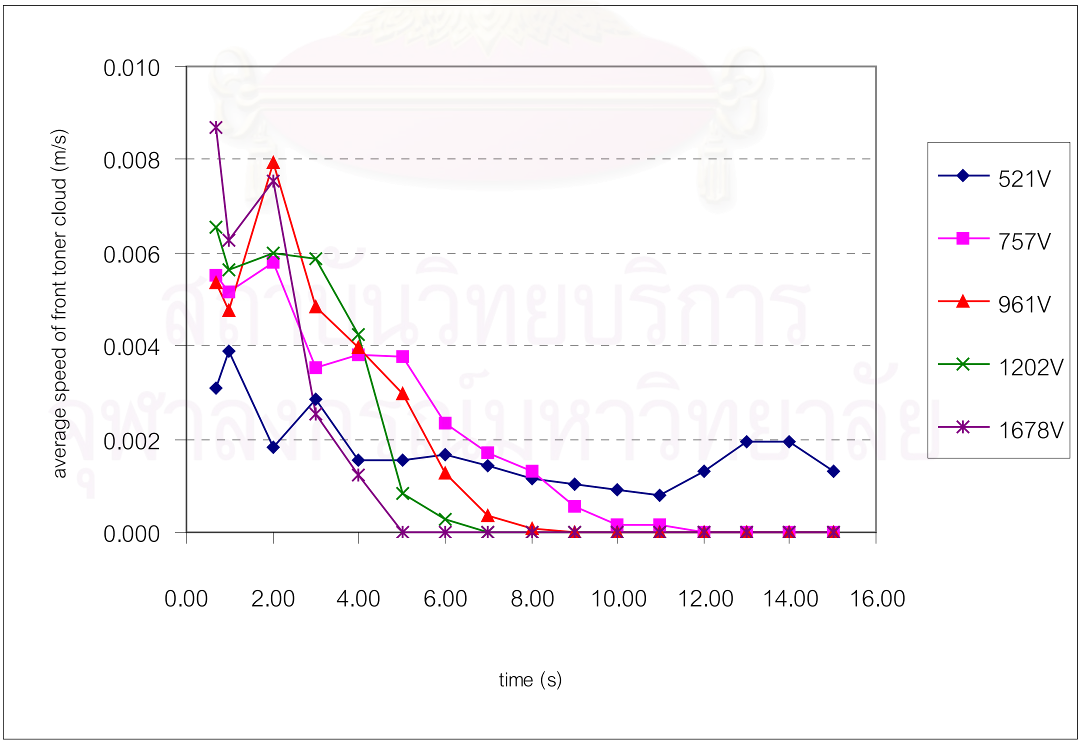
b)

Figure 4-14 Dependence of the toner cloud traveled distance on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 6 mg put at end side with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

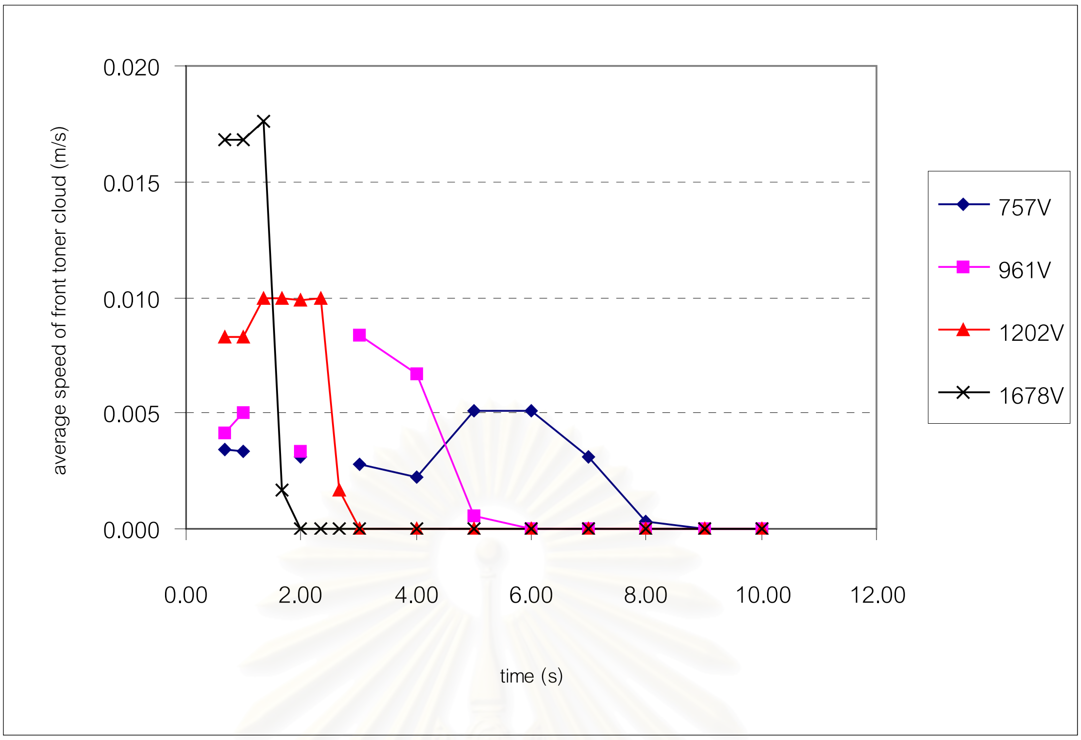
Considering the influence of applied voltage on the traveled distance of the front toner cloud at a certain time, the lowest applied voltage (521 V and 757V) produced the shortest distance whereas the 1678 V gave the longest distance of the front toner cloud traveled. These results suggests that the higher applied voltage made the toner cloud traveled faster and vice versa.

When the voltage was applied to the electrodes, the toner particles were charged and then moved between the electrodes due to the electrostatic force. When applied voltages was increased, the electrostatic force increased and then forced the toner particles to move with a higher speed and frequency.

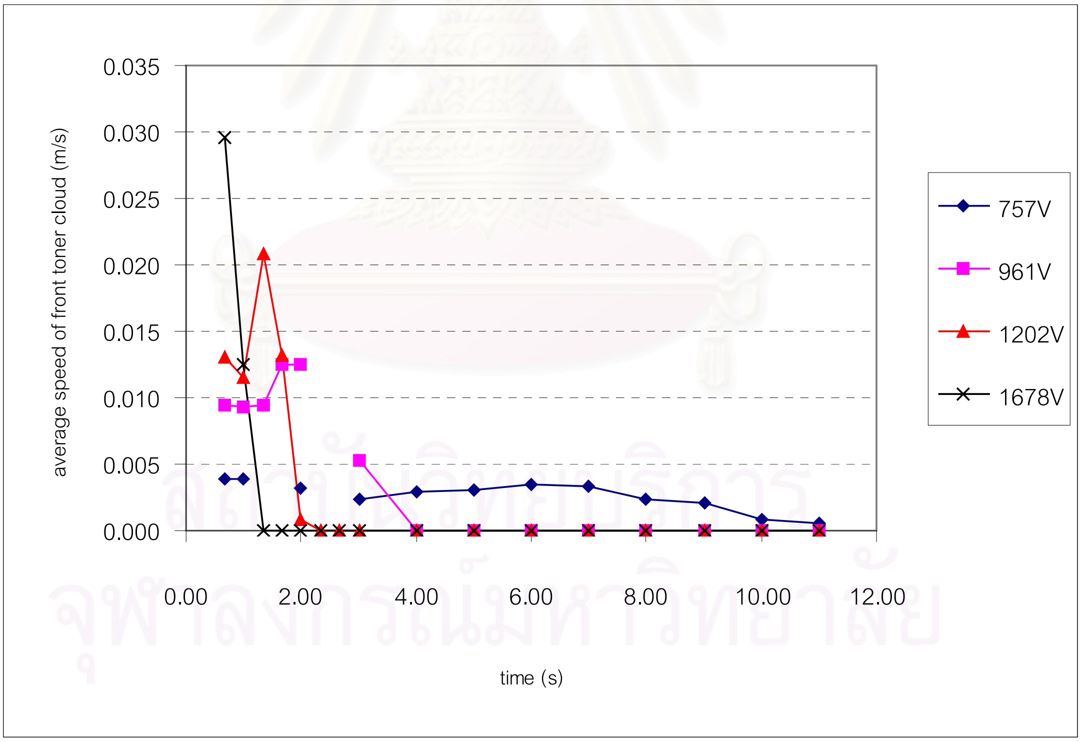
From Figures 4-3 to 4-14, the slope of the curve was nearly constant until the toner cloud arrived the electrode end. Concerning the slope of the increasing area of the front toner cloud, Figures 4-15 to 4-26 show the relationship between the average speed (first order derivative; $\frac{\Delta position}{time}$) of the front toner cloud by the time and the applied voltage from the fundamental data in Tables 4-1 to 4-30 and Figures 4-3 to 4-14.



a)

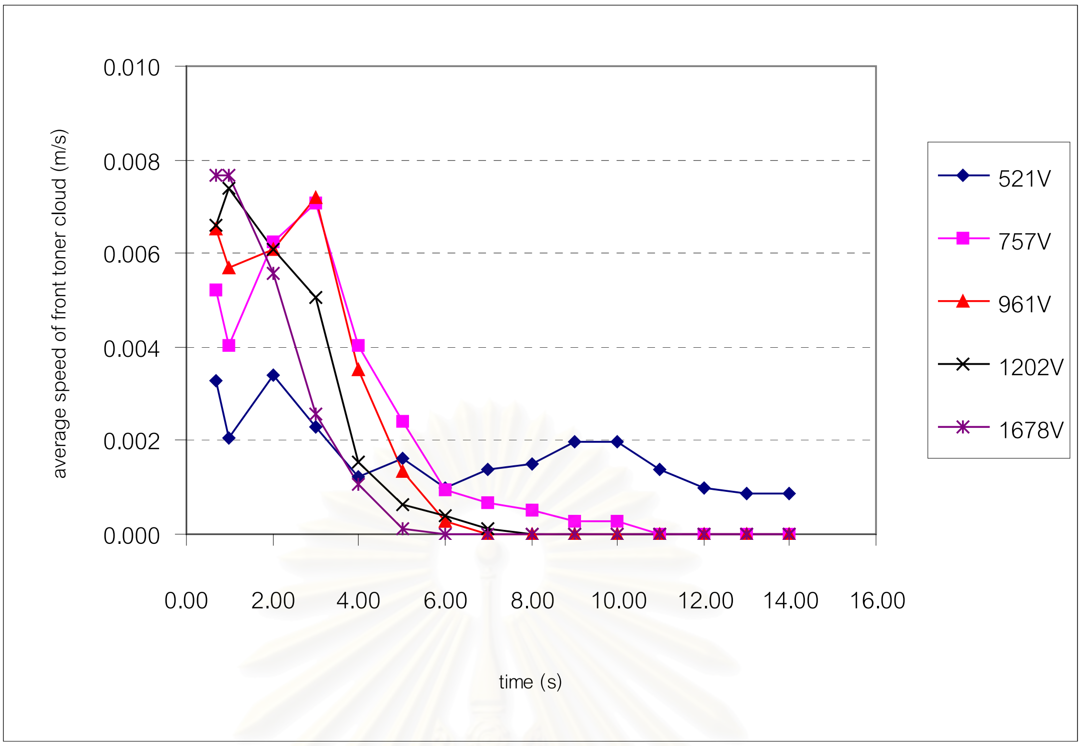


b)

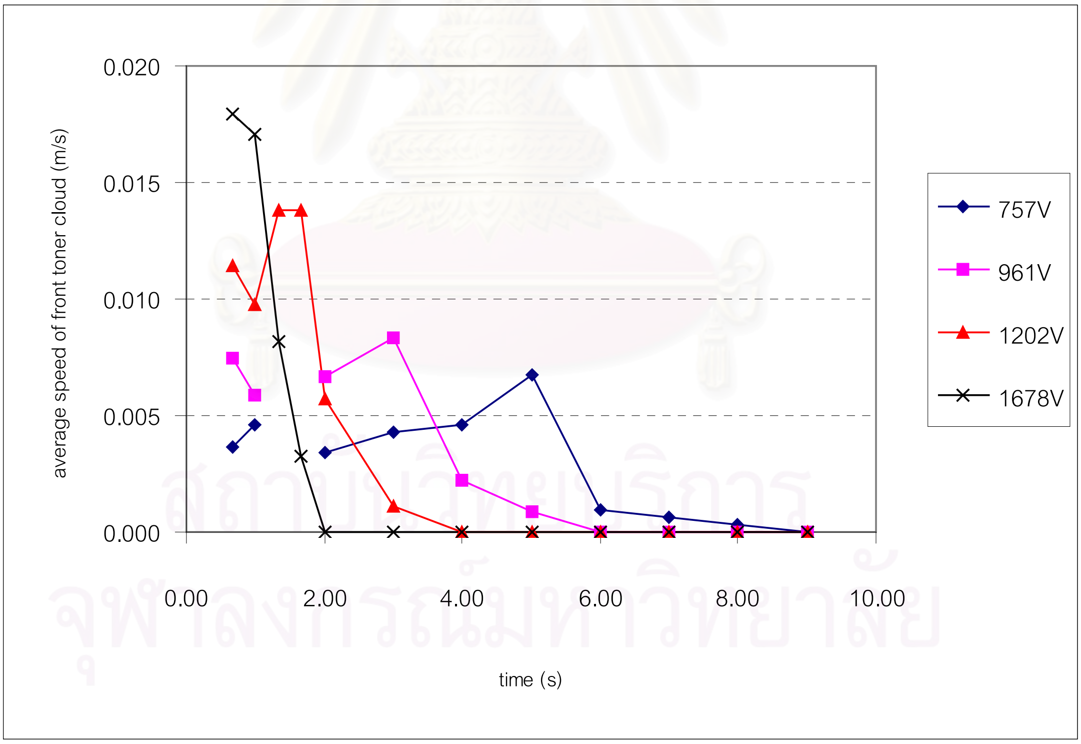


c)

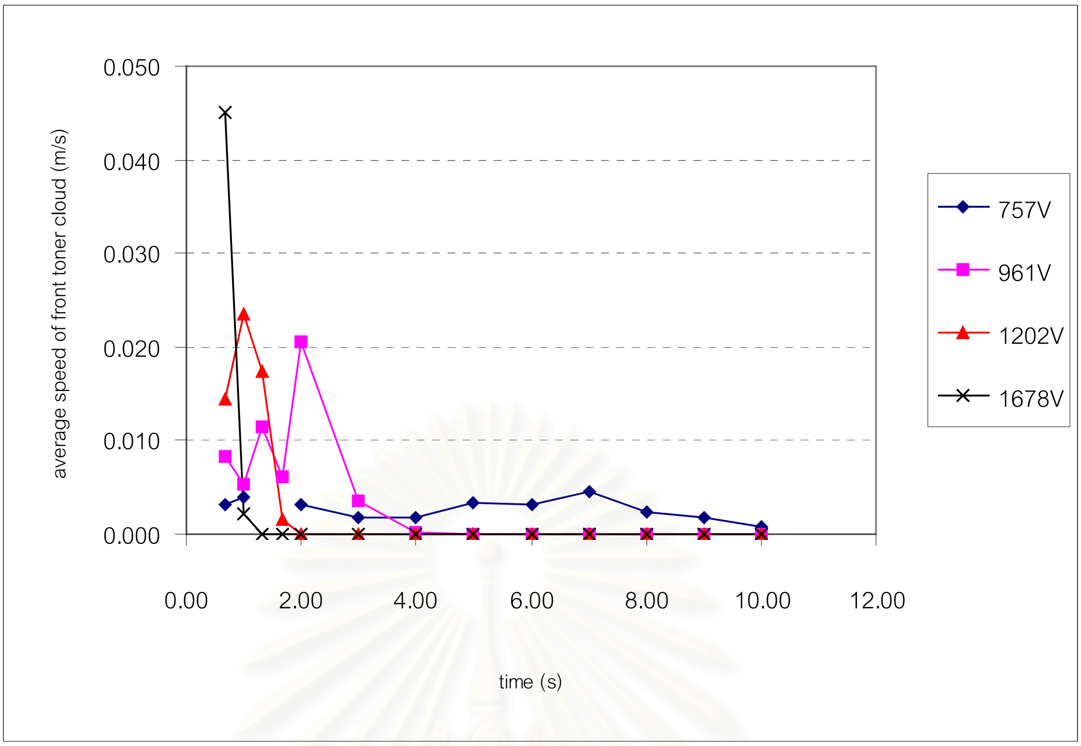
Figure 4-15 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 3 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.


0.010
0.008
0.006
0.004
0.002
0.000
average speed of front toner cloud (m/s)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
time (s)
521V
757V
961V
1202V
1678V

a)

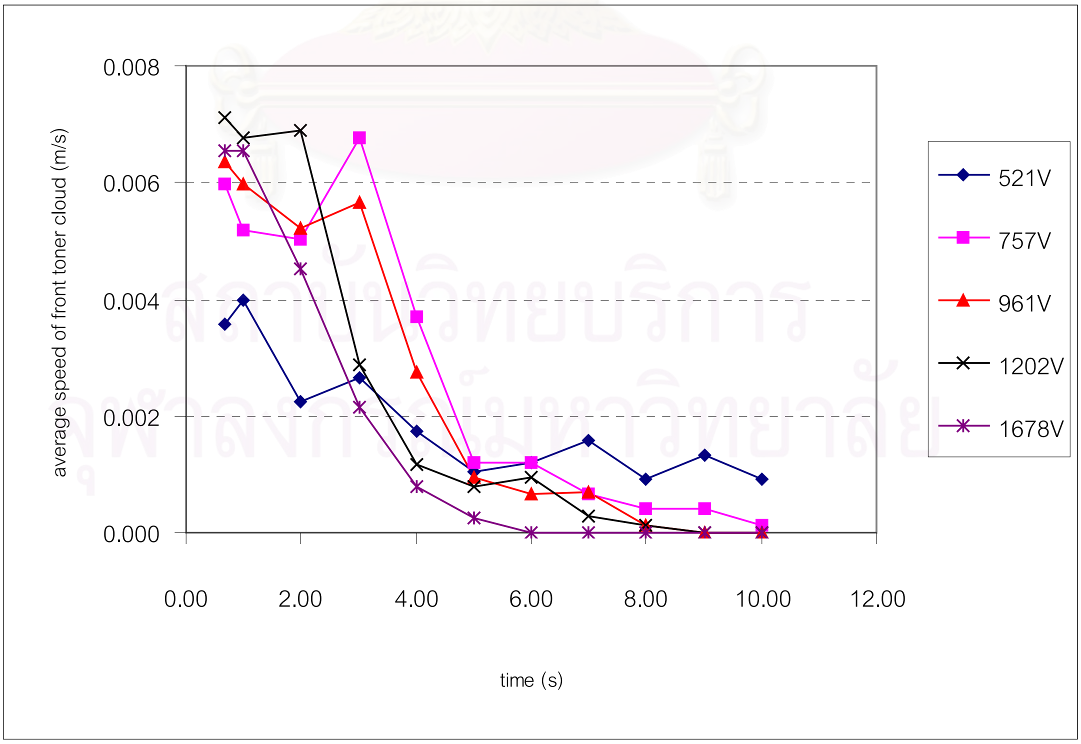

0.020
0.015
0.010
0.005
0.000
average speed of front toner cloud (m/s)
0.00
2.00
4.00
6.00
8.00
10.00
time (s)
757V
961V
1202V
1678V

b)

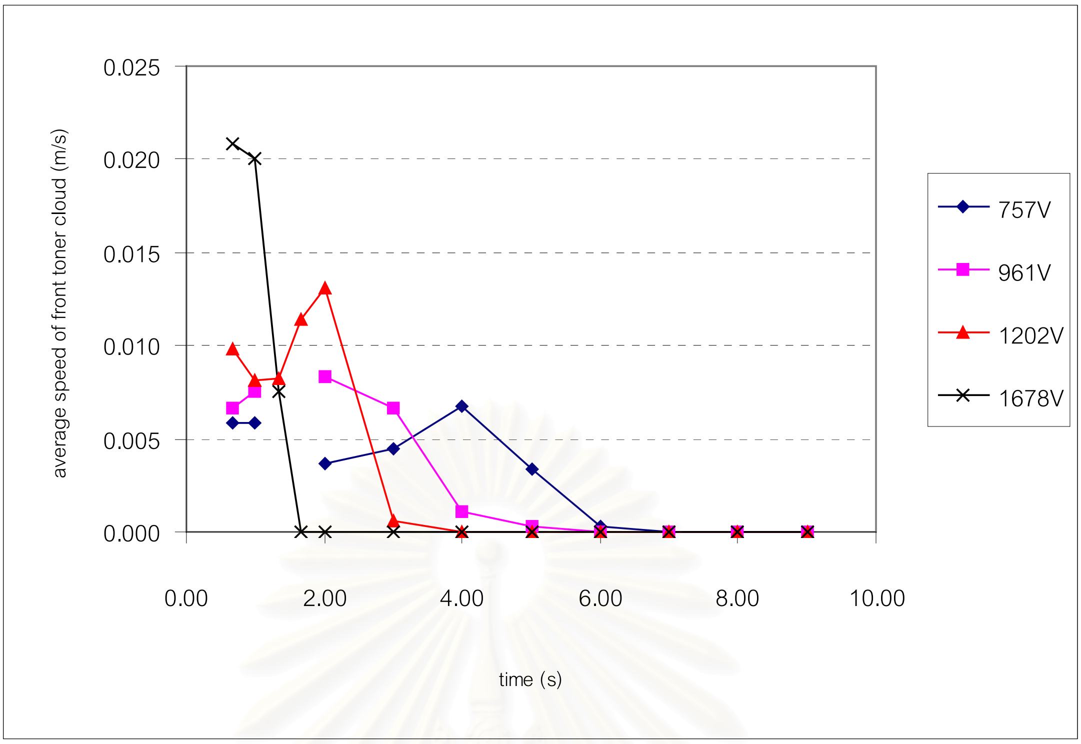


c)

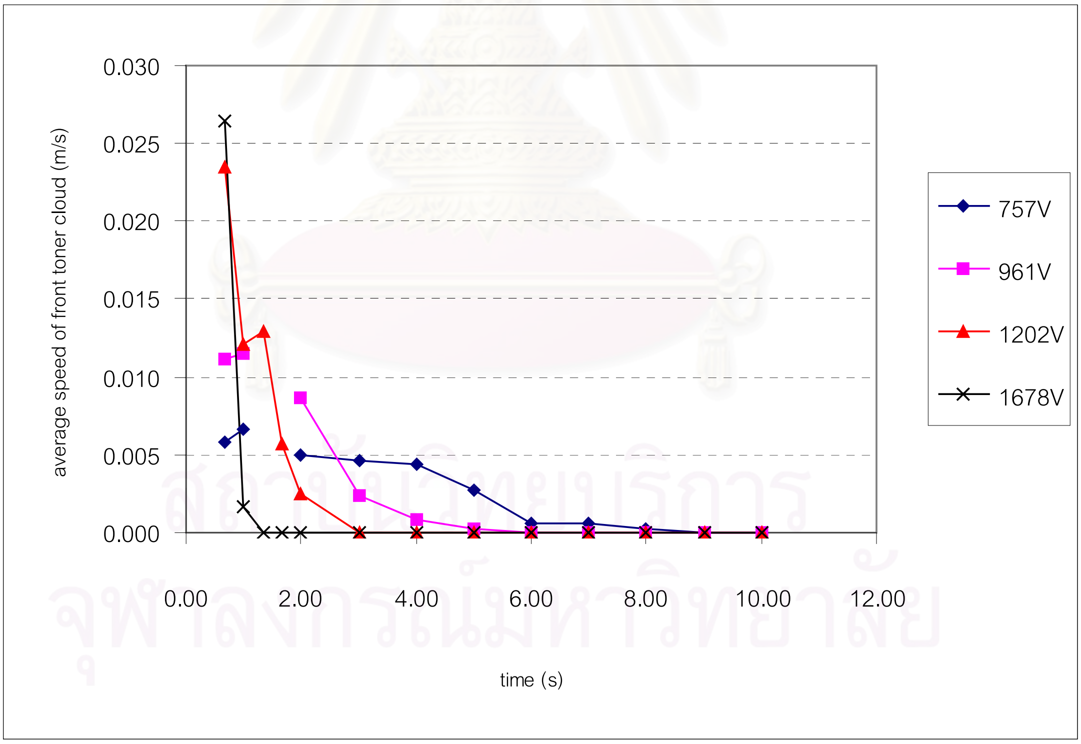
Figure 4-16 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 4 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.



a)

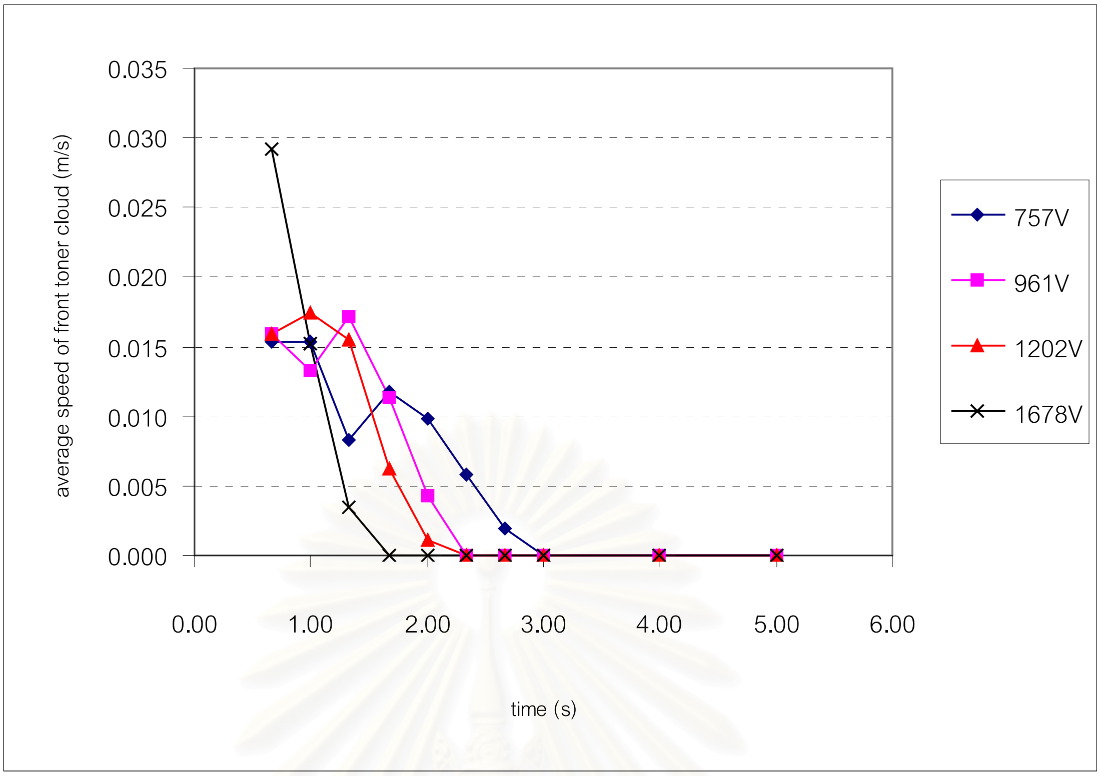


b)



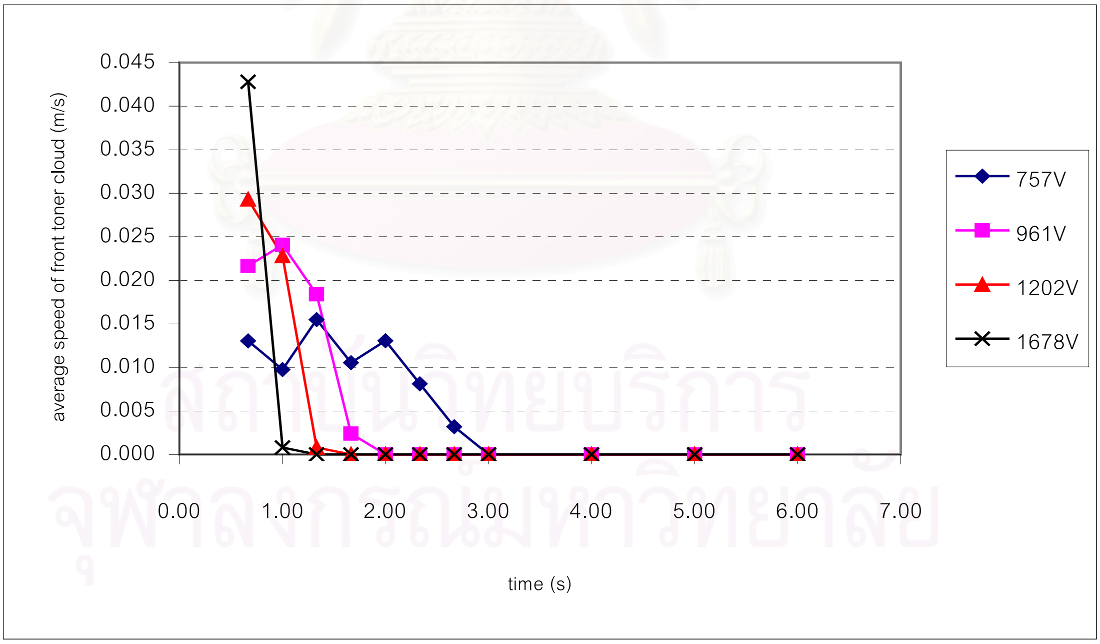
c)

Figure 4-17 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 6 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.



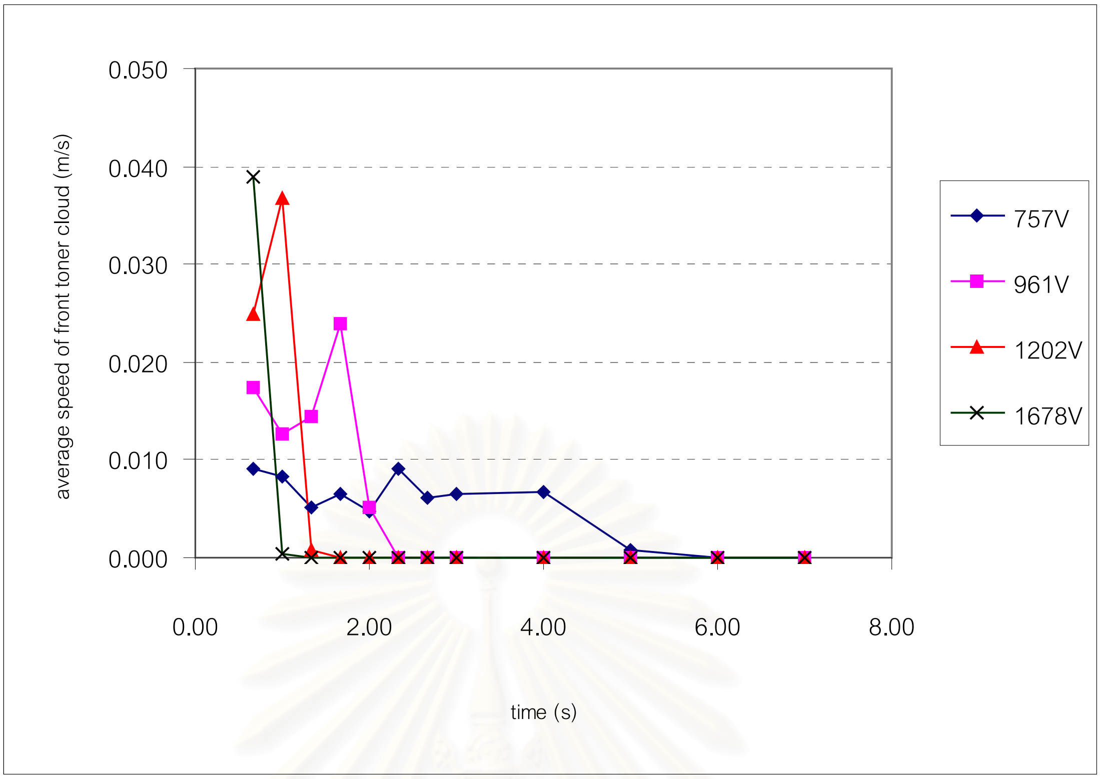
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
average speed of front toner cloud (m/s)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
time (s)
757V
961V
1202V
1678V

a)



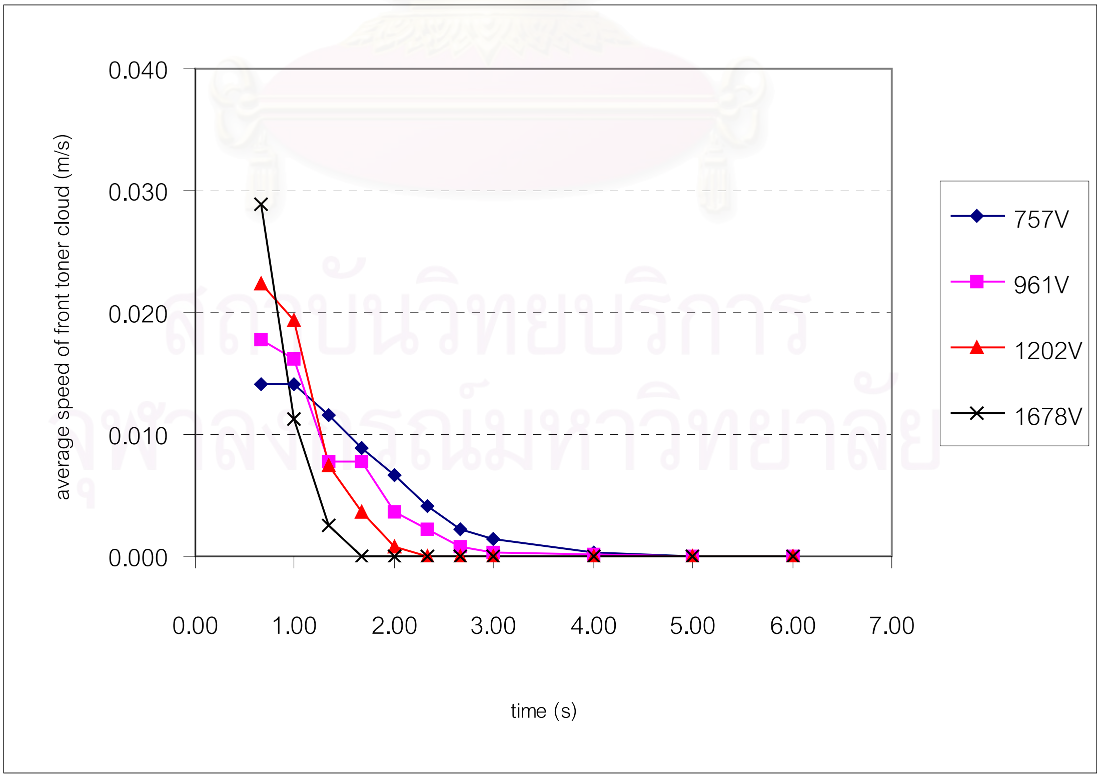
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
average speed of front toner cloud (m/s)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
time (s)
757V
961V
1202V
1678V

b)

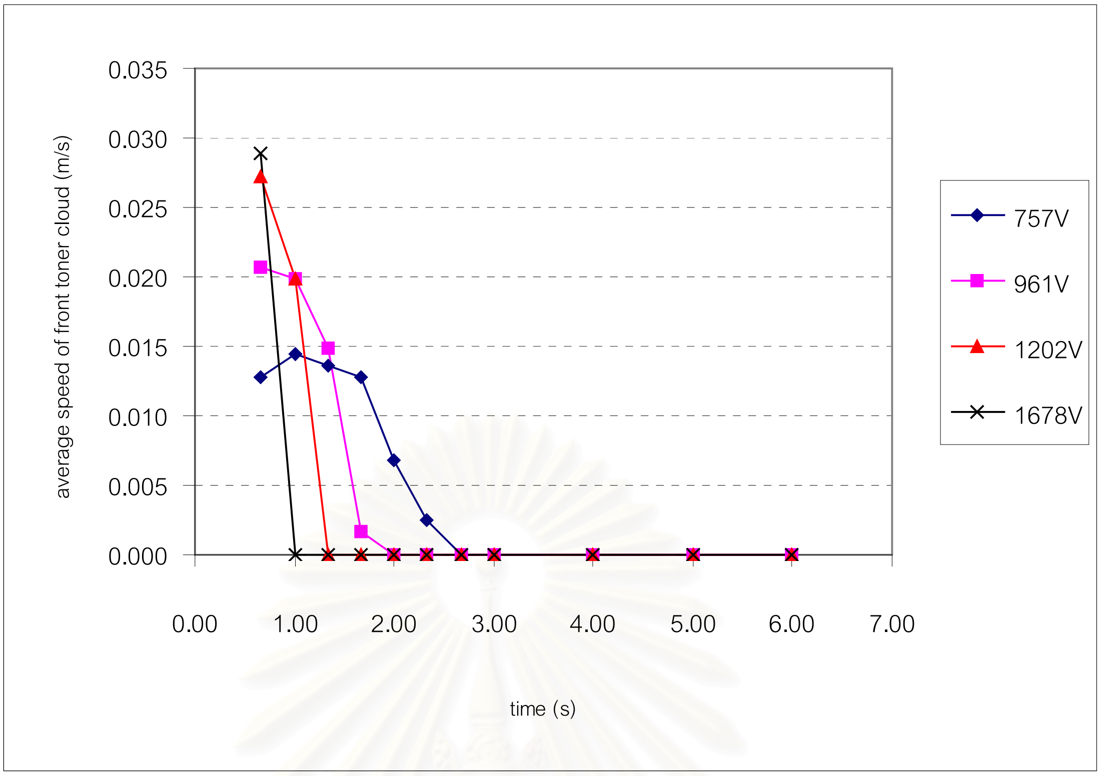


c)

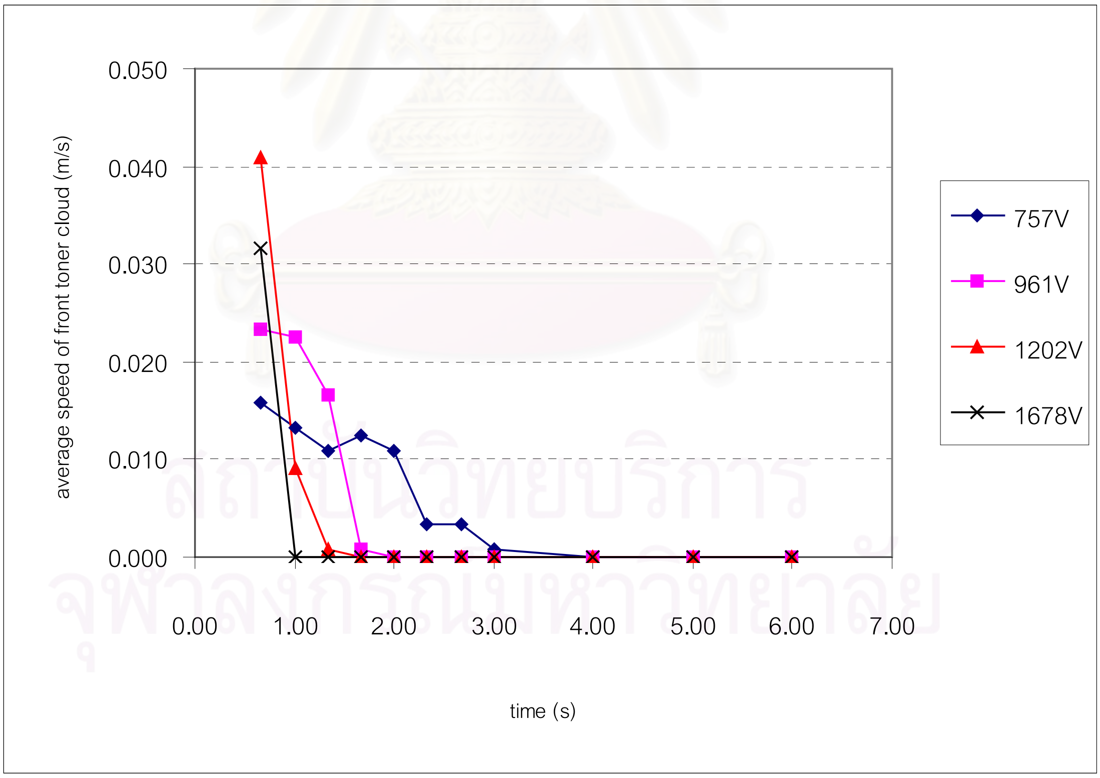
Figure 4-18 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 3 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.



a)

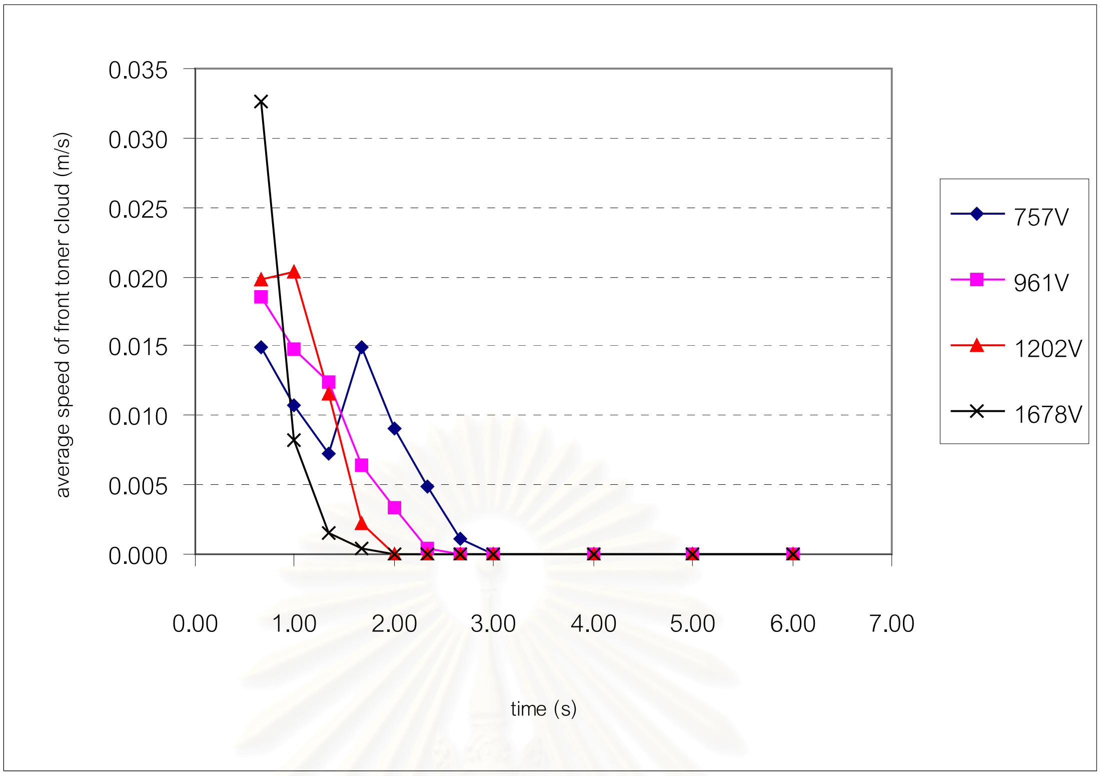


b)



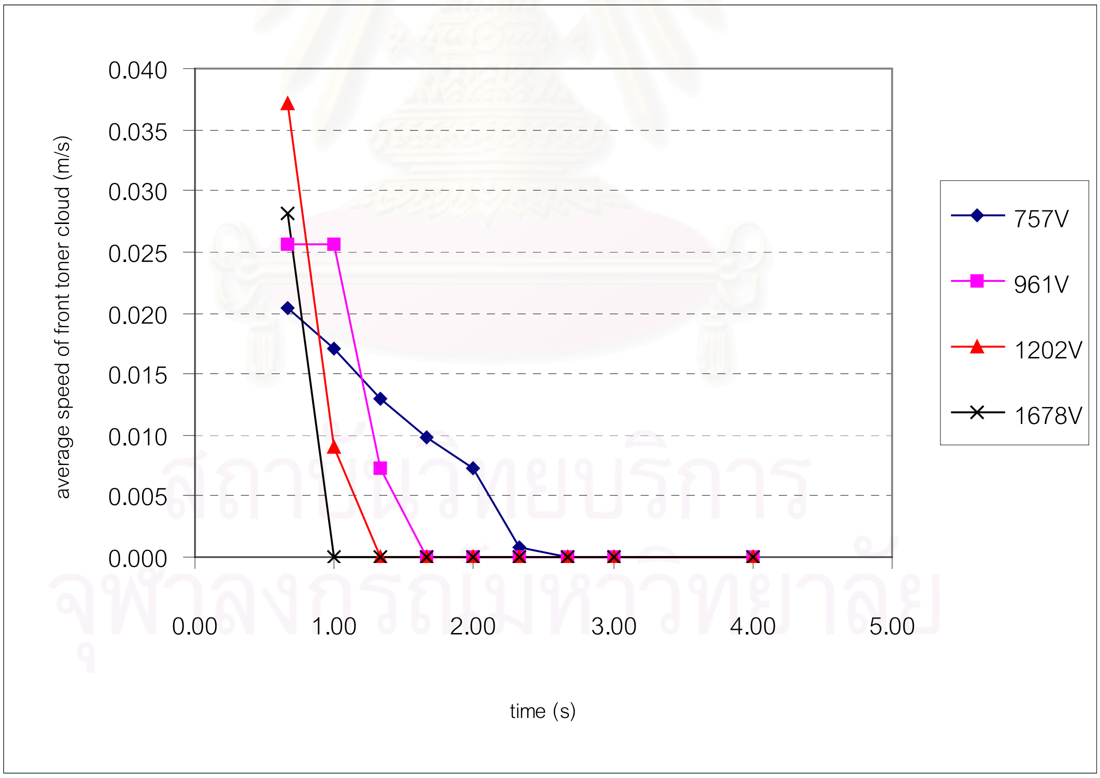
c)

Figure 4-19 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 4 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.



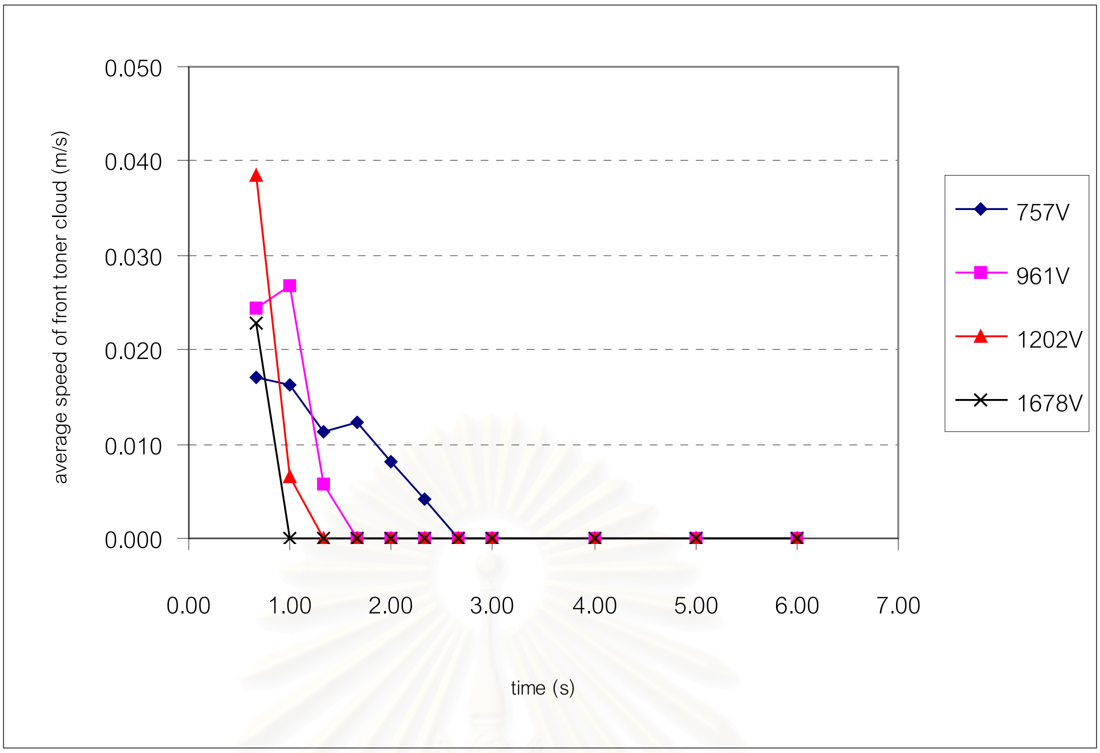
average speed of front toner cloud (m/s)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
time (s)
757V
961V
1202V
1678V

a)



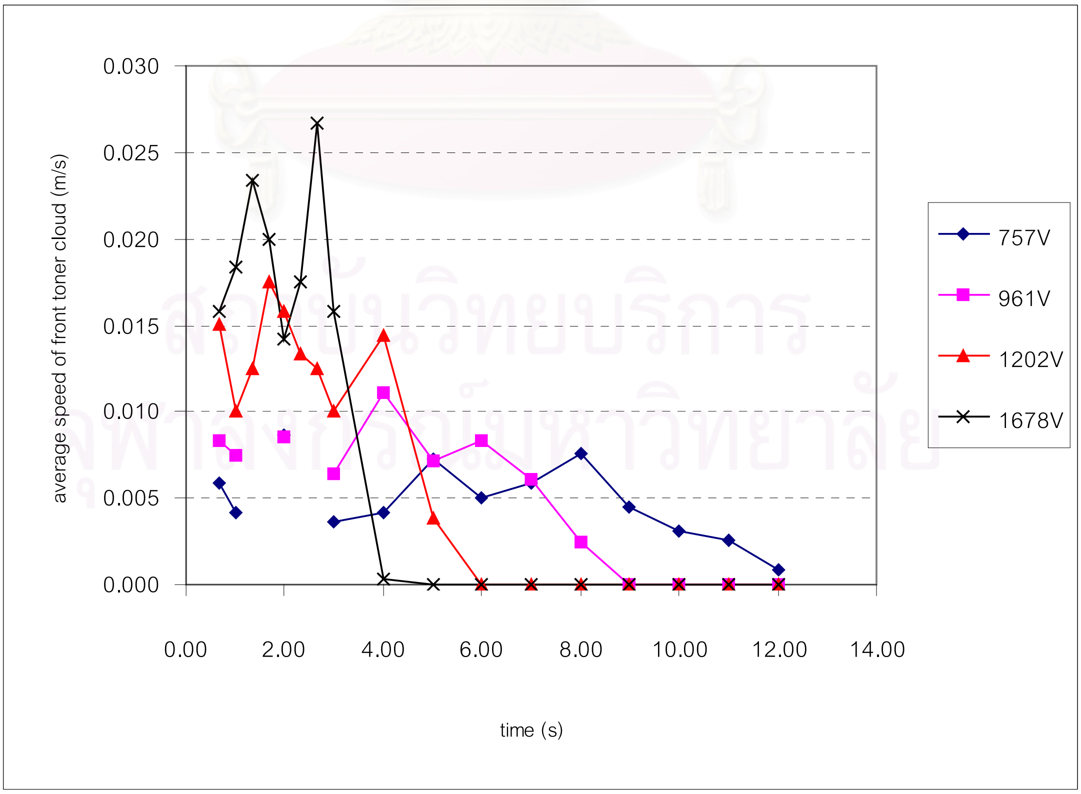
average speed of front toner cloud (m/s)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.00
1.00
2.00
3.00
4.00
5.00
time (s)
757V
961V
1202V
1678V

b)

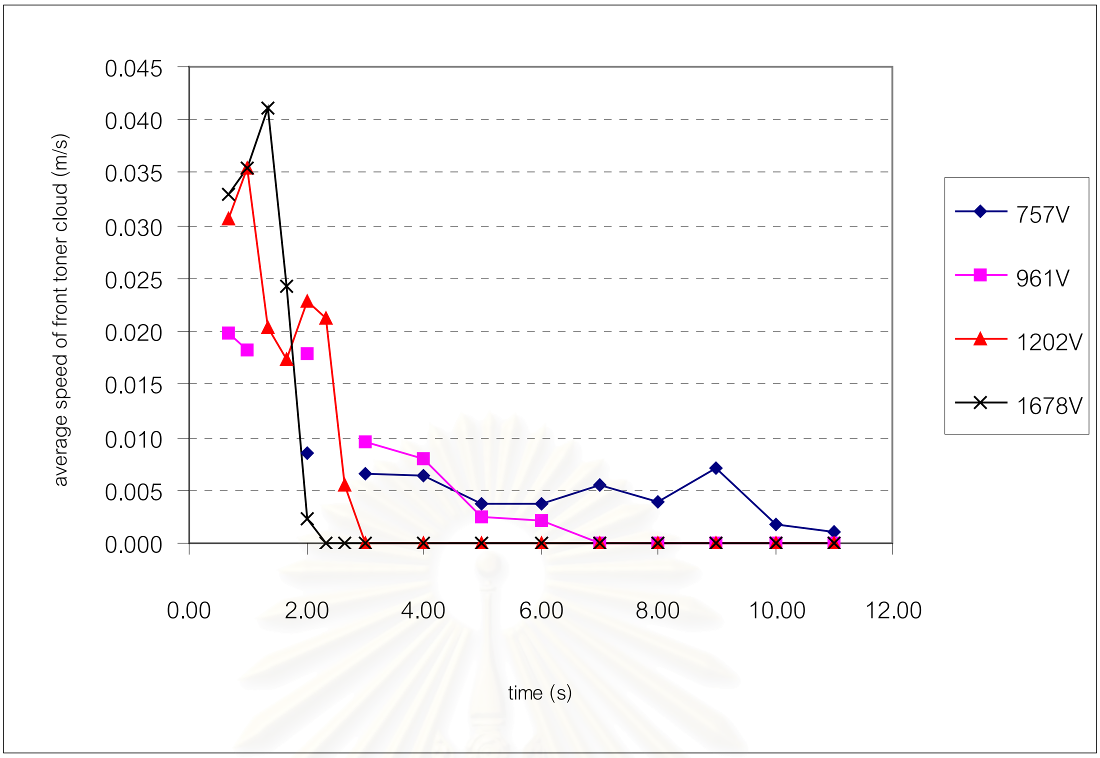


c)

Figure 4-20 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 6 mg put at the center with different nesa glass slopes of a) parallel, b) 0.64 degree and c) 0.95 degree.

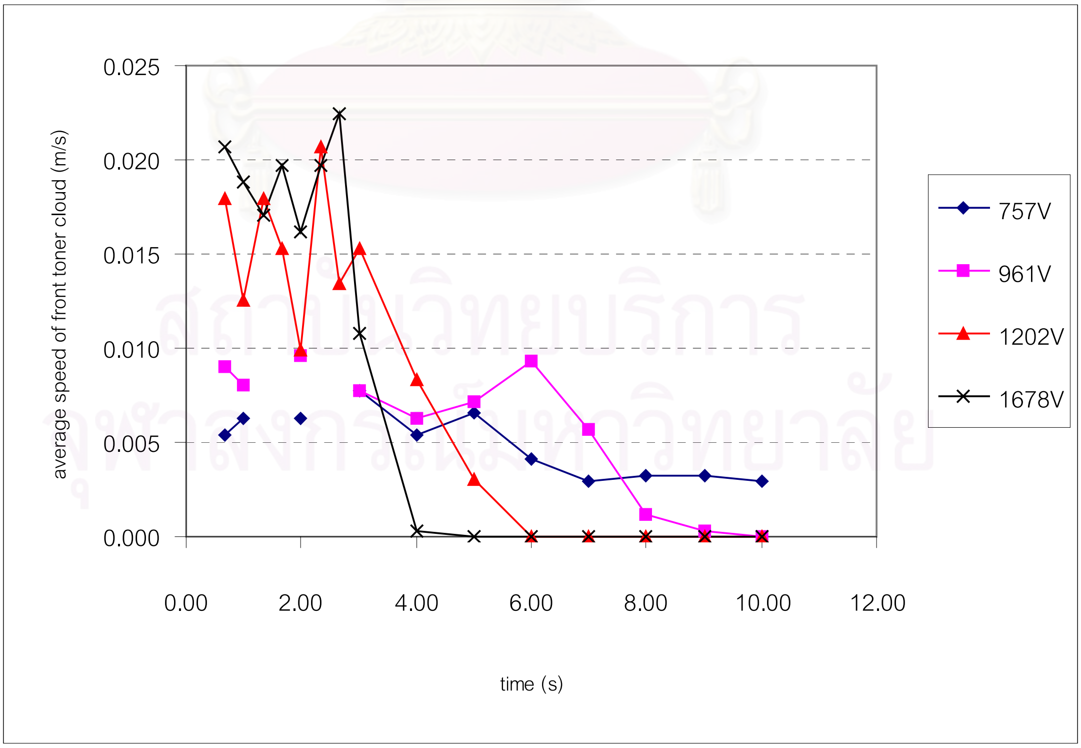


a)

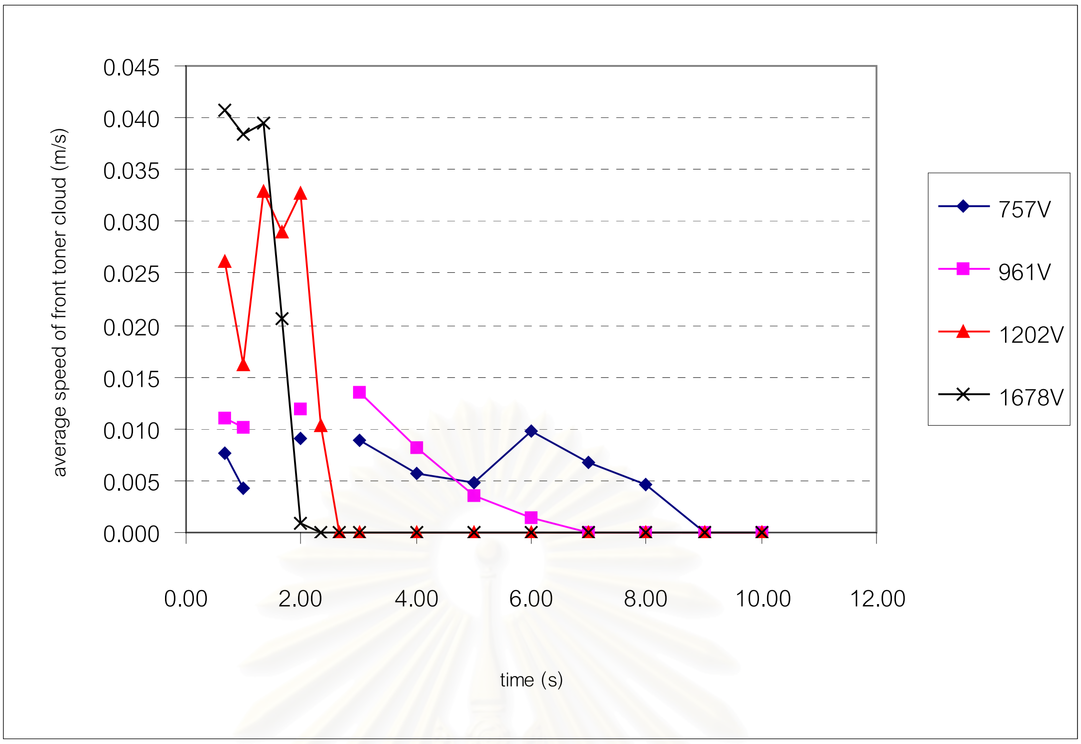


b)

Figure 4-21 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 3 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

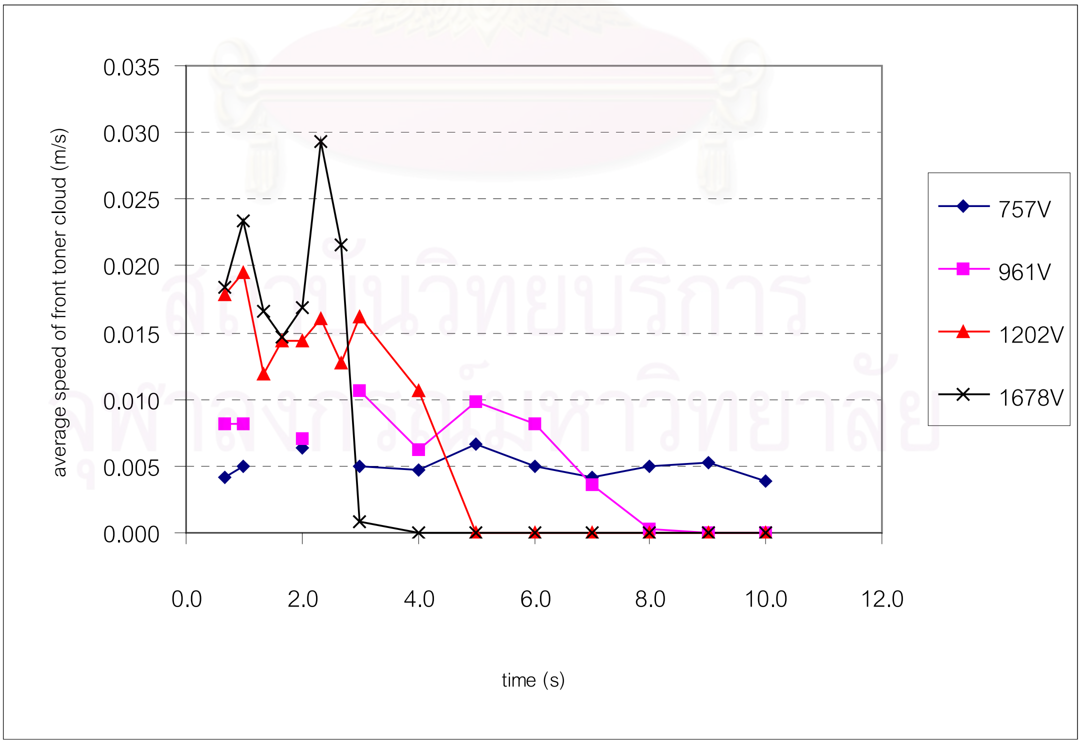


a)

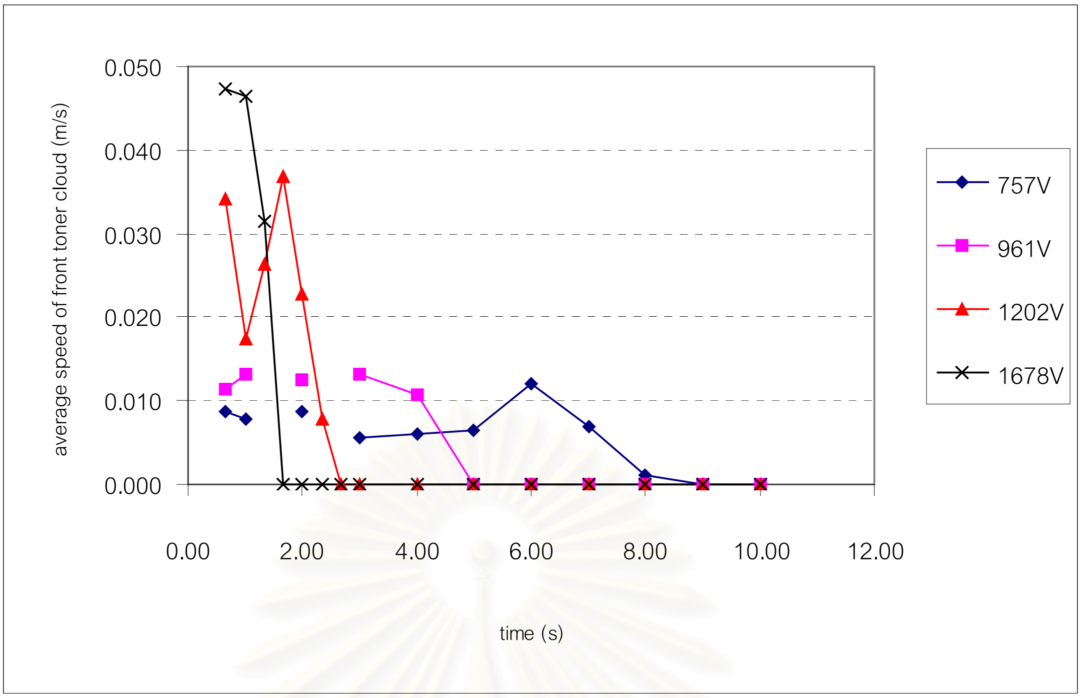


b)

Figure 4-22 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 4 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

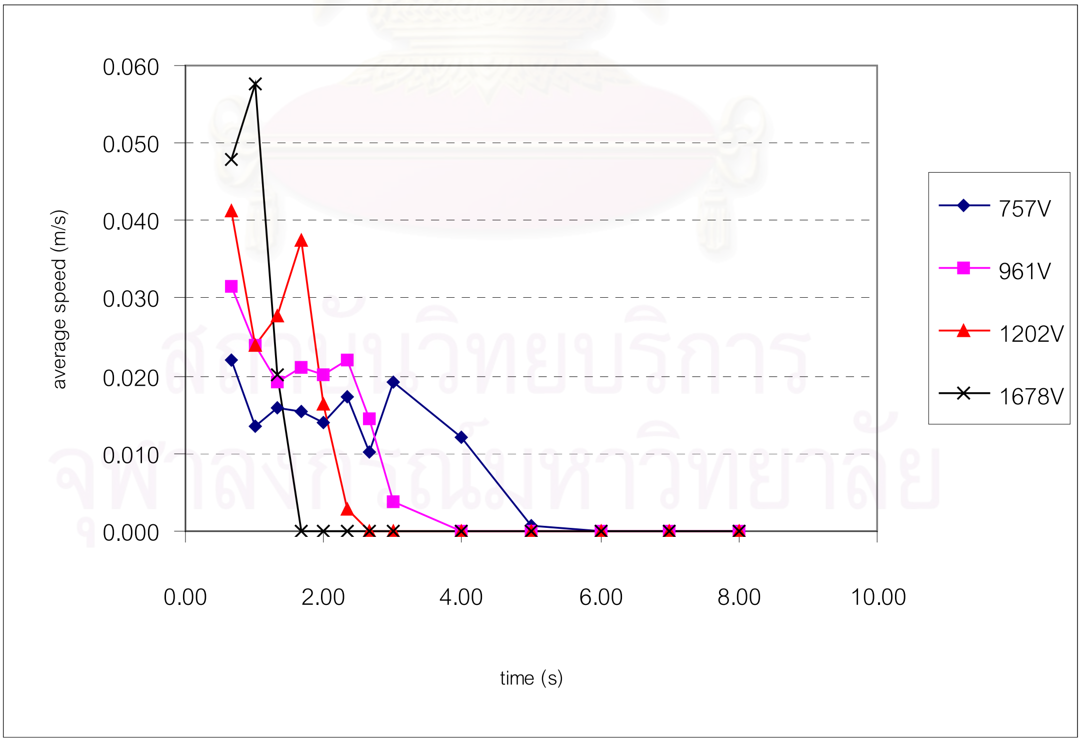


a)

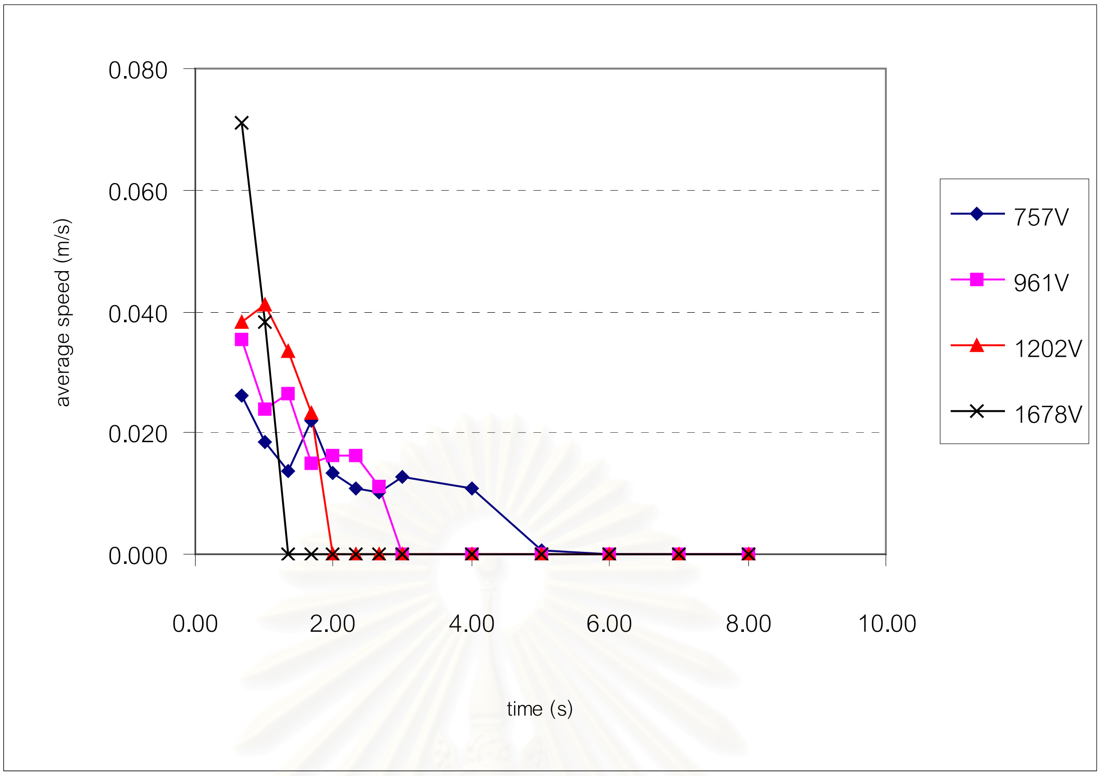


b)

Figure 4-23 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.5 mm and toner 6 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

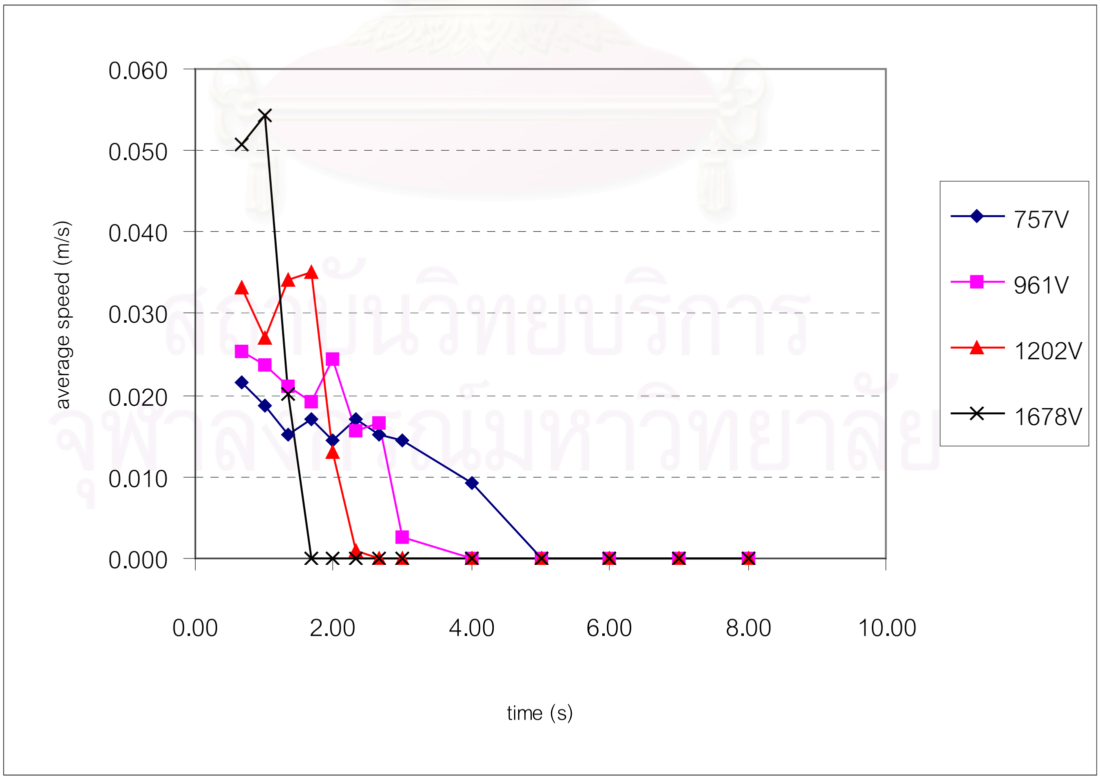


a)

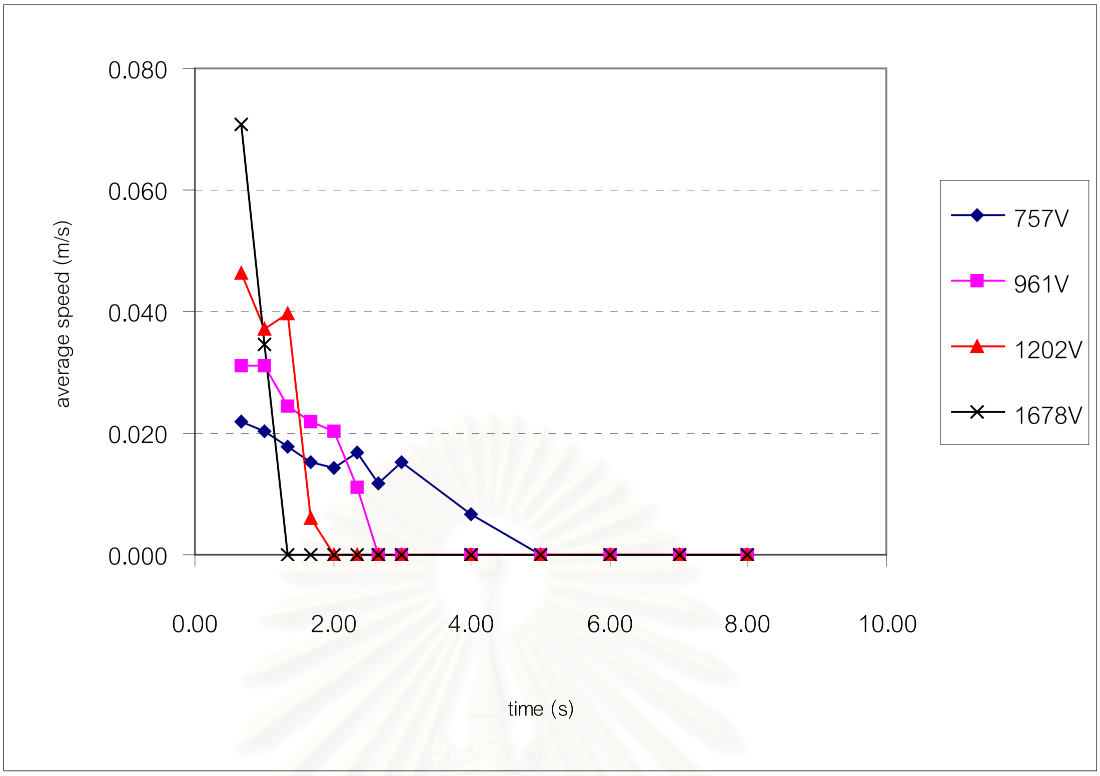


b)

Figure 4-24 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 3 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

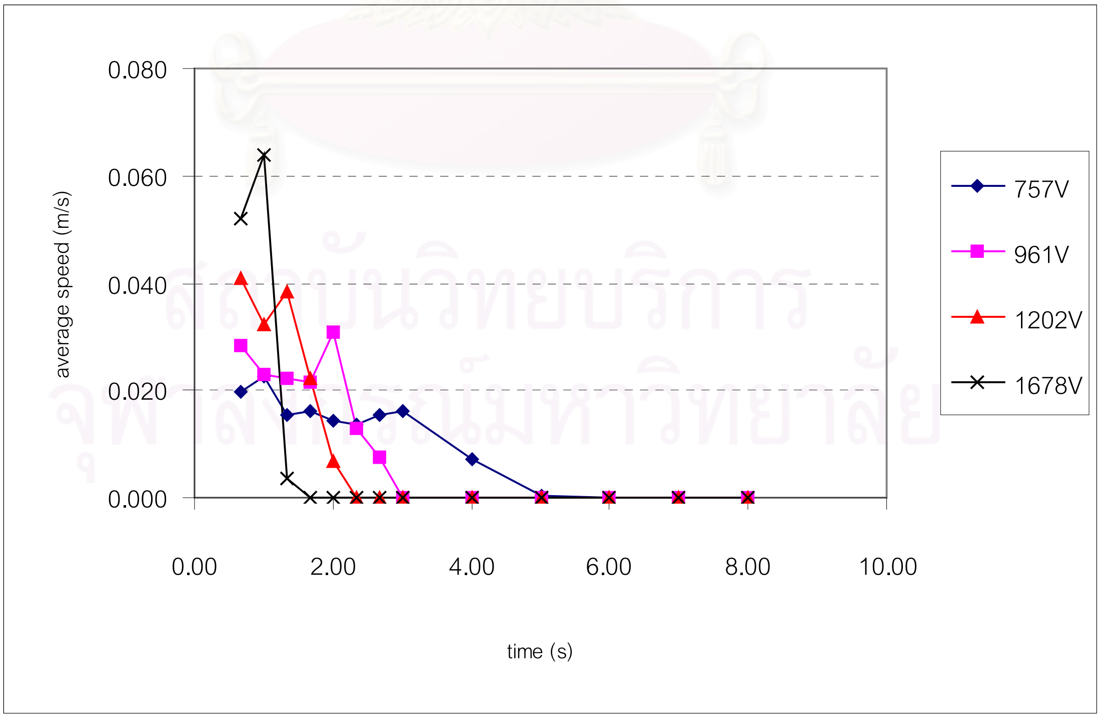


a)

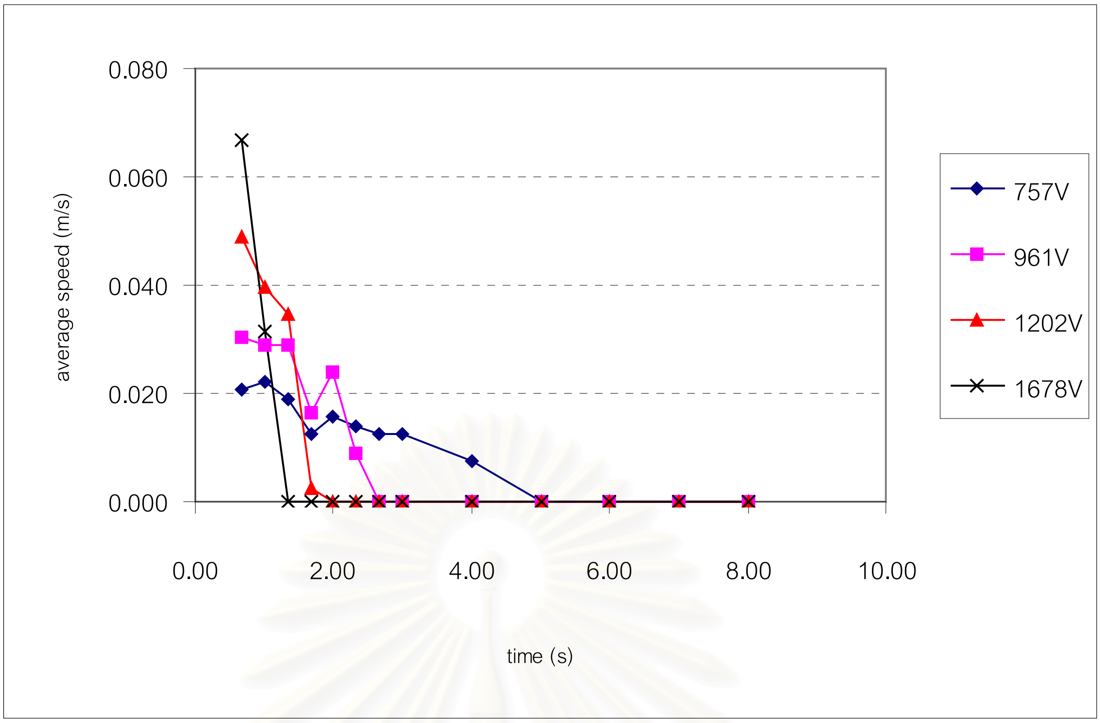


b)

Figure 4-25 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 4 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.



a)



b)

Figure 4-26 Dependence of the average speed of the front toner cloud on the applied voltage at the fixed depth of the dented electrode of 0.2 mm and toner 6 mg put at the electrode end with different nesa glass slopes of a) 0.64 degree and b) 0.95 degree.

From Figures 4-15 to 4-26, the slope of the average speed curve at the lower applied voltage seems nearly constant till the toner cloud arrives the electrode end but it turned very steep with the higher applied voltage. Actually, the curve should change in the same direction. However, because the scale of the data was very rough and the toner cloud moved very fast at high applied voltage, which made the curves non-straight. It should be observed that the front of toner cloud moved with a constant speed at lower applied voltages and moved very fast at higher applied voltages.

Several mechanisms are considered to explain this toner cloud motion. The first one is the random scattering occurred after the collision to the electrodes because of the irregular shape of toners. The second is toner scattering during its jumping. The toner scattering occurred by direct collision between toners or coulombs repulsion between the same polarity of toner particles.

The first one shall be discussed in the following section. When the toner shape is round, the charged toner particles will move up and down in the electric field (neglect the collision between toner particles) as shown in Figure 4-27 a). However, the random scattering direction at the collision of electrodes occurred because the shape of toner particles in this experiment is irregular as shown in Figure 4-27 b).

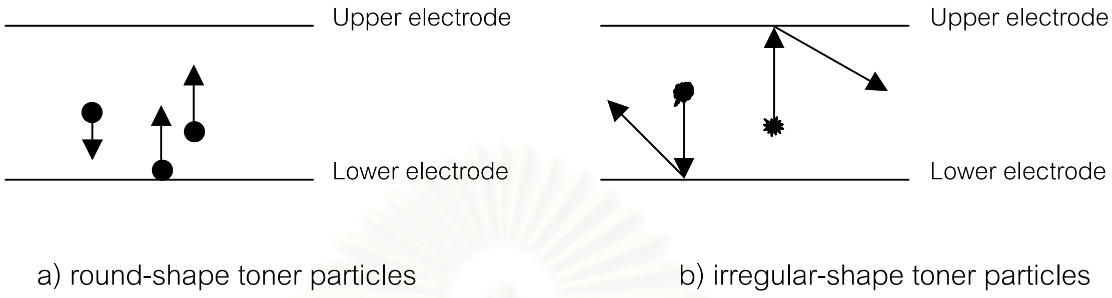


Figure 4-27 The conductive toner movements under the electric field, a) round-shape toner particles, and b) irregular-shape toner particles.

The basic probability concepts will be illustrated by "the random-walk and binomial distribution."[18] A toner particle starts out from the center of dented electrode taking an equal length (mean free part; l) at each step. In its simplest idealized form, the particles under the applied voltage will move each time, and each step, with the probability of its being to the right is p, while the probability of its being to the left is q = 1 – p. (In the simplest case p = q; but in general $p \neq q$). The x axis was chosen to lie along the dented electrode surface so that x = 0 is the position of the point of origin, the center. After a total of N such steps, each of the length l, the particle is located at

$$x = ml$$

where m is an integer (positive, negative, or zero) lying between

$$-N \leq m \leq N$$

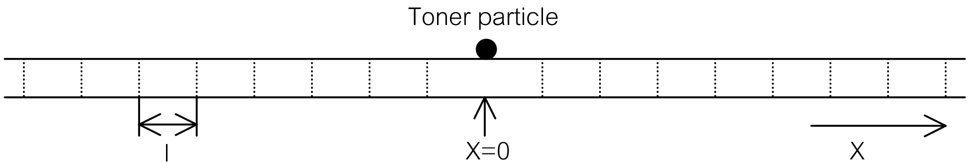


Figure 4-28 The random walk of toner particle in one dimension.

We want to calculate the probability $P_N(m)$ of finding the particle at the position x = ml after N such steps.

Let n_1 denote the number of steps at the right of the electrode, and n_2 represent the corresponding number of steps to the left. Of course, the number of steps N is simply

$$N = n_1 + n_2 \tag{4.1}$$

The net displacement (measured to the right in units of a step length) is given by

$$m = n_1 - n_2 \tag{4.2}$$

If it is known that in some sequence of N steps the particle has taken n_1 steps to the right, then its net displacement from the origin is determined. Indeed, the preceding relations immediately yield

$$m = n_1 - n_2 = n_1 - (N - n_1) = 2n_1 - N \tag{4.3}$$

Now, the probability of any particle given sequence of n_1 steps to the right and n_2 steps to the left is given simply by multiplying the respective probabilities by

$$pp \cdots pqq \cdots q = p^{n_1} q^{n_2} \tag{4.4}$$

But there are many different possible ways of taking N steps so that n_1 of them are to the right and n_2 are to the left. Indeed, the number of distinct possibilities is given by

$$\frac{N!}{n_1! n_2!} \tag{4.5}$$

Hence the probability $W_N(n_1)$ of taking (in a total of N steps) n_1 steps to the right and n_2 = N – n_1 steps to the left, in any order, is obtained by multiplying the probability of this sequence by the number of possible sequences of such steps. This gives

$$W_N(n_1) = \frac{N!}{n_1! n_2!} p^{n_1} q^{n_2} \tag{4.6}$$

The probability function is called the binomial distribution. The reason is represent a typical term encountered in expanding $(p + q)^N$ by the binomial theorem. The binomial expansion is given by the formula

$$(p+q)^N = \sum_{n=0}^{N} \frac{N!}{n!(N-n)!} p^N q^{N-n} \qquad (4.7)$$

If it is known that the particle has performed n_1 steps to the right in a total of N steps, then its net displacement m from the origin is determined. Thus the probability $P_N(m)$ that the particle is found at the position m after N steps is the same as WN(n1), i.e.,

$$P_N(m) = W_N(n_1) \qquad (4.8)$$

But

$$n_1 = \frac{1}{2}(N+m), \qquad n_2 = \frac{1}{2}(N-m) \qquad (4.9)$$

By substitution of these relations

$$P_N(m) = \frac{N!}{[(N+m)/2]![(N-m)/2]!} p^{(N+m)/2}(1-p)^{(N-m)/2} \qquad (4.10)$$

In the case where p = q = ½ ,this assumes the symmetrical form

$$P_N(m) = \frac{N!}{[(N+m)/2]![(N-m)/2]!} \left(\frac{1}{2}\right)^N \qquad (4.11)$$

After N random steps, the probability of the particle being a distance of N steps away from the origin is very small, while the probability of its being located in the vicinity of the origin is the largest.

One can also compute the dispersion of m, i.e., the dispersion of the net displacement to the right. By (4.3) $m = n_1 - n_2 = n_1 - (N - n_1) = 2n_1 - N$

Hence one obtains

$$\Delta m \equiv m - \overline{m} = (2n_1 - N) - (2\overline{n}_1 - N) = 2(n_1 - \overline{n}_1) = 2\Delta n_1 \qquad (4.12)$$

and $$(\Delta m)^2 = 4(\Delta n_1)^2$$

Taking averages, one gets by the dispersion of n1, $\overline{(\Delta n_1)^2} = Npq$

$$\overline{(\Delta m)^2} = 4\overline{(\Delta n_1)^2} = 4Npq \tag{4.13}$$

In particular, for p = q = ½,

$$\overline{(\Delta m)^2} = N \tag{4.14}$$

Figure 4-29 illustrates the binomial distribution, where p = q = ½, but with the total number of steps N=20. The envelope of these discrete values of $P_N(m)$ is a bell-shaped curve. The physical significance of this is obvious. After N random steps, the probability of the particle being a distance of N steps away from the origin is very small, while the probability of its being located in the vicinity of the origin is the largest. The graph shows the probability $W_N(n_1)$ of n_1 right steps, or equivalent to the probability $P_N(m)$ of a net displacement of m units to the right. It could be said that the square average of toner position relates to N.

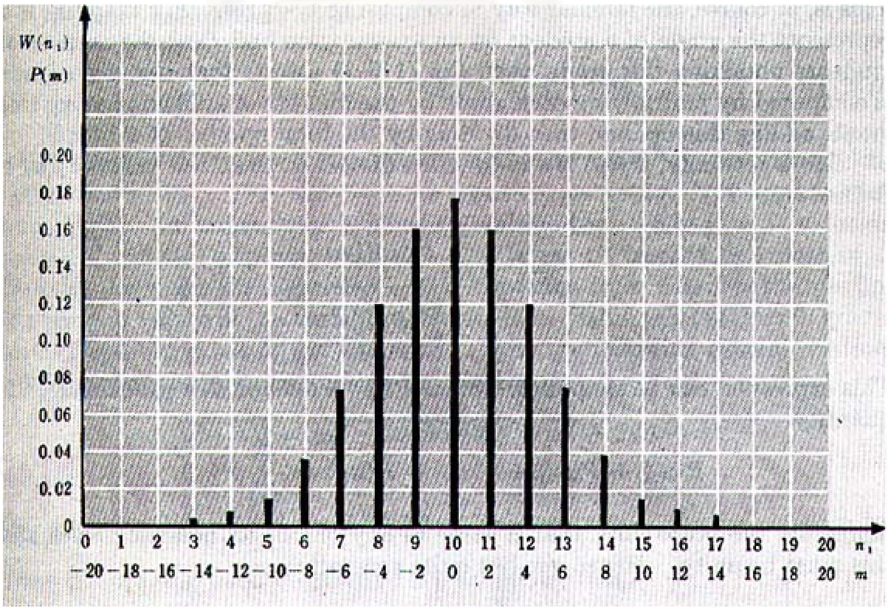


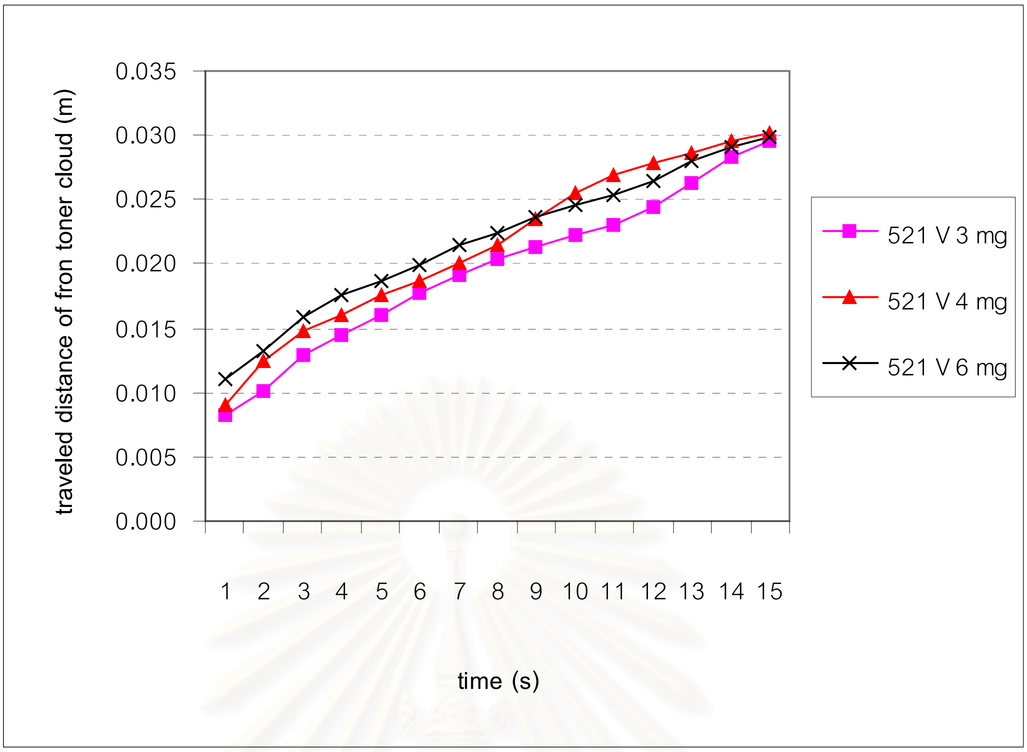
Figure 4-29 Binomial probability distribution for p = q = ½ when N=20 steps.

Furthermore, the speed of toner cloud also depend on the toner amount, the depth of the dented electrode, the slope of the nesa glass and the slope of the system as follows:

4.1.2 Dependence of toner cloud motion on toner amount

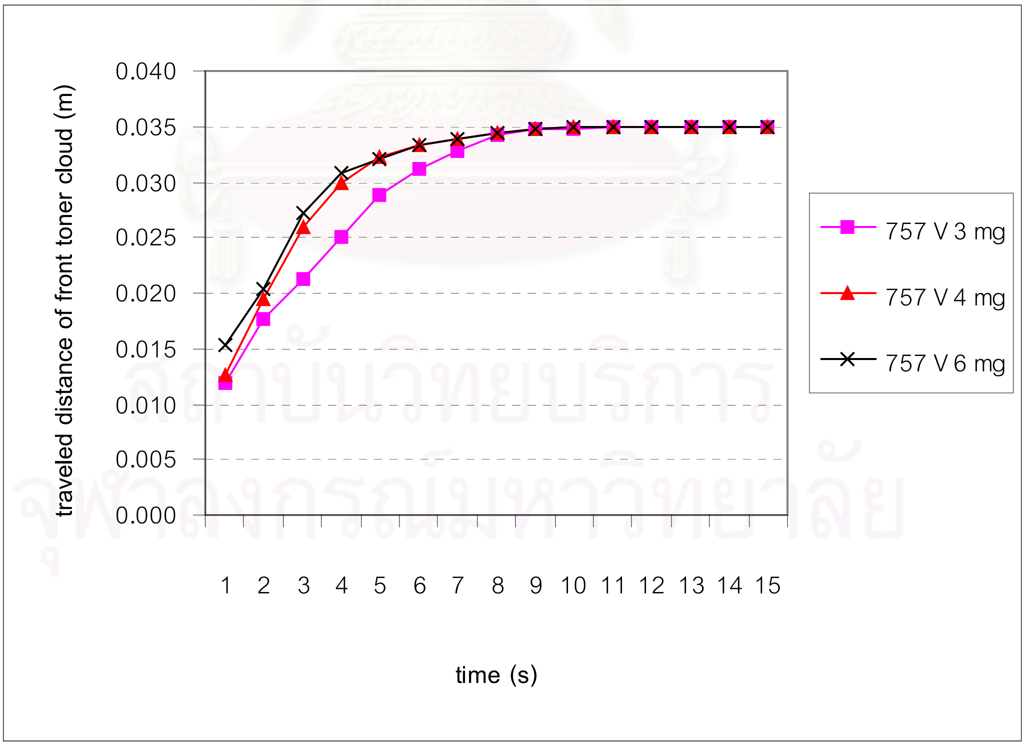
The toner amount of 3, 4 and 6 mg with the resistivity of $1.55 \times 10^{10}\ \Omega$ cm was used for the toner cloud study. Figures 4-30 to 4-35 show the dependence of the toner cloud speed on the toner amount in their corresponding to the nesa glass slope at the fixed depth of 0.5 mm and 0.2 mm of the dented electrode with different applied voltages. The graphs show the similar tendency when increasing the slopes of the nesa glass. That is, increasing toner amount increases the speed of the front toner cloud propagation.

Comparing the toner amount, the greater the toner amount, the higher the speed of the front toner cloud propagation. Therefore, one can observe the fastest toner cloud propagation at the toner amount of 6 mg, and the slowest toner cloud propagation at the toner amount of 3 mg, while the toner amount of 4 mg gives the intermediate speed of propagation.



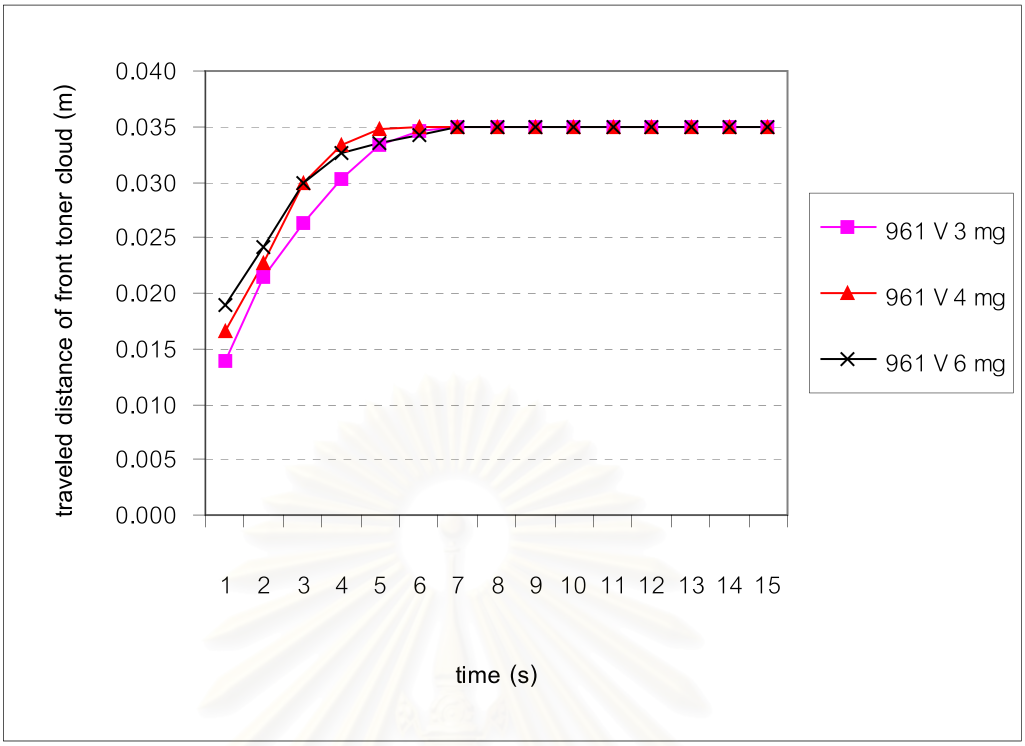
traveled distance of fron toner cloud (m)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time (s)
521 V 3 mg
521 V 4 mg
521 V 6 mg

a)

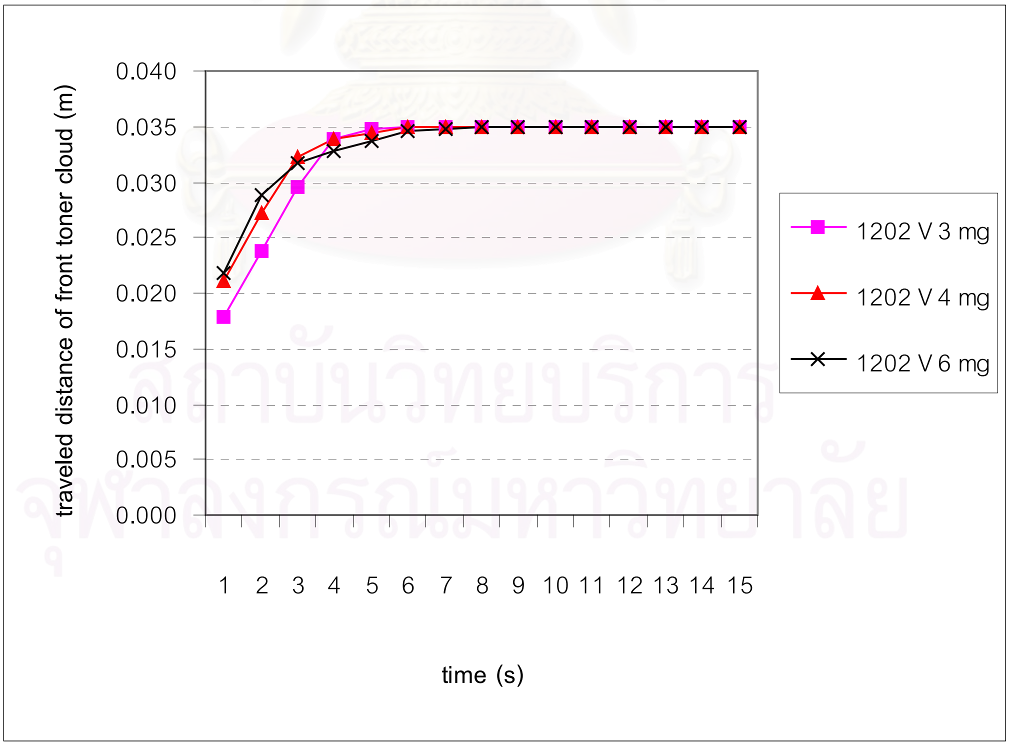


traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time (s)
757 V 3 mg
757 V 4 mg
757 V 6 mg

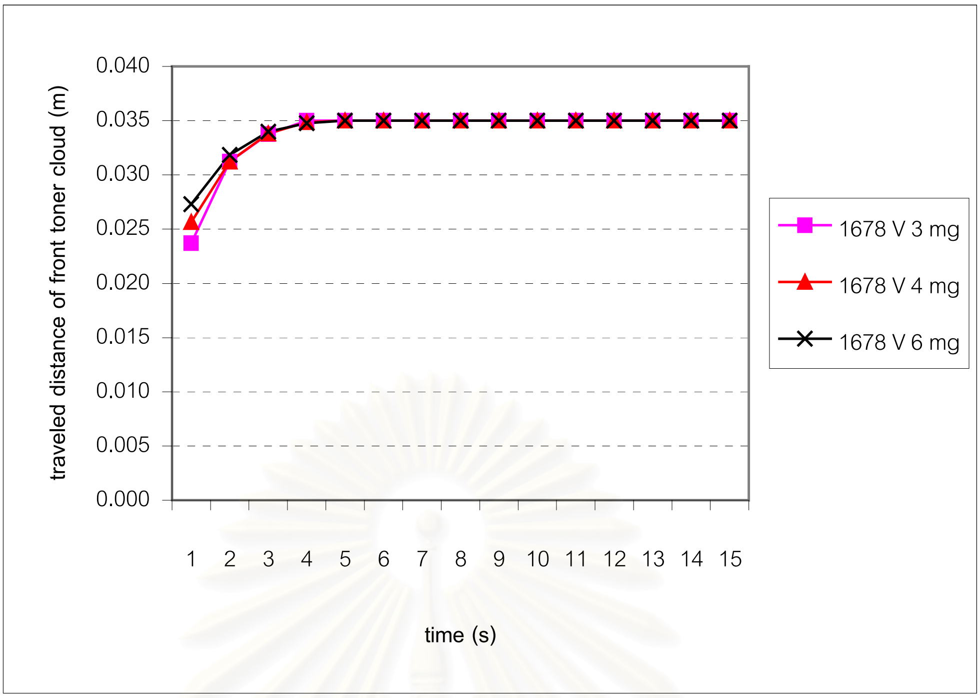
b)


0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time (s)
961 V 3 mg
961 V 4 mg
961 V 6 mg

c)

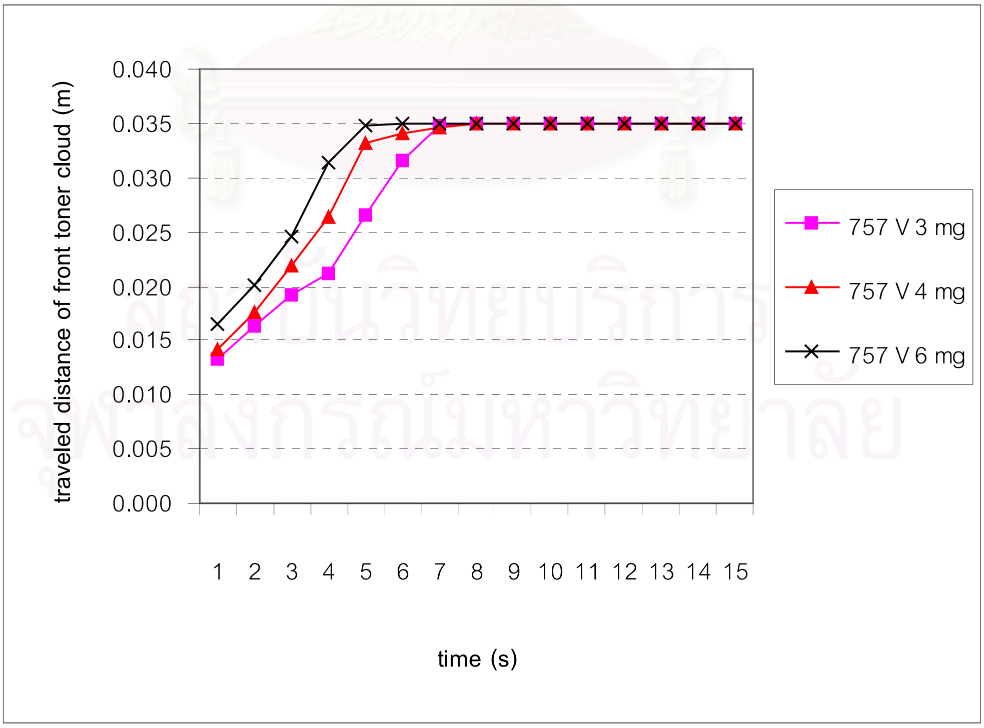

0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time (s)
1202 V 3 mg
1202 V 4 mg
1202 V 6 mg

d)

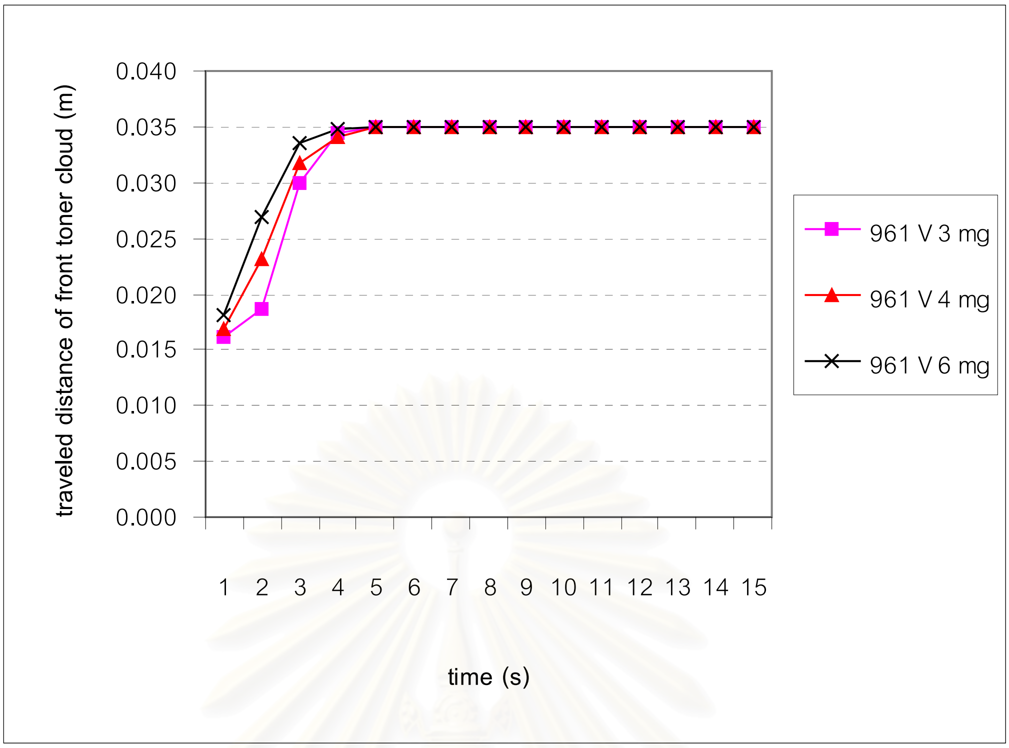


e)

Figure 4-30 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set parallel to the dented electrode at the fixed 0.5 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 521 V, b) 757 V, c) 961 V, d) 1202 V and e) 1678 V.

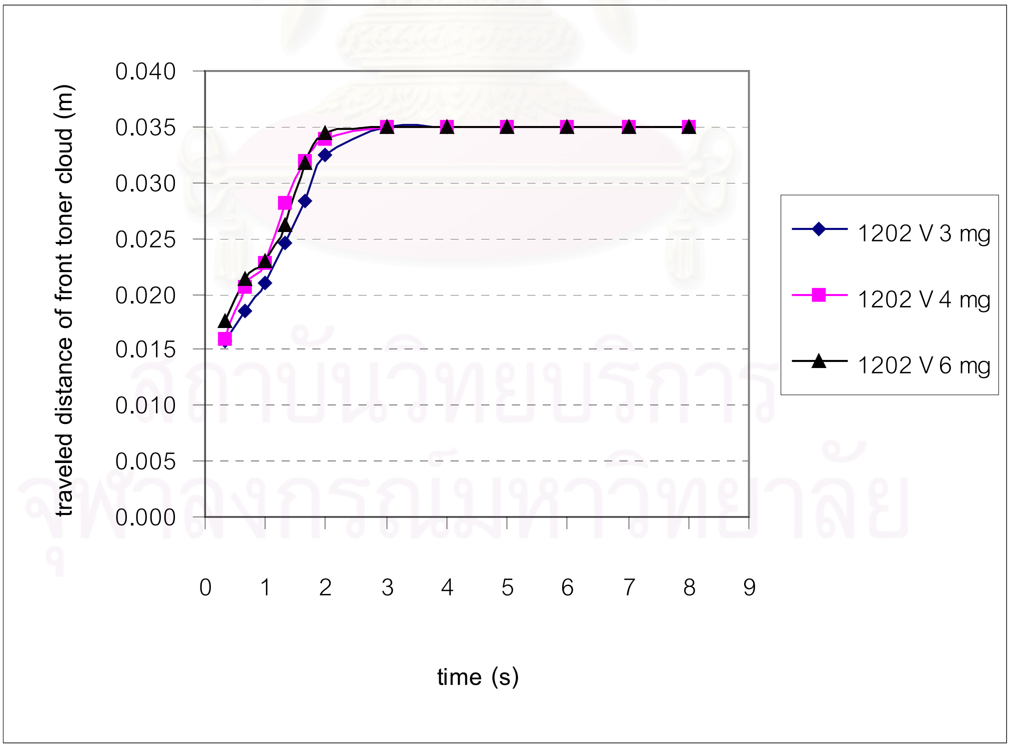


a)



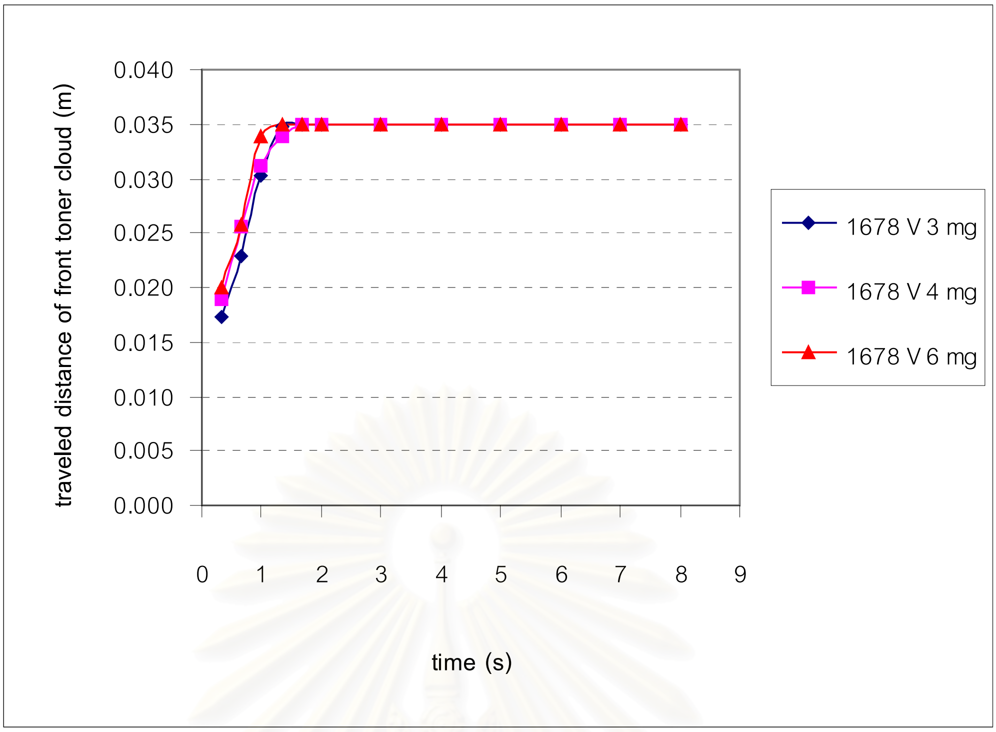
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time (s)
961 V 3 mg
961 V 4 mg
961 V 6 mg

b)



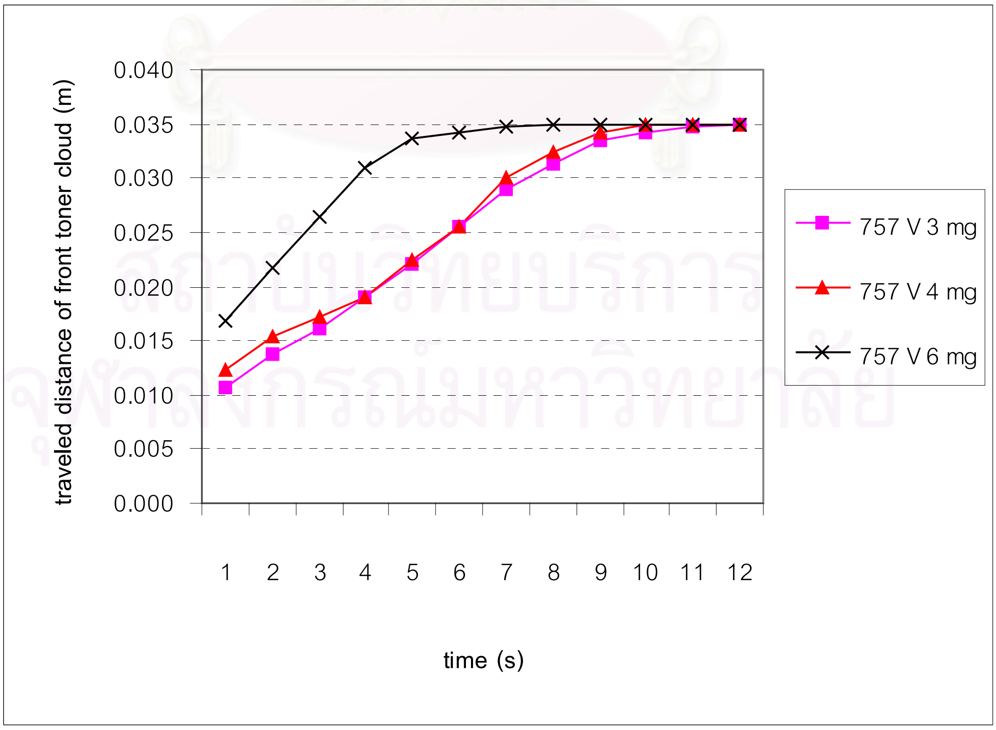
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0 1 2 3 4 5 6 7 8 9
time (s)
1202 V 3 mg
1202 V 4 mg
1202 V 6 mg

c)

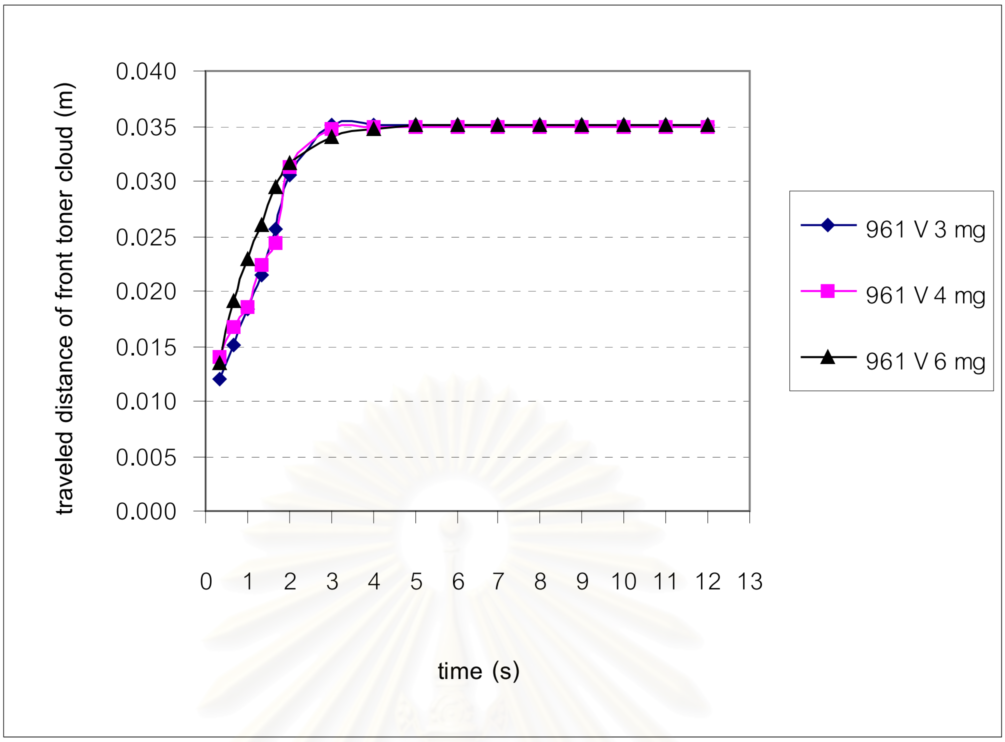


d)

Figure 4-31 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set at 0.64 degree to the dented electrode at the fixed 0.5 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.

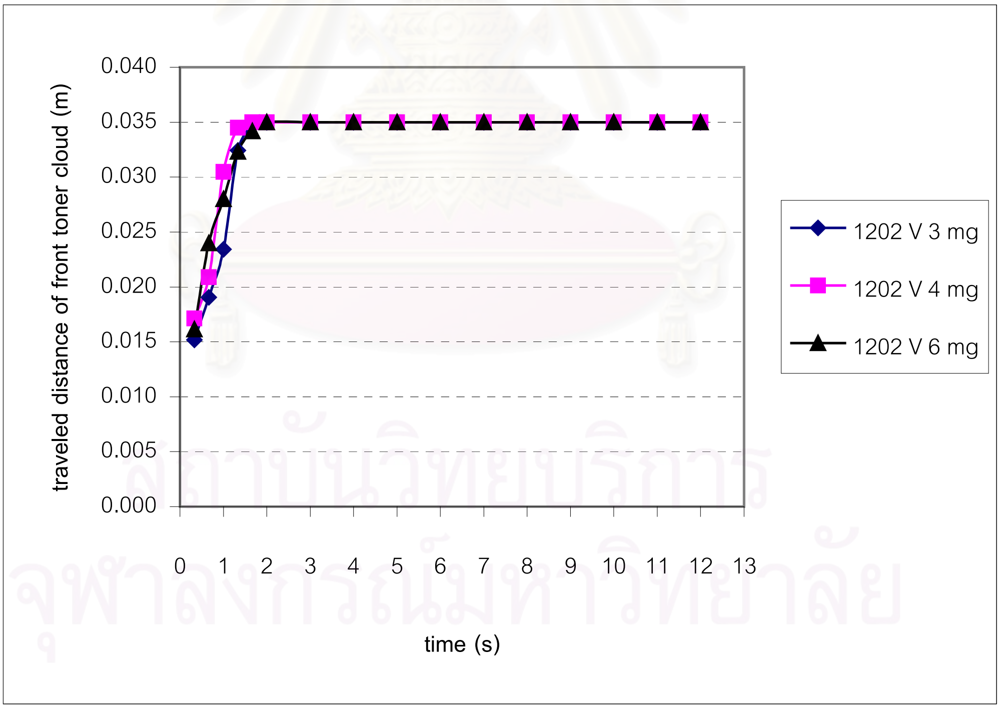


a)



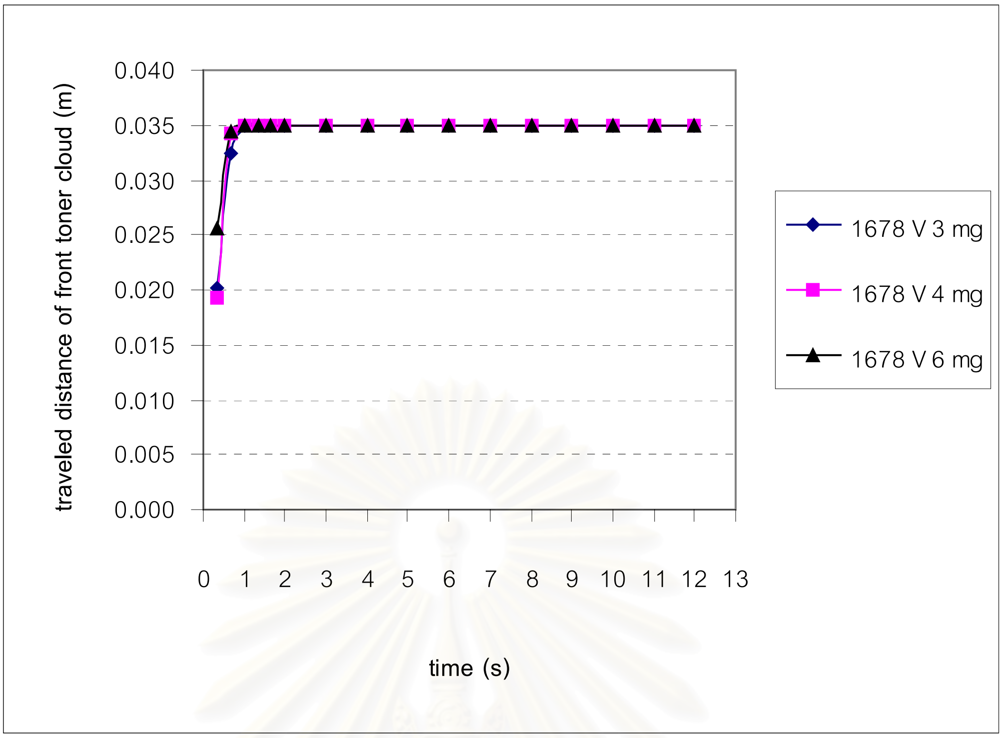
traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13
time (s)
961 V 3 mg
961 V 4 mg
961 V 6 mg

b)



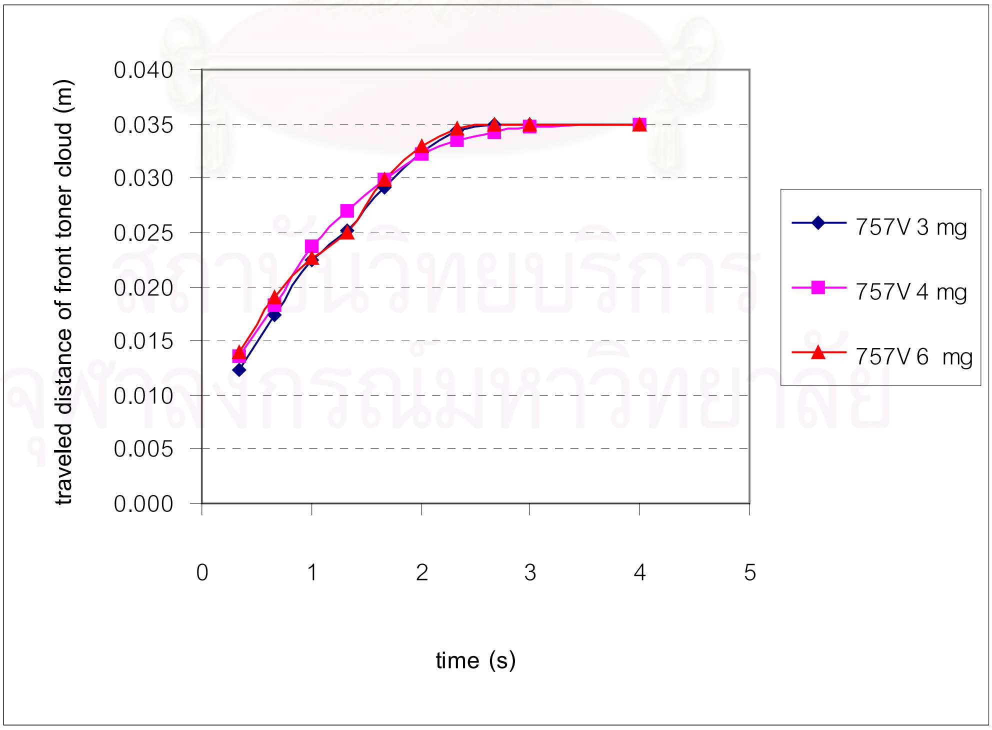
traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13
time (s)
1202 V 3 mg
1202 V 4 mg
1202 V 6 mg

c)

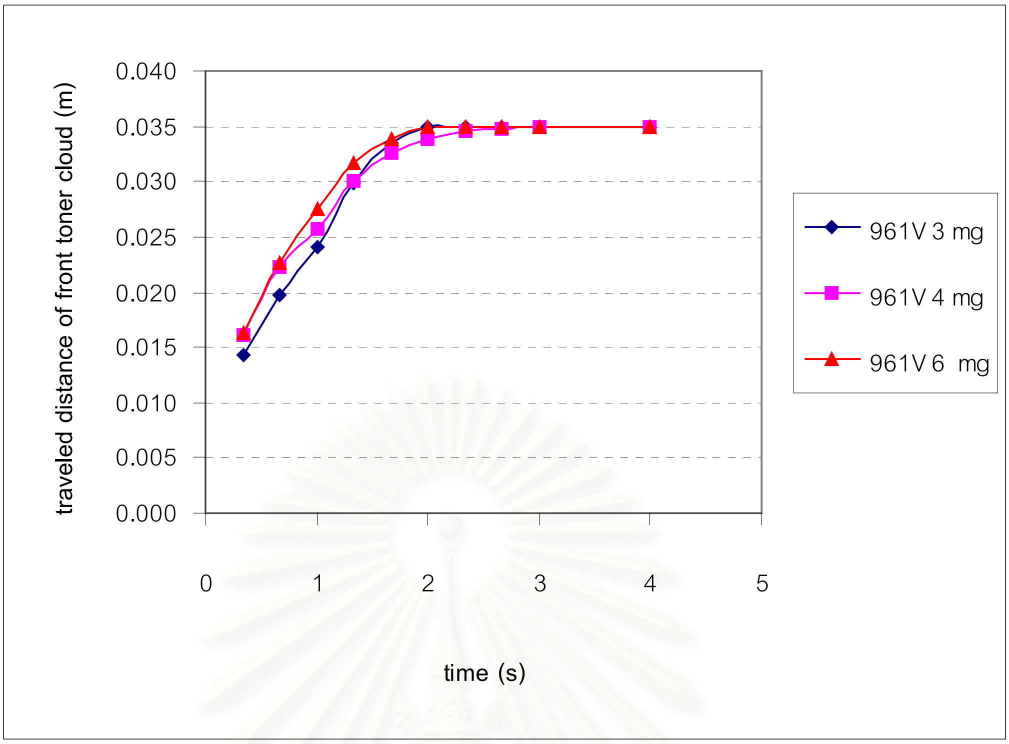


d)

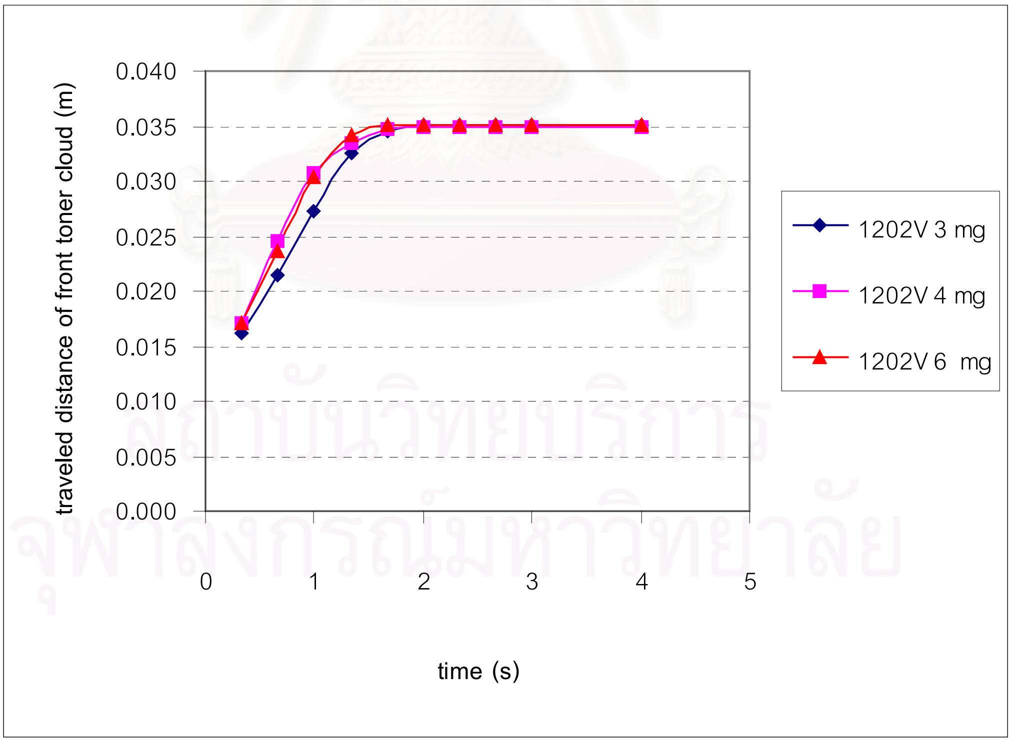
Figure 4-32 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set at 0.95 degree to the dented electrode at the fixed 0.5 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.



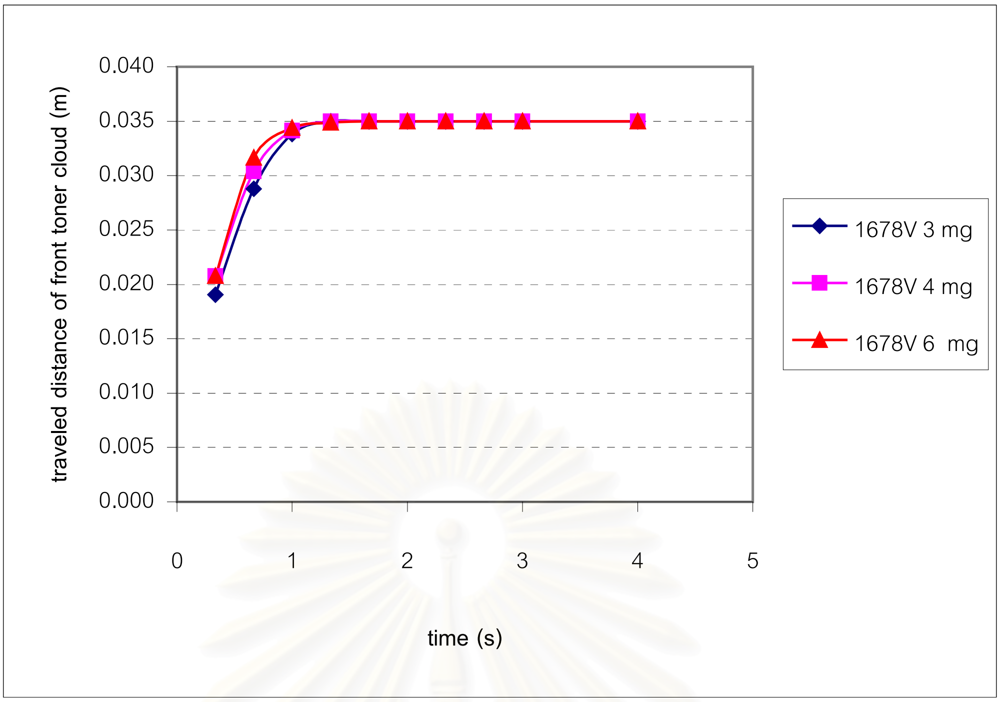
a)


traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
961V 3 mg
961V 4 mg
961V 6 mg

b)

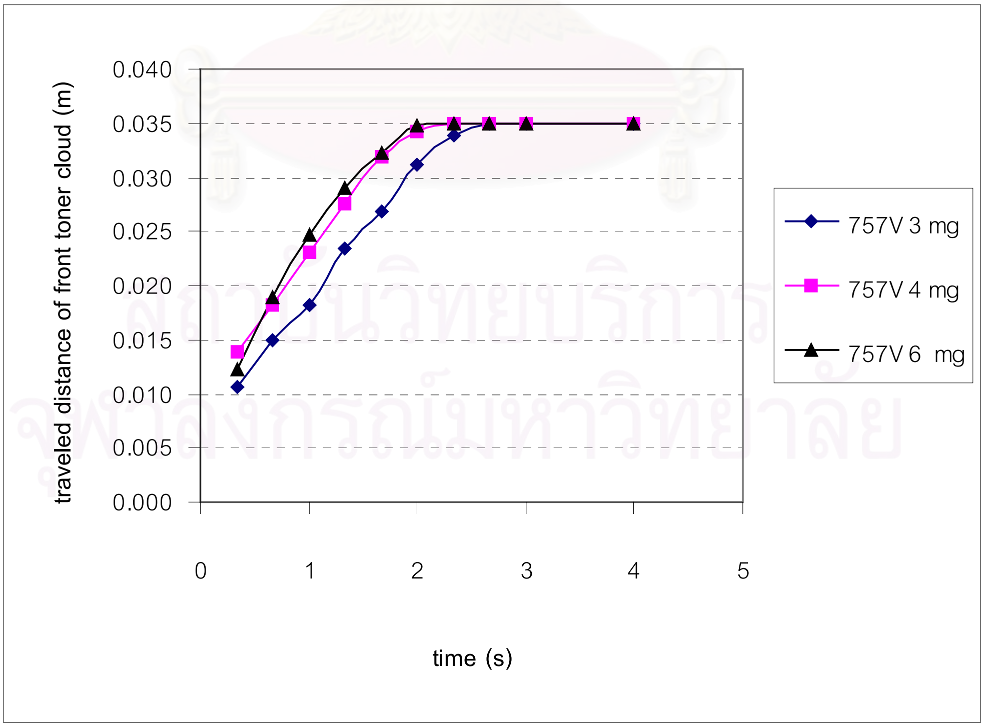

traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
1202V 3 mg
1202V 4 mg
1202V 6 mg

c)

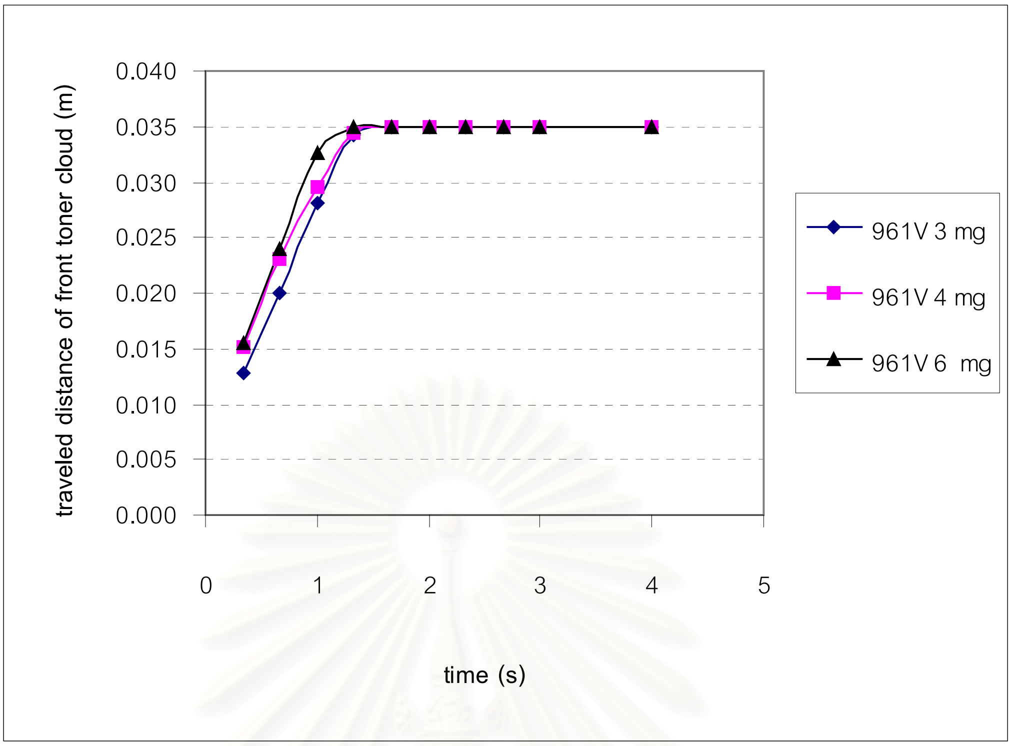


d)

Figure 4-33 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set parallel to the dented electrode at the fixed 0.2 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.

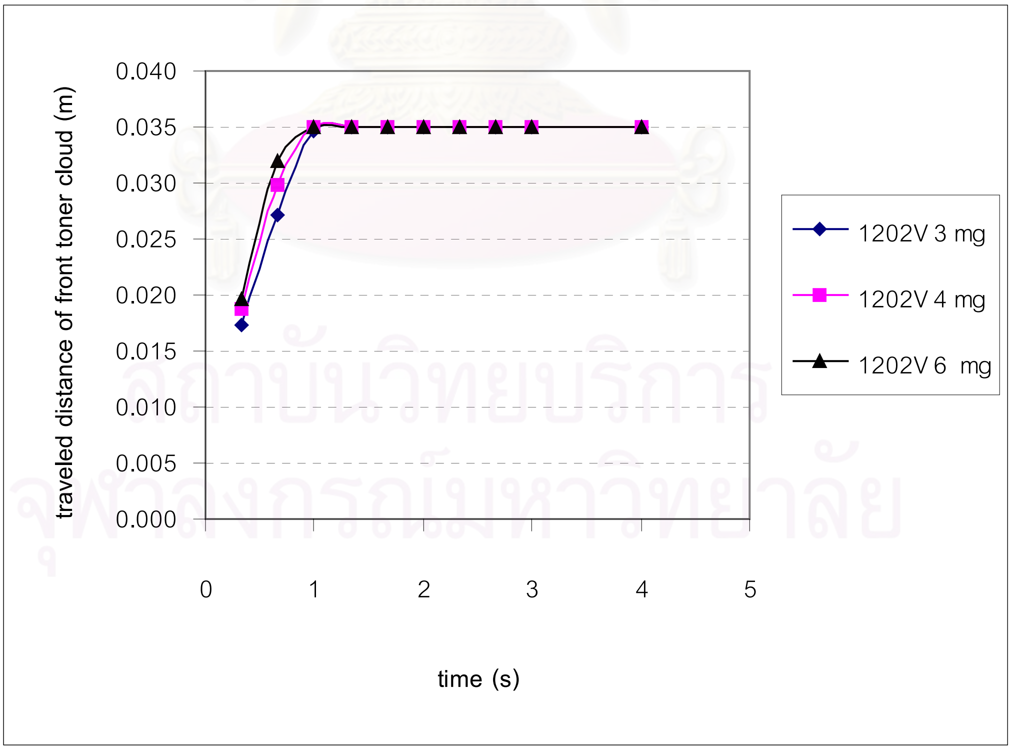


a)



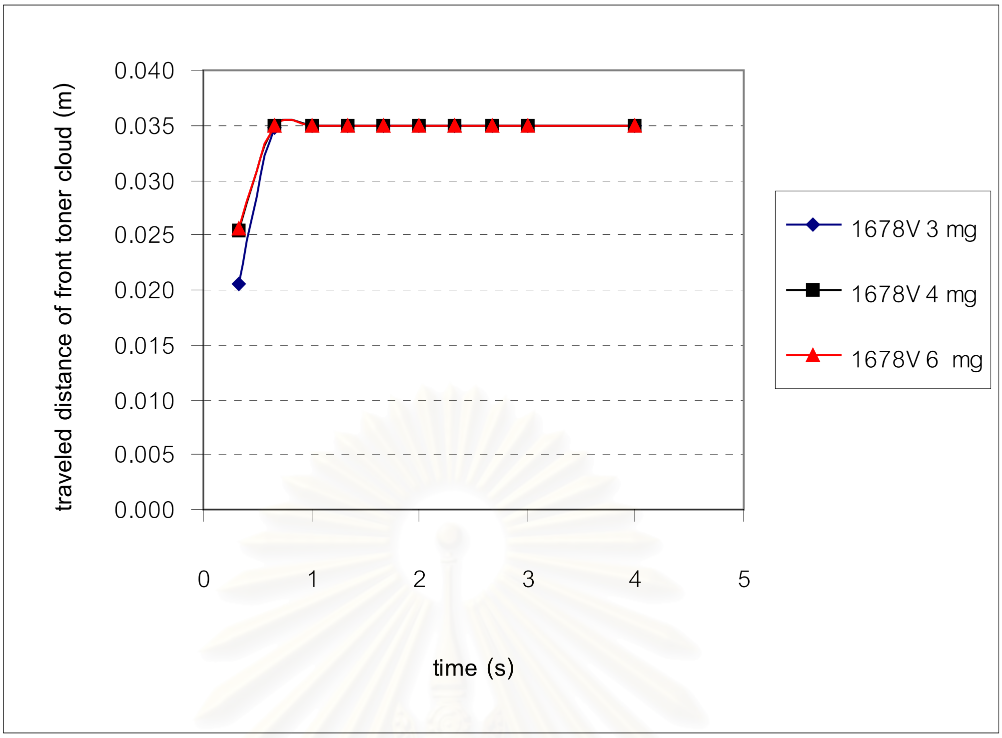
traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
961V 3 mg
961V 4 mg
961V 6 mg

b)



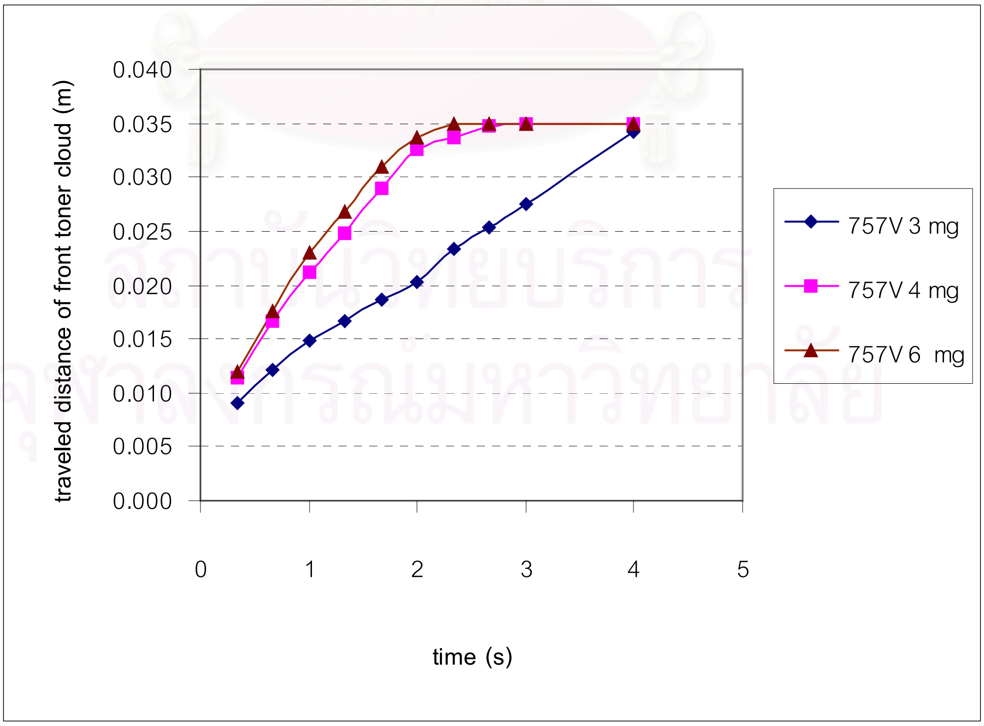
traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
1202V 3 mg
1202V 4 mg
1202V 6 mg

c)

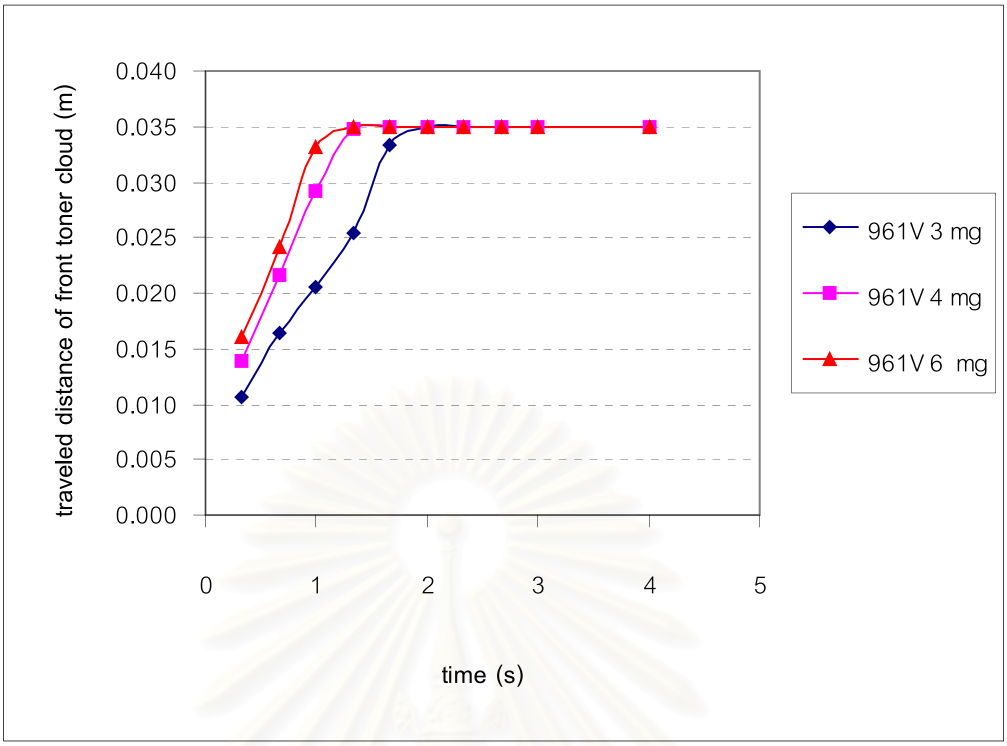


d)

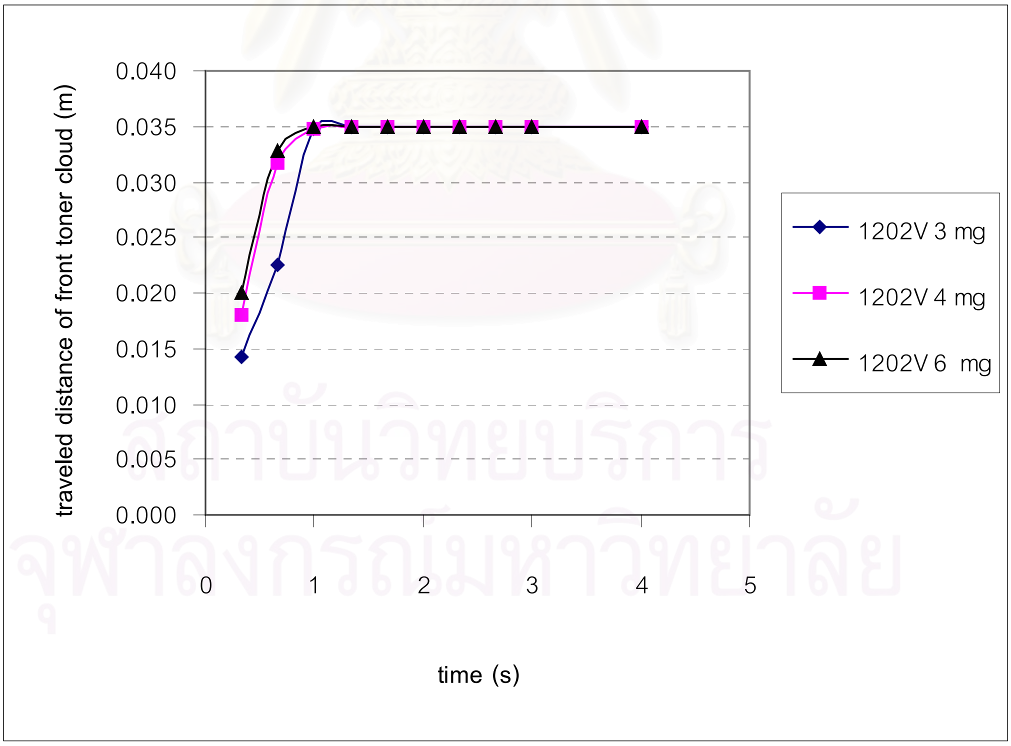
Figure 4-34 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set at 0.64 degree to the dented electrode at the fixed 0.2 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.



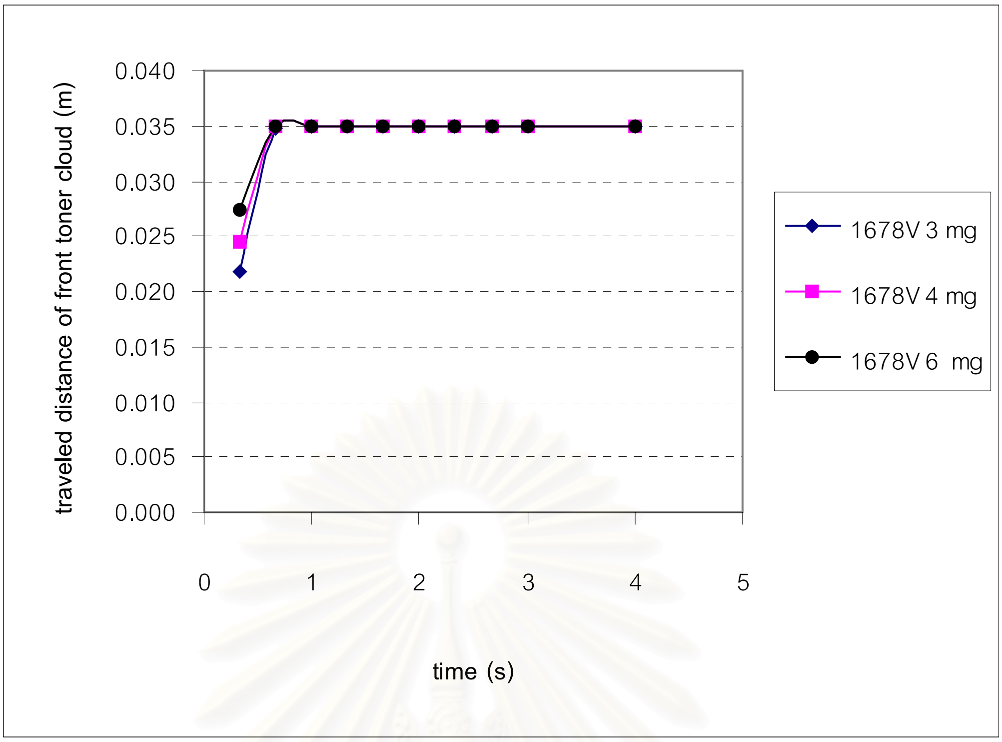
a)


traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
961V 3 mg
961V 4 mg
961V 6 mg

b)


traveled distance of front toner cloud (m)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
1
2
3
4
5
time (s)
1202V 3 mg
1202V 4 mg
1202V 6 mg

c)



d)

Figure 4-35 Dependence of traveled distance of the front toner cloud on the toner amount in case of the nesa glass set at 0.95 degree to the dented electrode at the fixed 0.2 mm depth of the dented electrode, put toner at the center, different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.

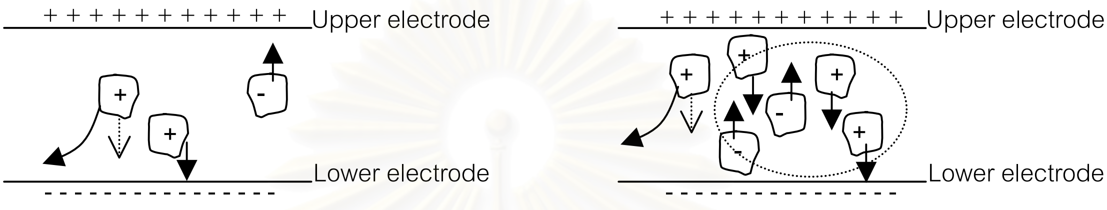
Figures 4-30 to 4-35 show the dependence of the front toner cloud speed on the toner amount in their corresponding to nesa glass slope. The graphs show the tendency that the increasing toner amount increases the speed of the front toner cloud propagation. The tendency resulting toner-toner interactions by two possibilities were categorizied: the Coulomb repulsion and the collision.

As mentioned previously, toner cloud motion occurs due to the Coulomb repulsion force. The results of these experiments, which may be explained by the Coulomb's law[19] formulated for the force between two-point charges in the MKS system as

$$\vec{F}_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\frac{\vec{r}_{12}}{r_{12}} \tag{4.15}$$

where $\vec{F}_1$ is the force on charge q_1, $\vec{r}_{12}$ is the vector for q_1 from q_2, r_{12} is the magnitude of $\vec{r}_{12}$, and ε_0 is known as the permittivity of free space and is numerically equal to 8.854×10^{-12} $C^2/N{\cdot}m^2$.

In the microscopic sense, the interaction of the same polarity toner charge particle induced the toner charge trajectory as shown in Figure 4-36 a).



a) the microscopic sense b) the macroscopic sense

Figure 4-36 The Coulomb repulsion force induced the toner particle trajectory in a) the microscopic sense and b) the macroscopic sense

If a system of N charges is considered, the force on the *i*th charge is given by

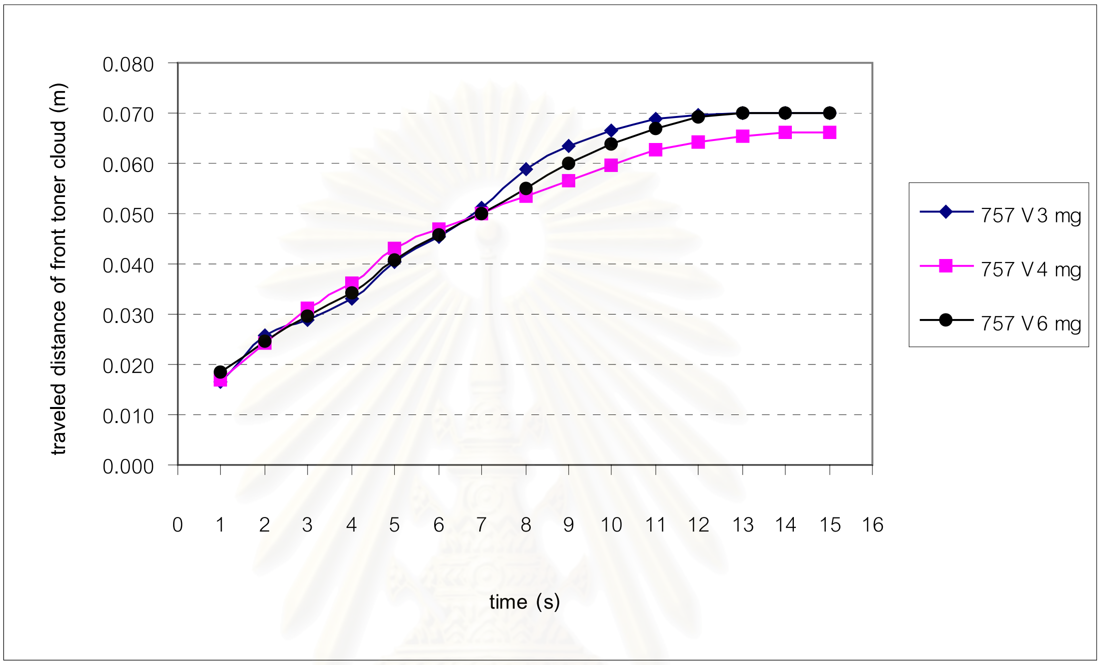
$$\vec{F}_i = q_i \sum_{j \neq i}^{N} \frac{q_j}{4\pi\varepsilon_0} \frac{\vec{r}_{ij}}{r_{ij}^{\ 3}} \tag{4.16}$$

$$\vec{r}_{ij} = \vec{r}_i - \vec{r}_j \tag{4.17}$$

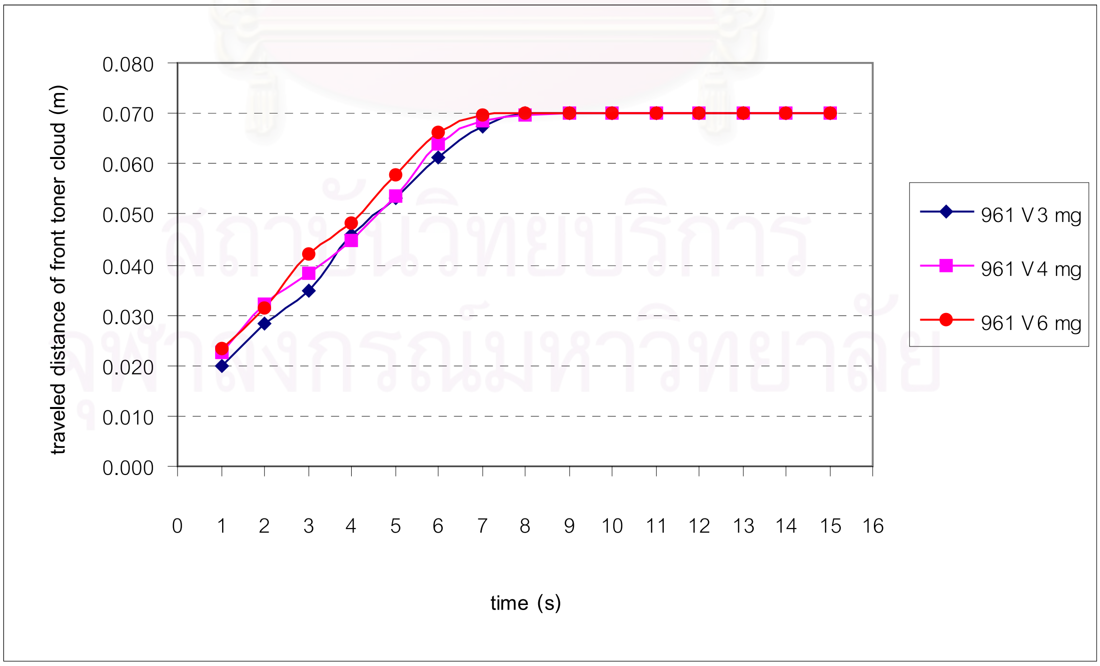
where the summation on the right of equation 4.16 is extended over all of the charges except the *i*th.

It is clear that the force on one toner particle charge comes from the interaction force between toner particles, which can be enhanced by increasing toner amount as shown in Figure 4-36 b). The repulsive force from other particles governed the toner particles to propagate along the dented electrode surface faster after increasing the amount of toner.

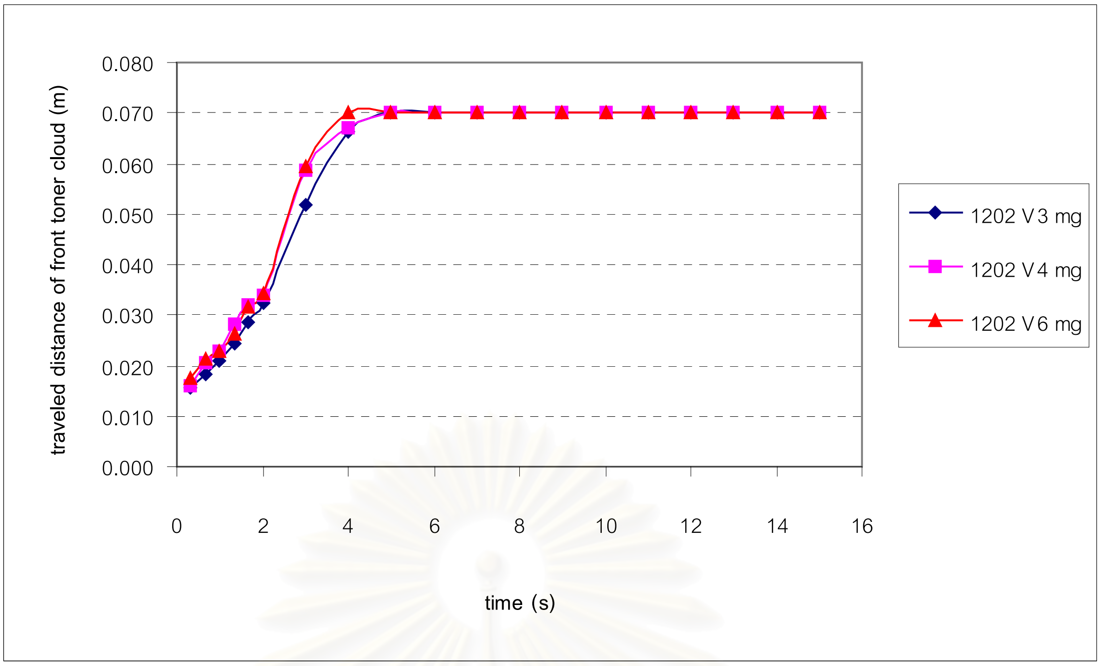
Likewise, when the toner was put at one end of the dented electrode, the toner cloud speed increases with increasing toner amount in the same manner of putting the toner at the center of the electrode. The tendencies of the front toner cloud traveled distance are shown in Figures 4-37 to 4-40. The resulting lines from the effect of increasing toner amount on the front toner cloud speed are similar to the case of putting the toner at the center of the electrode. The higher toner amount still gives the faster speed of the front toner cloud.



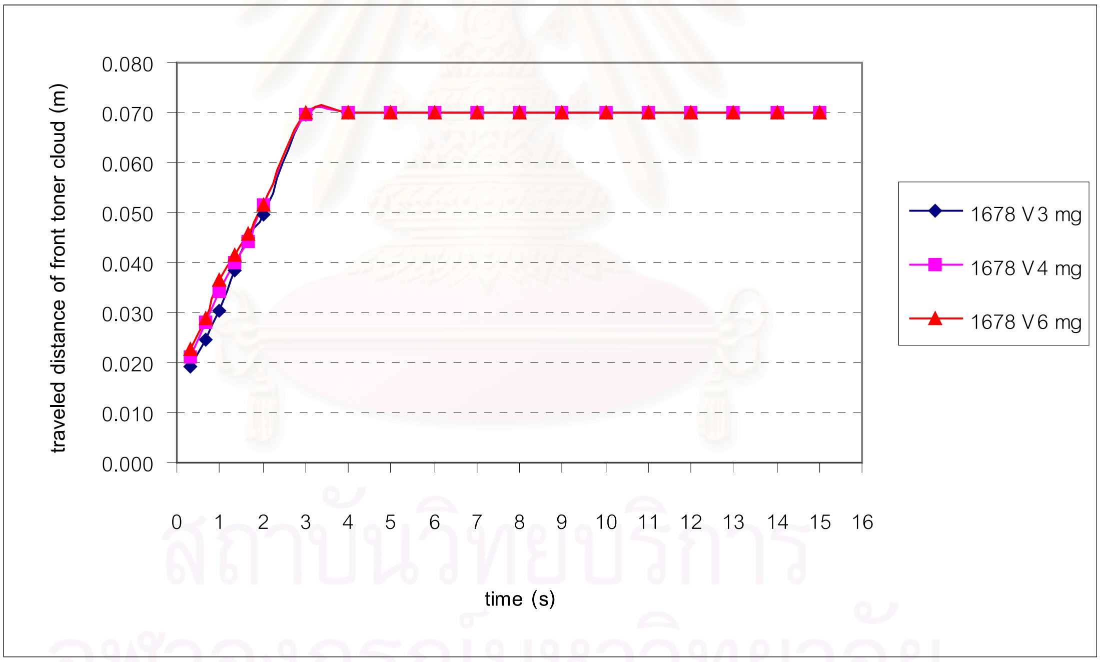
a)



b)

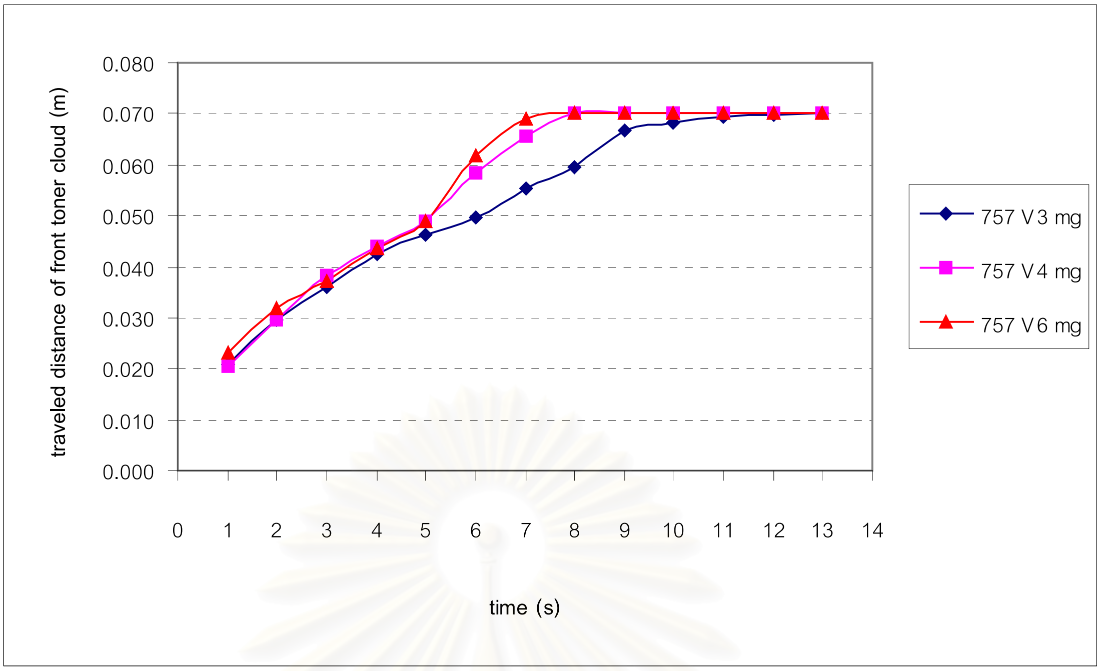


c)

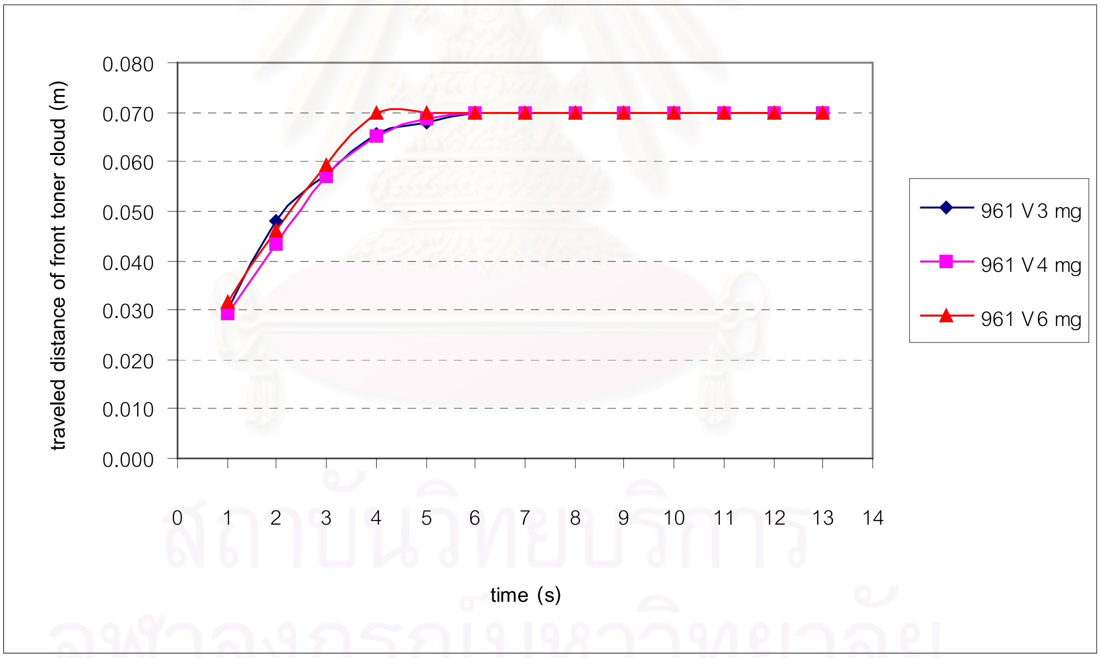


d)

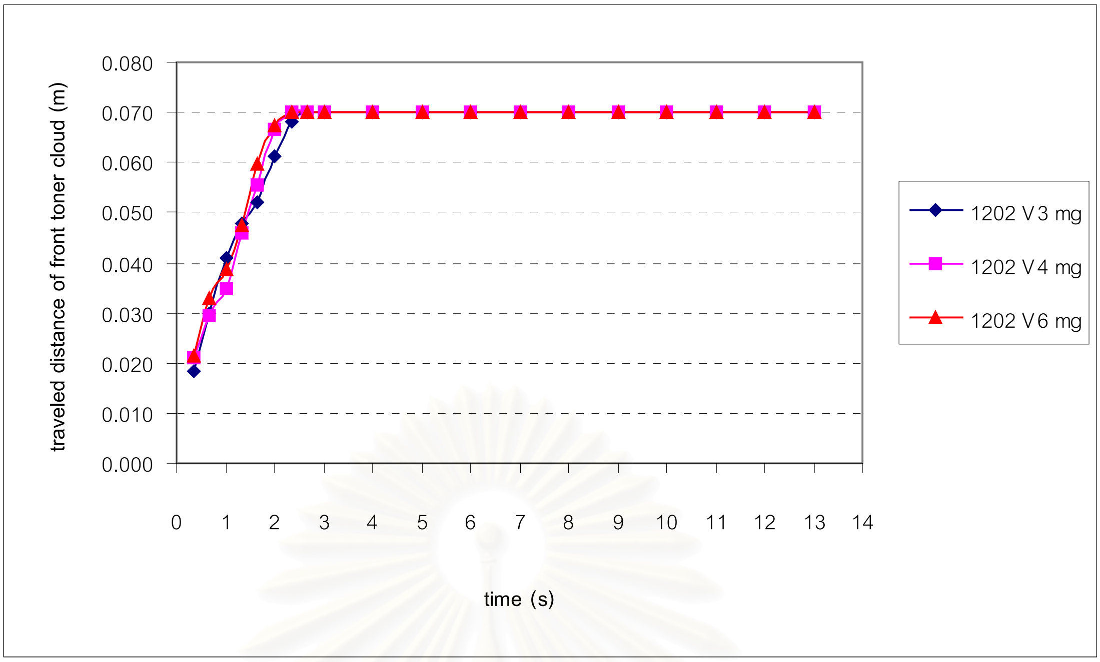
Figure 4-37 Dependence of the front toner cloud displacement on the toner amount in case of the nesa glass set at 0.64 degree to the dented electrode at the fixed 0.5 mm depth of the dented electrode, put toner at the end of electrode with different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.


0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
traveled distance of front toner cloud (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
time (s)
757 V3 mg
757 V4 mg
757 V6 mg

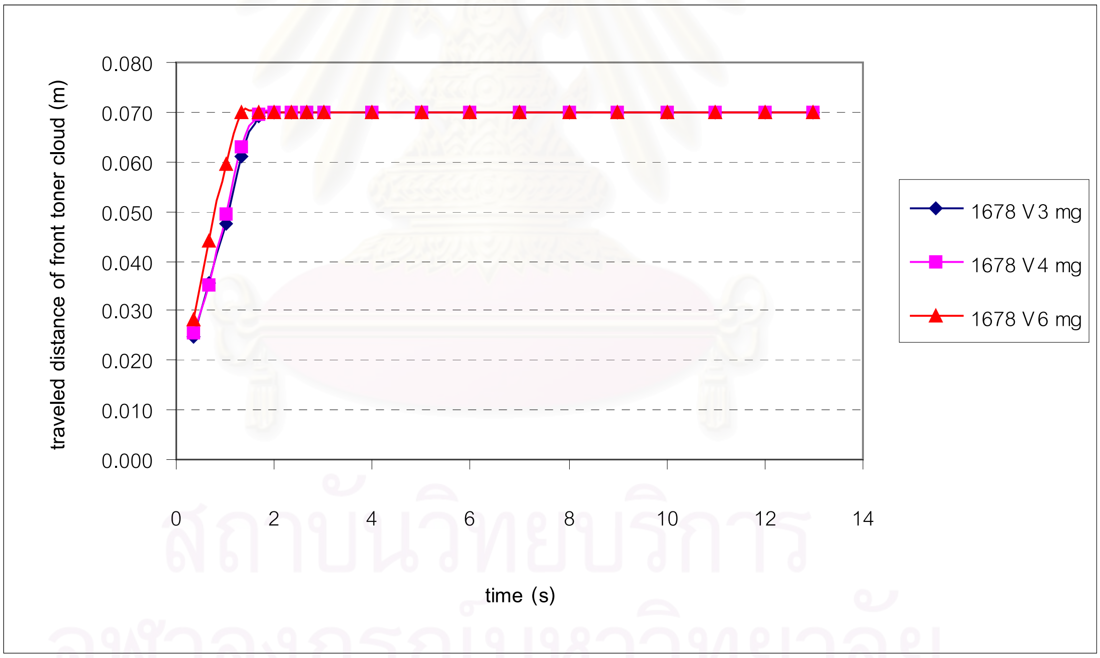
a)


0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
traveled distance of front toner cloud (m)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
time (s)
961 V3 mg
961 V4 mg
961 V6 mg

b)

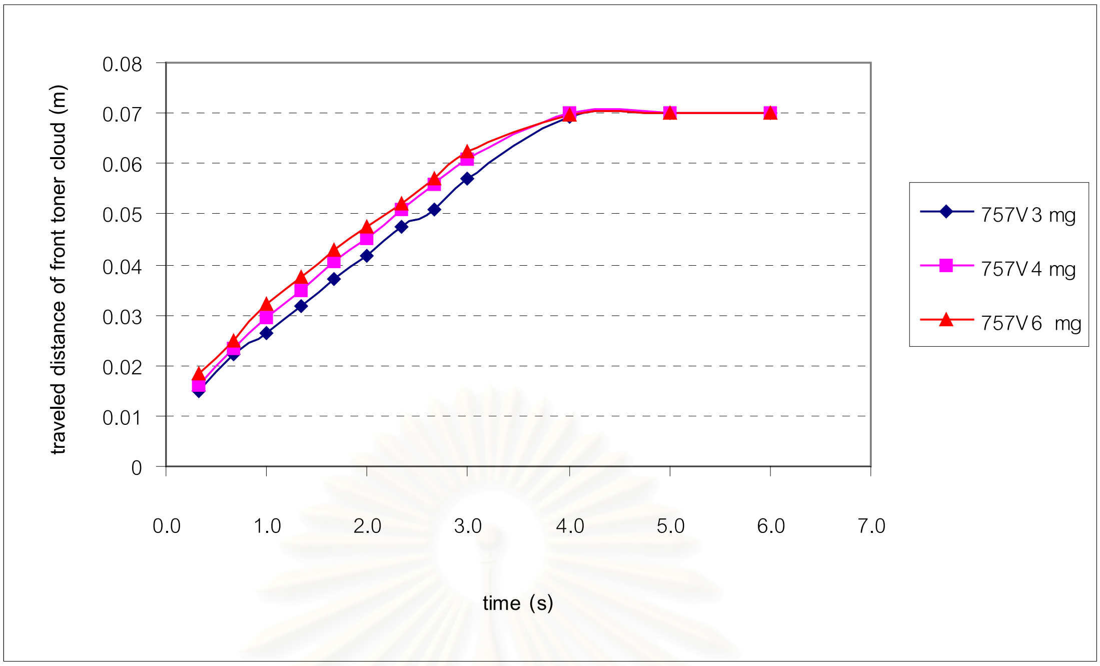


c)

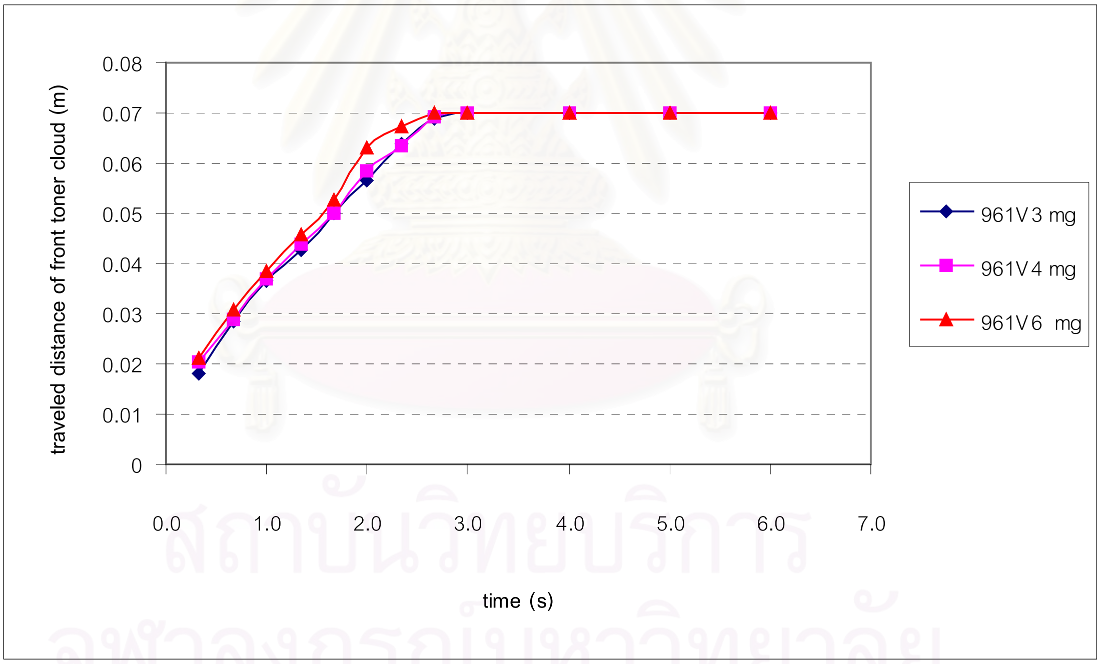


d)

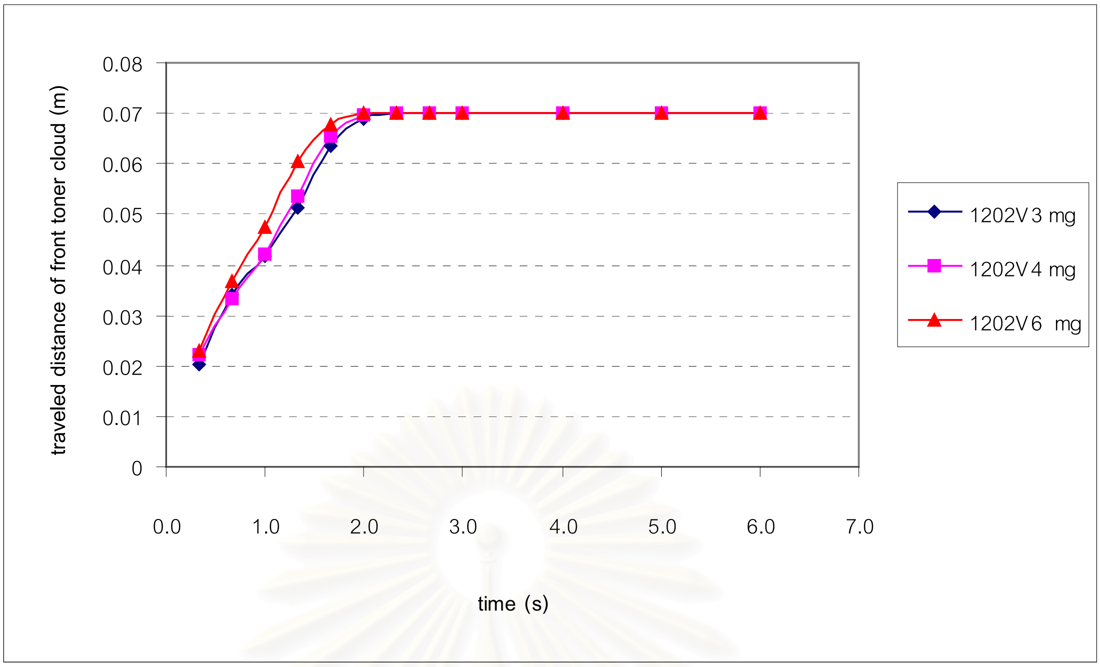
Figure 4-38 Dependence of the front toner cloud displacement on the toner amount in case of the nesa glass set at 0.95 degree to the dented electrode at the fixed 0.5 mm depth of the dented electrode, put toner at the center with different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
traveled distance of front toner cloud (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
time (s)
757V3 mg
757V4 mg
757V6 mg

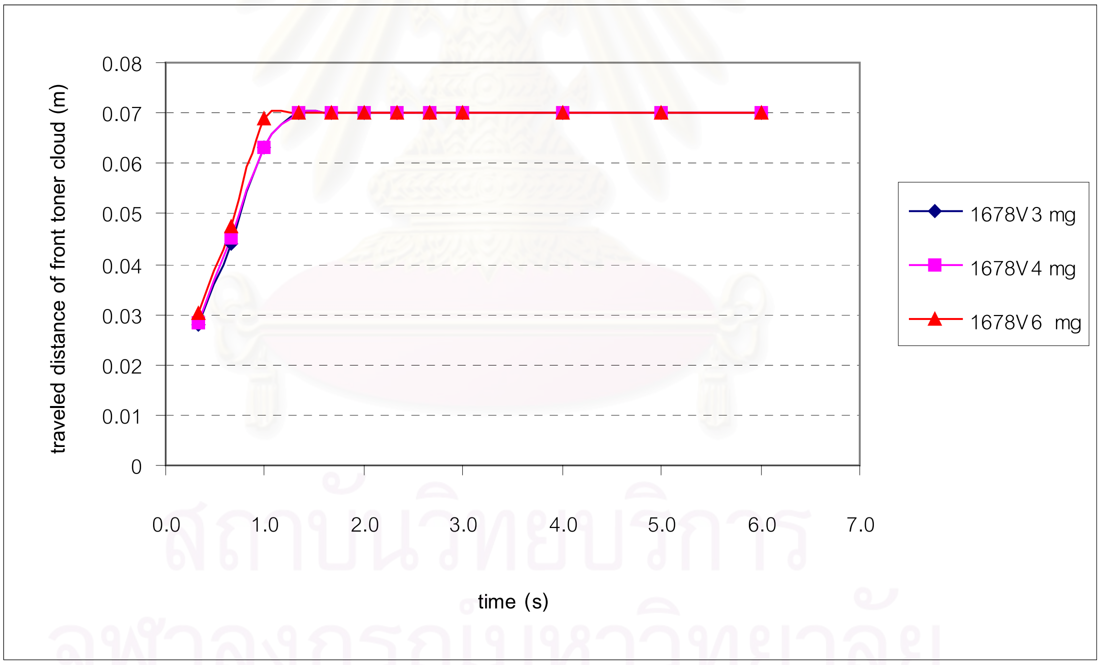
a)


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
traveled distance of front toner cloud (m)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
time (s)
961V3 mg
961V4 mg
961V6 mg

b)

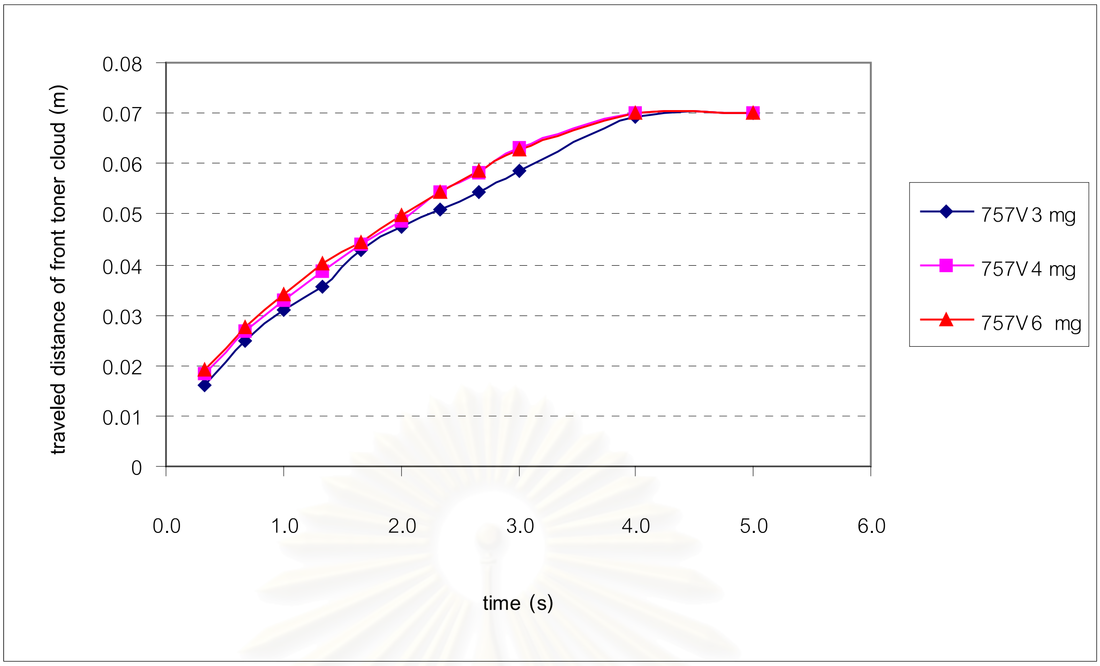


c)



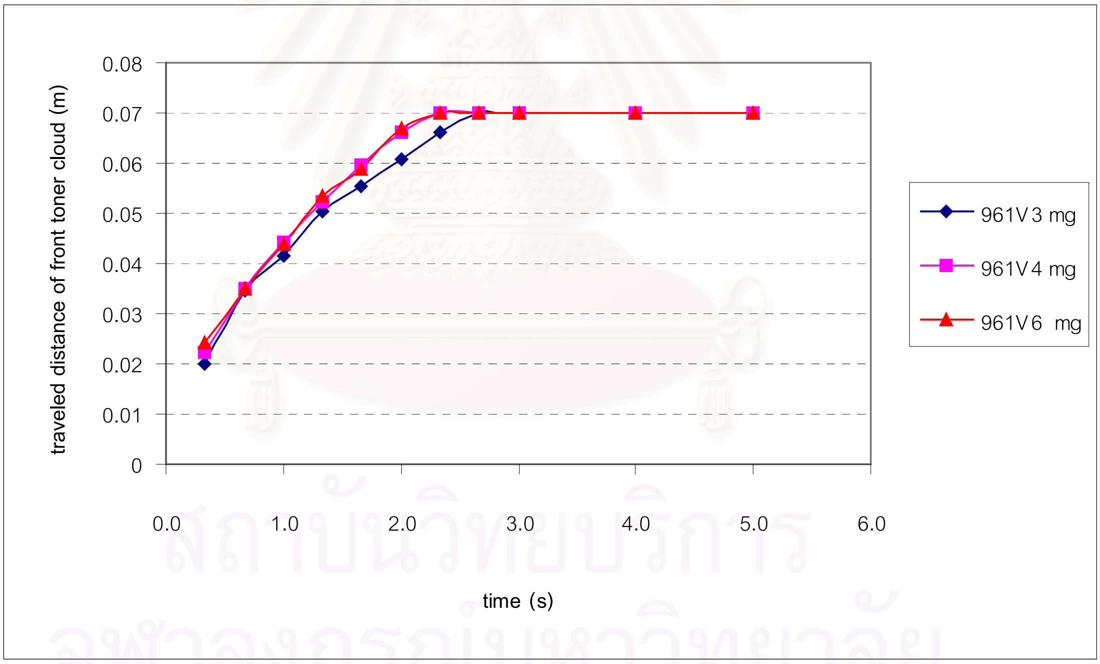
d)

Figure 4-39 Dependence of the front toner cloud displacement on the toner amount in case of the nesa glass set at 0.64 degree to the dented electrode at the fixed 0.2 mm depth of the dented electrode, put toner at the end of electrode with different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.



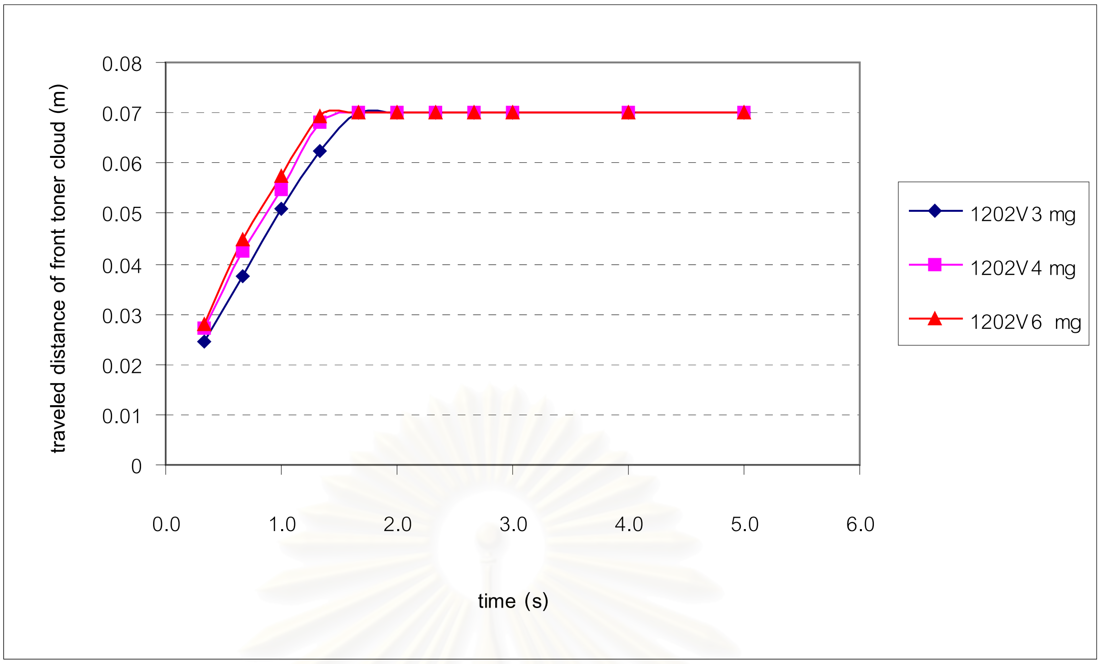
traveled distance of front toner cloud (m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
time (s)
757V3 mg
757V4 mg
757V6 mg

a)

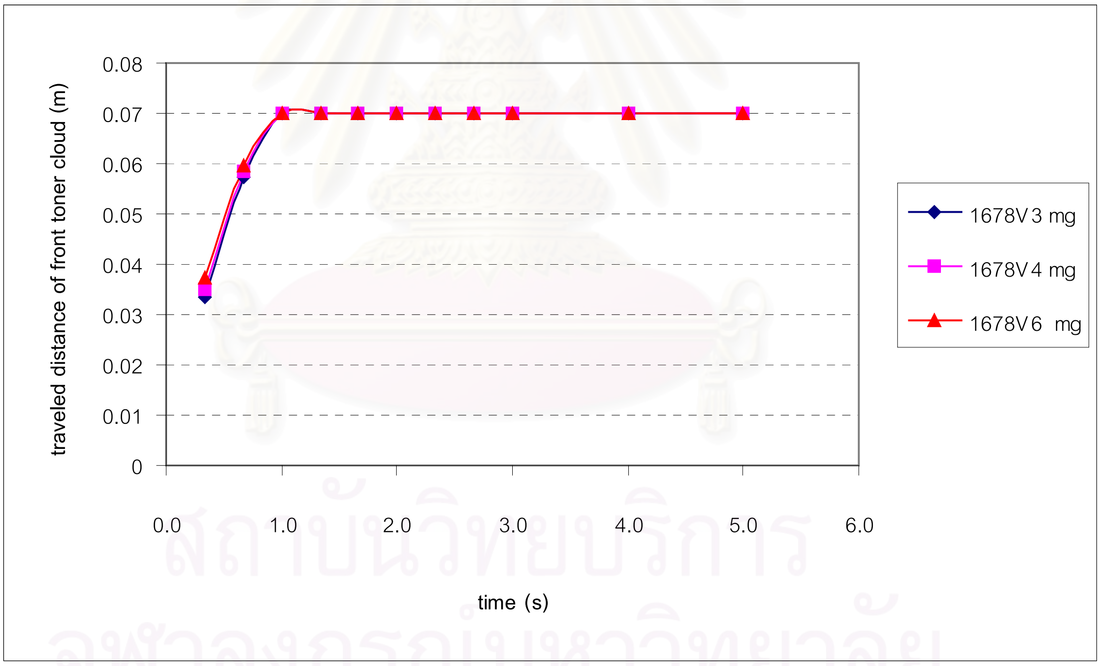


traveled distance of front toner cloud (m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
time (s)
961V3 mg
961V4 mg
961V6 mg

b)



c)



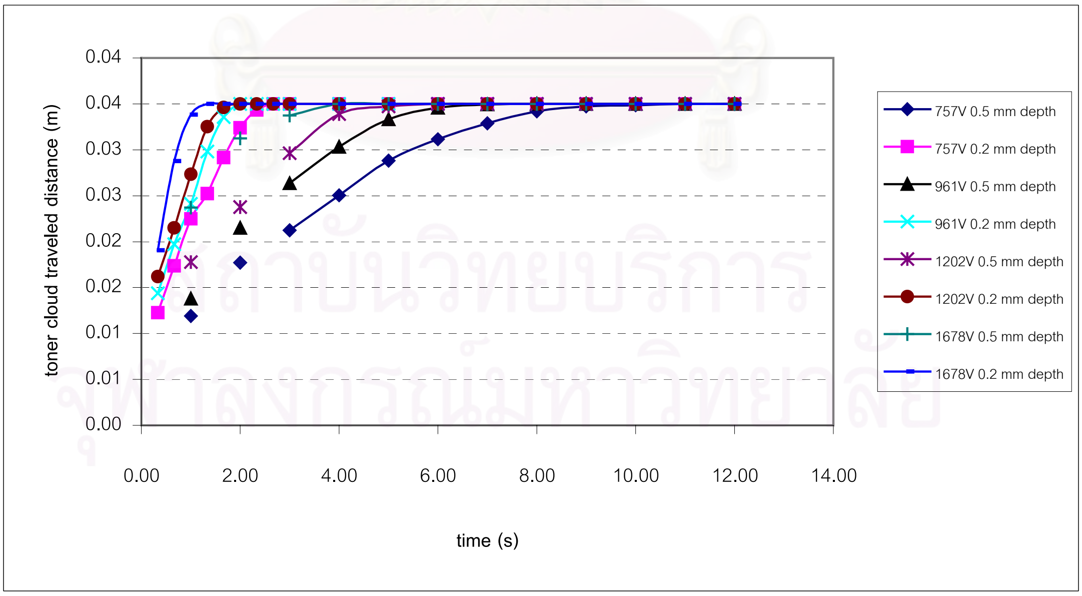
d)

Figure 4-40 Dependence of the front toner cloud displacement on the toner amount in case of the nesa glass set at 0.95 degree to the dented electrode at the fixed 0.2 mm depth of the dented electrode, put toner at the center of dented electrode with different applied voltages of a) 757 V, b) 961 V, c) 1202 V and d) 1678 V.

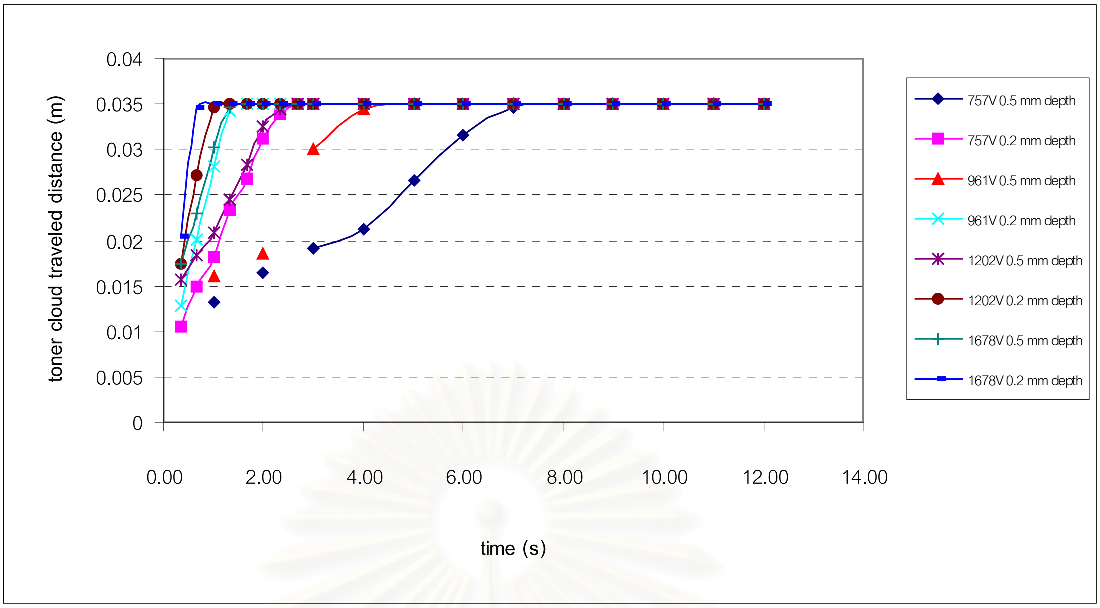
4.1.3 Dependence of the toner cloud motion on the depth of the dented electrode

Dependence of the toner cloud traveled distance on the applied voltage at the depths of the dented electrode of 0.2 and 0.5 mm are shown in Figures 4-41 to 4-46. The results in Figure 4-41 show that the toner cloud traveled distance increases when the applied voltage increases. For the effect of the depth of the dented electrode on the toner cloud traveled distance, the depth of the dented electrode of 0.2 mm gives the longer traveled distance while that of 0.5 mm produces the shorter traveled distance.

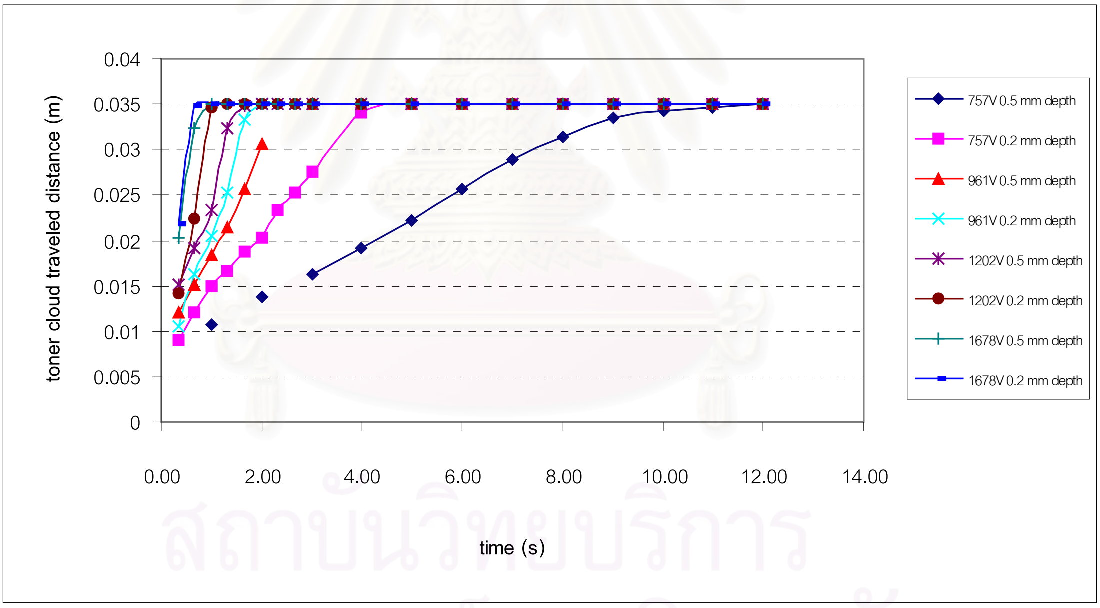
In the same manner as shown in Figures 4-32 to 4-46, the smaller depth of the dented electrode produces the longer toner cloud traveled distance at any toner amount, any nesa glass slope and toner input position. The 0.5 mm depth of the dented electrode gives the smallest distance of toner cloud motion while the 0.2 mm depth of the dented electrode yields the longest value of traveled distance.



a)

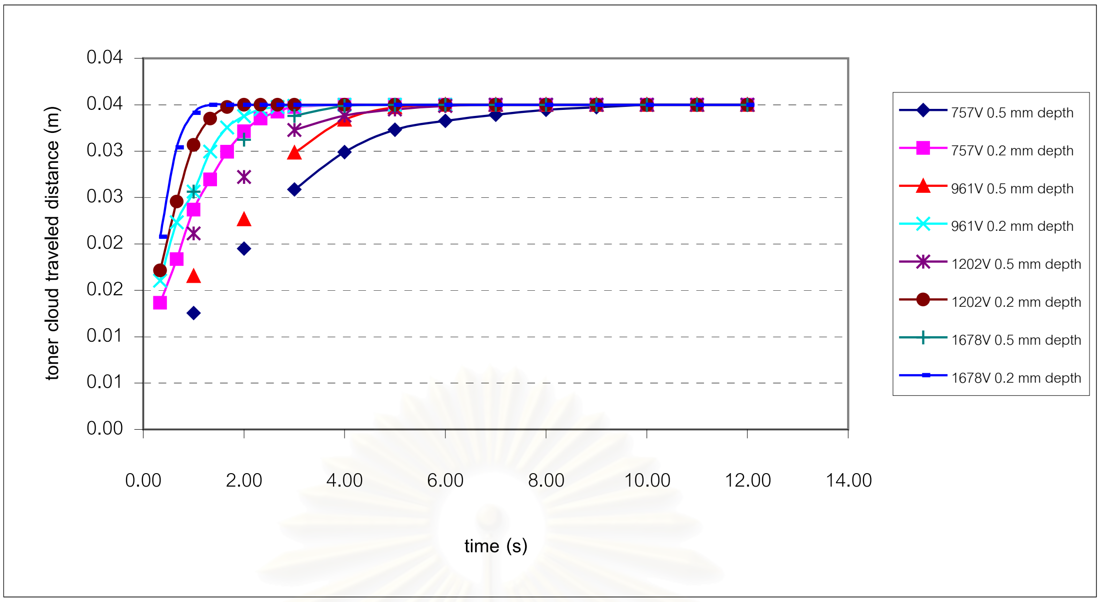


b)



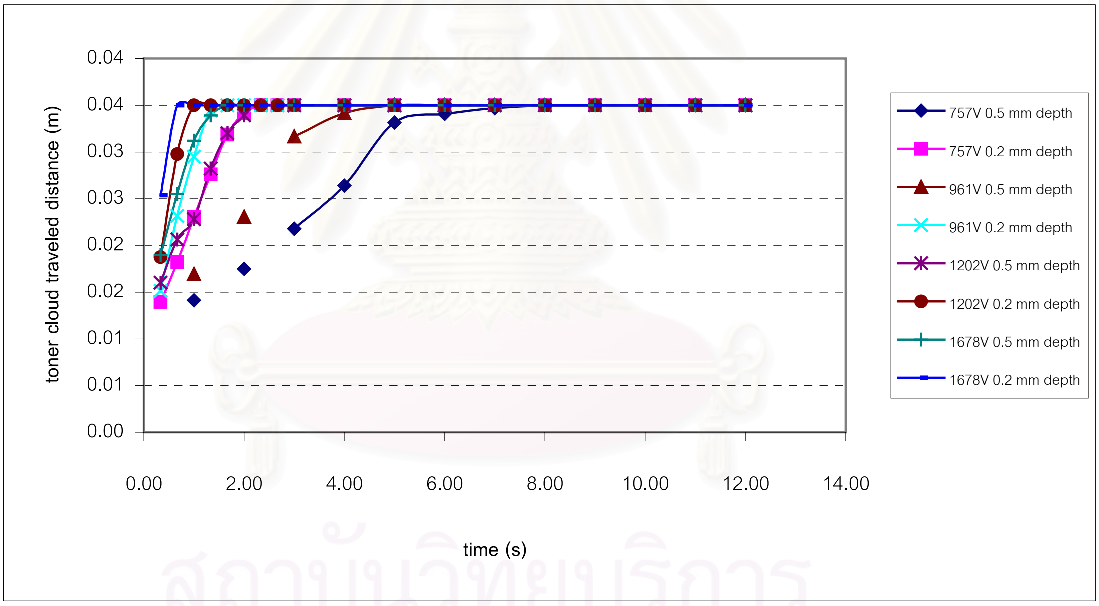
c)

Figure 4-41 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 3 mg toner put at the center of the electrode with a) nesa glass parallel b) nesa glass slope 0.64 degree and c) nesa glass slope 0.95 degree



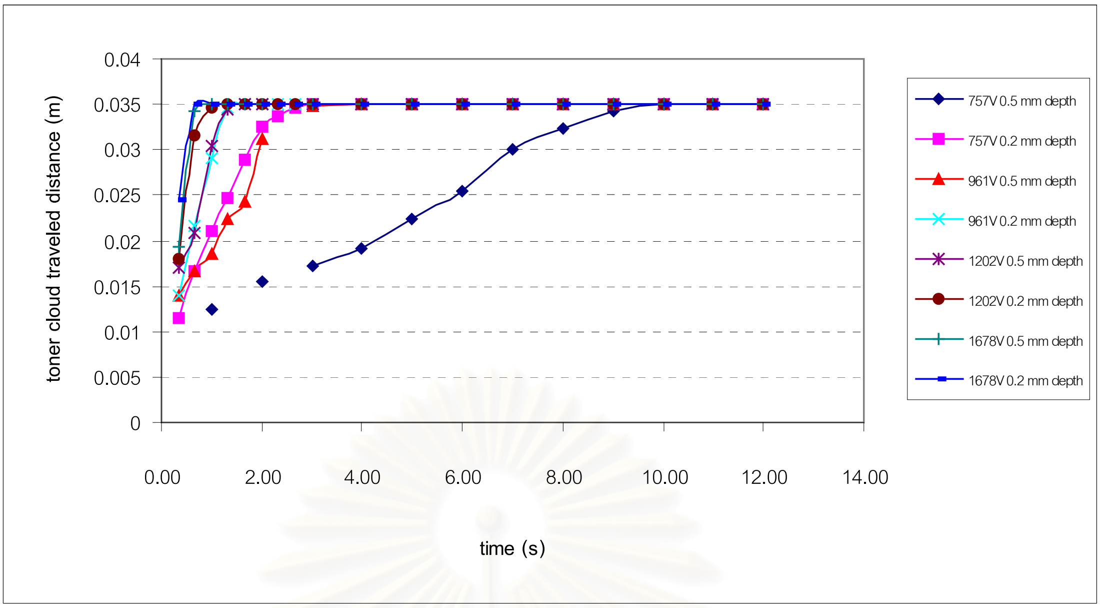
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
toner cloud traveled distance (m)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
time (s)
757V 0.5 mm depth
757V 0.2 mm depth
961V 0.5 mm depth
961V 0.2 mm depth
1202V 0.5 mm depth
1202V 0.2 mm depth
1678V 0.5 mm depth
1678V 0.2 mm depth

a)



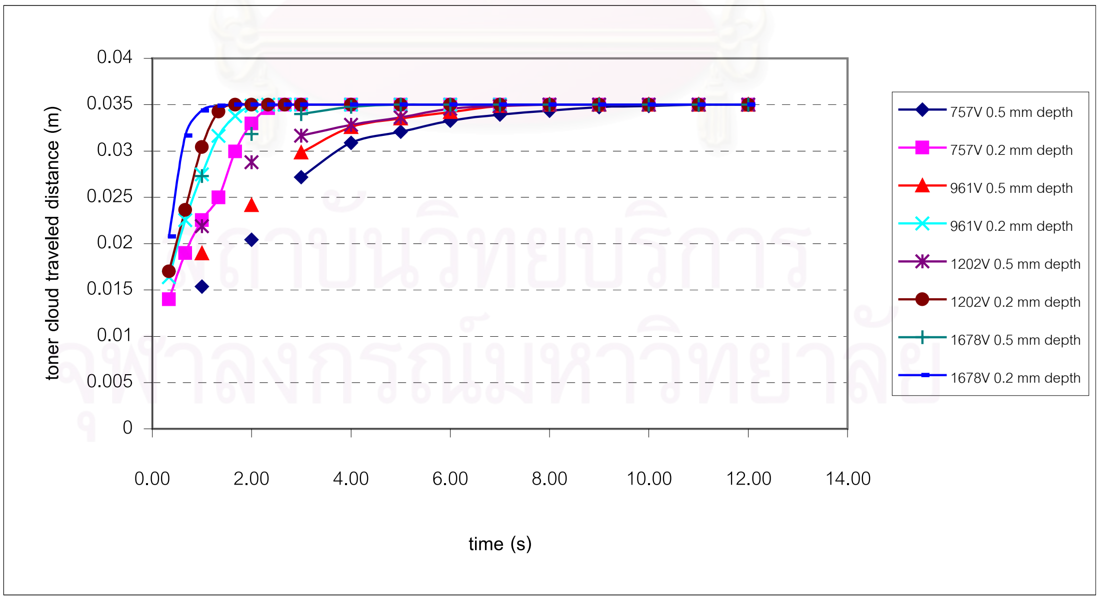
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
toner cloud traveled distance (m)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
time (s)
757V 0.5 mm depth
757V 0.2 mm depth
961V 0.5 mm depth
961V 0.2 mm depth
1202V 0.5 mm depth
1202V 0.2 mm depth
1678V 0.5 mm depth
1678V 0.2 mm depth

b)

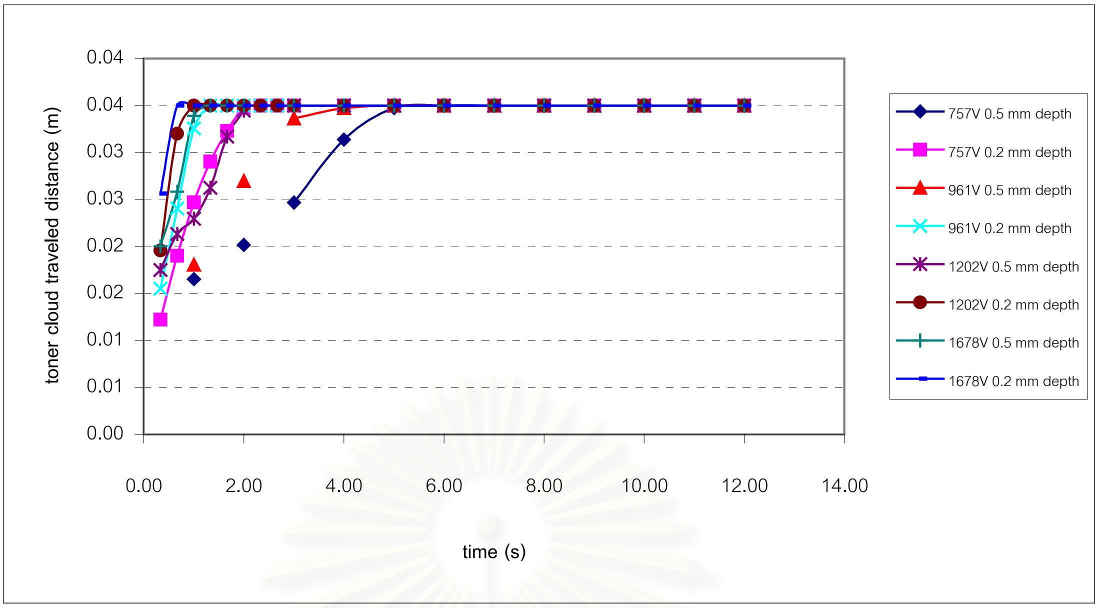


c)

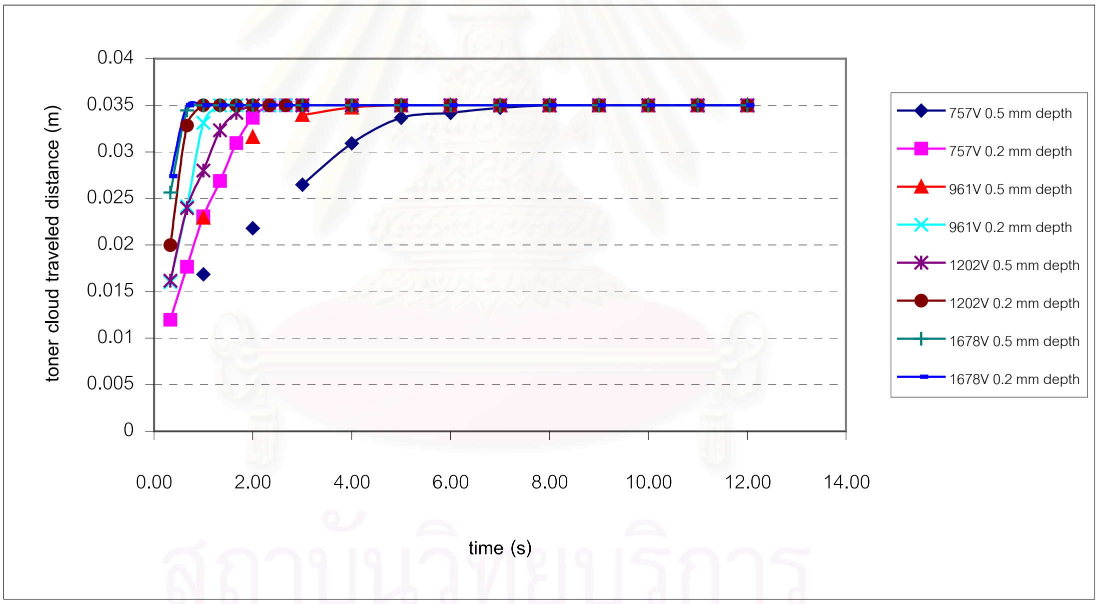
Figure 4-42 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 4 mg toner put at the center of the electrode with a) nesa glass parallel b) nesa glass slope 0.64 degree and c) nesa glass slope 0.95 degree



a)

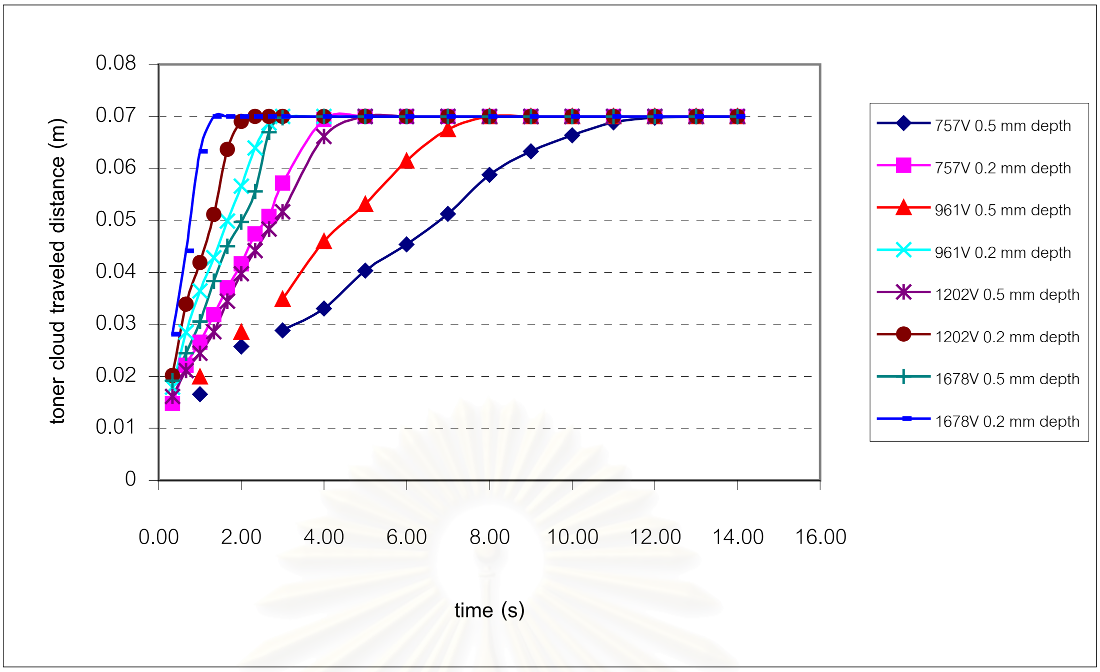


b)

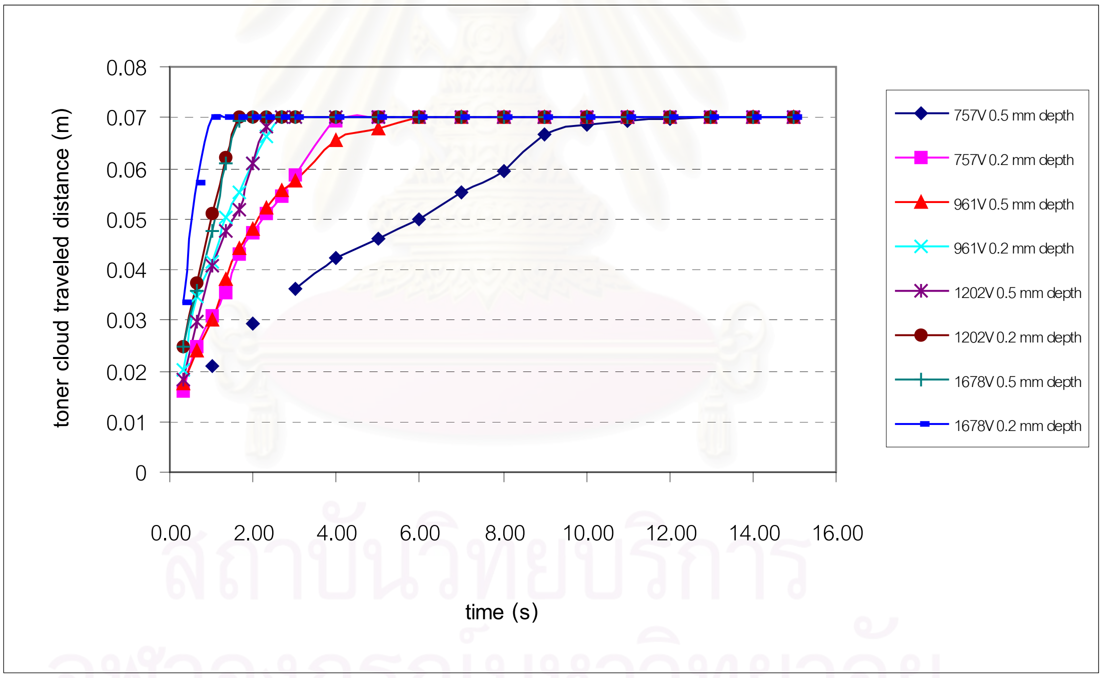


c)

Figure 4-43 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 6 mg toner put at the center of the electrode with a) nesa glass parallel b) nesa glass slope 0.64 degree and c) nesa glass slope 0.95 degree

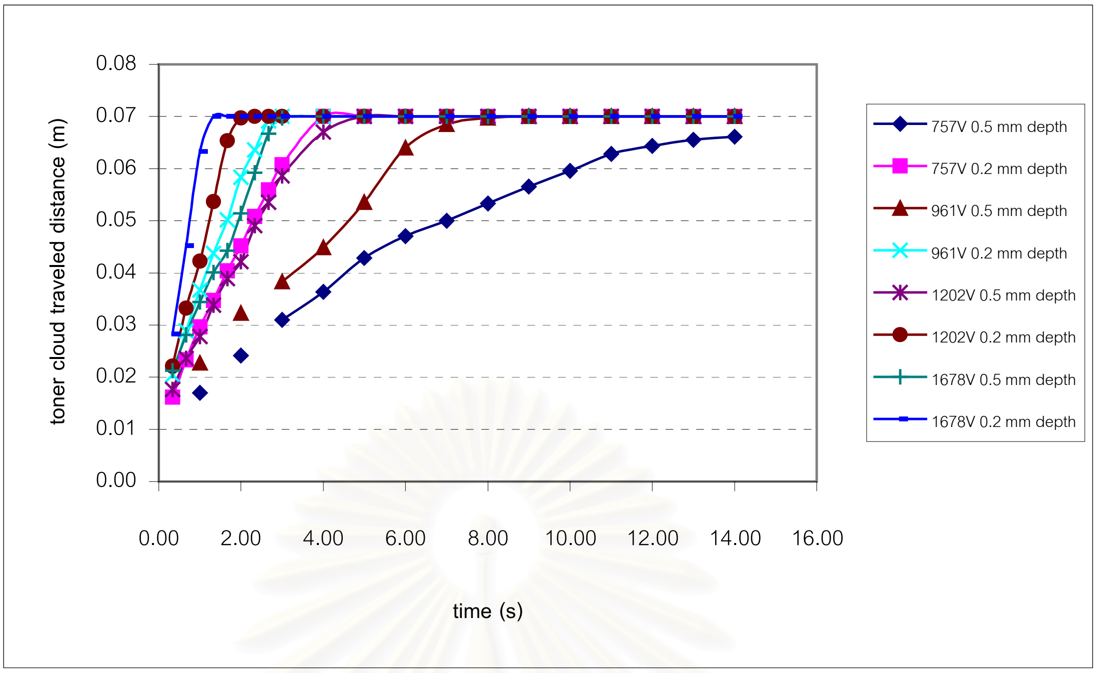


a)

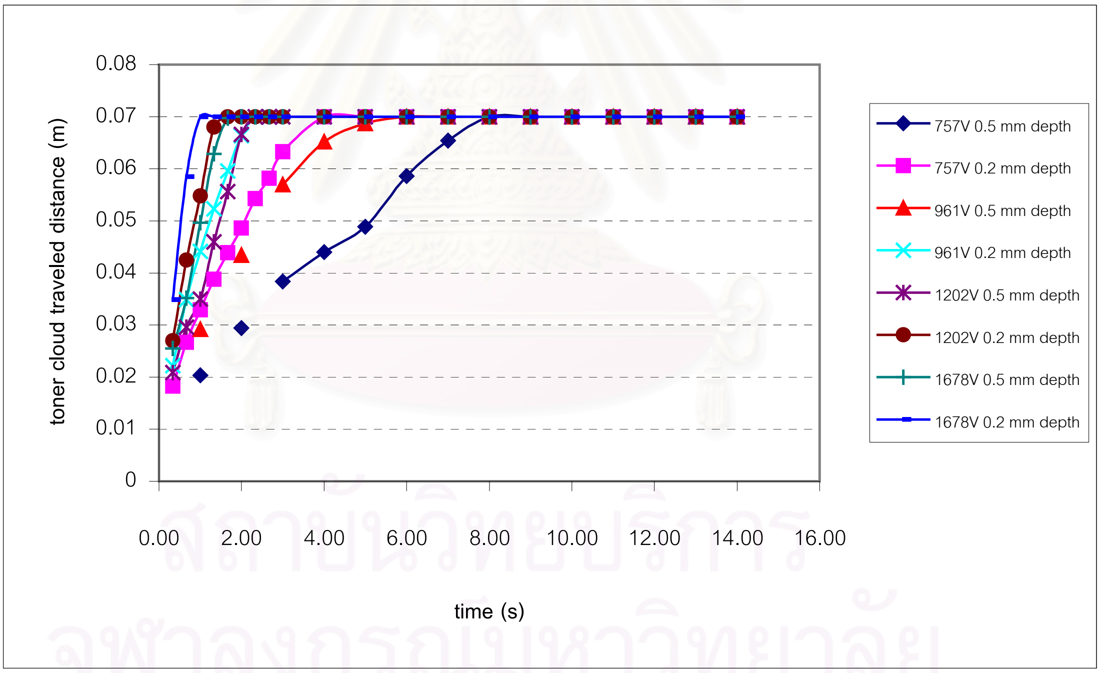


b)

Figure 4-44 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 3 mg toner put at the electrode end with a) nesa glass slope 0.64 degree and b) nesa glass slope 0.95 degree

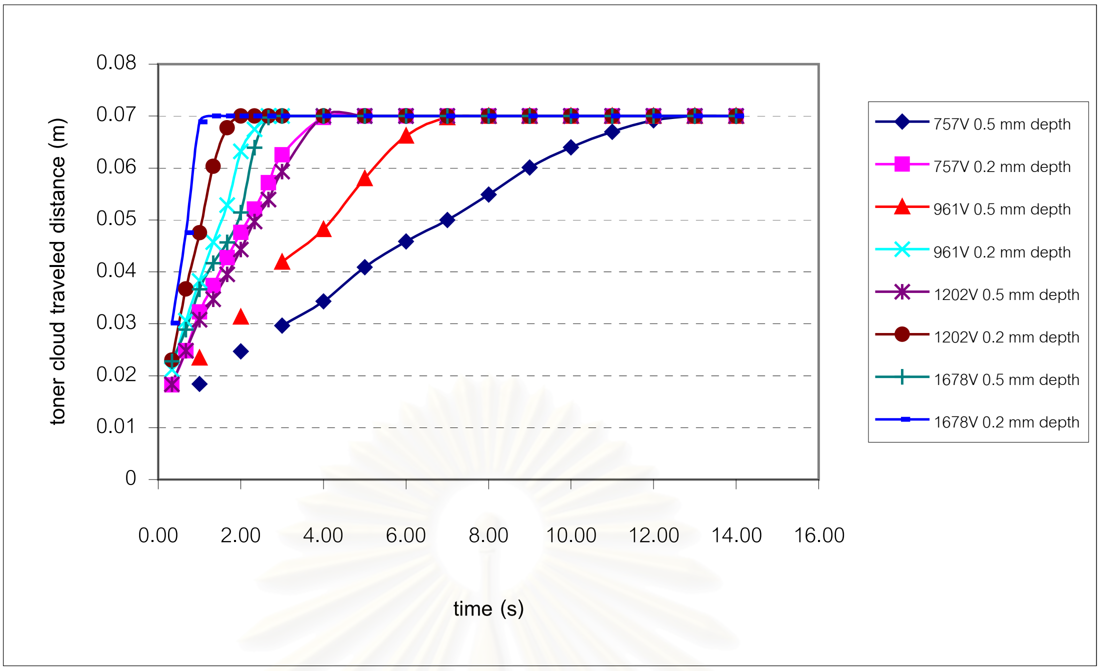


a)

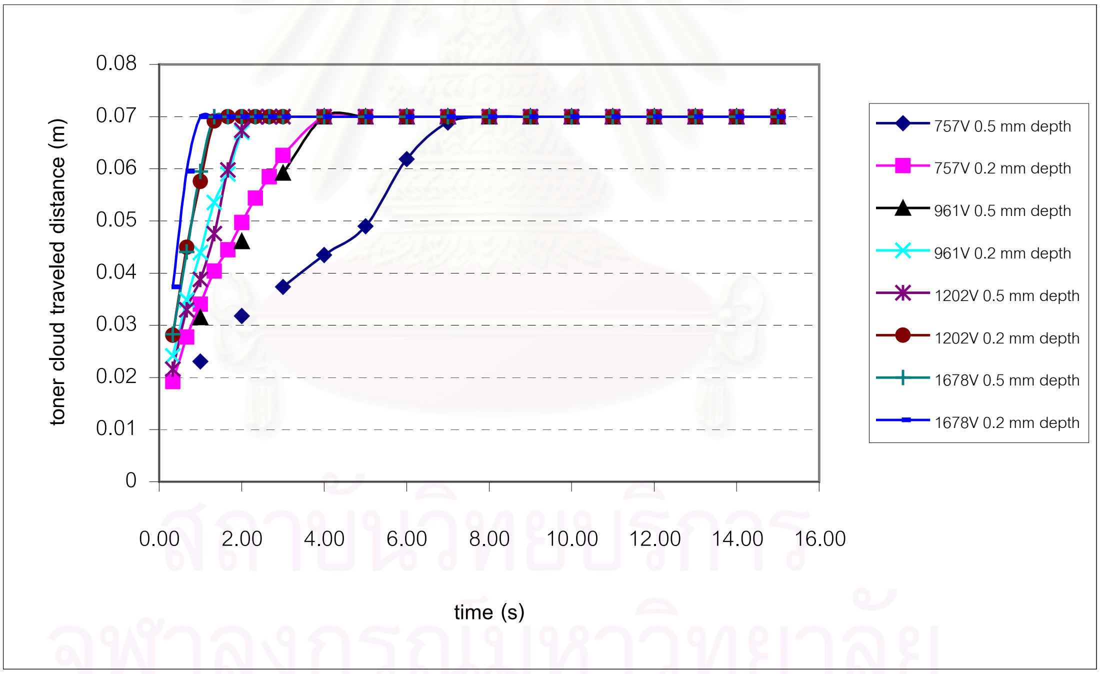


b)

Figure 4-45 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 4 mg toner put at the electrode end with a) nesa glass slope 0.64 degree and b) nesa glass slope 0.95 degree



a)



b)

Figure 4-46 Dependence of the toner cloud traveled distance on the applied voltage for the depth of the dented electrode of 6 mg toner put at the electrode end with a) nesa glass slope 0.64 degree and b) nesa glass slope 0.95 degree.

The electric force from the surface of the dented electrode imposes the toner particles while the electric force line must always be perpendicular to the surface. For both dented electrodes, the electric force lines of the dented electrode have the component towards the central axis of the dented electrode. Since the electric force lines of the deeper depth of the dented electrode can carry more components towards the central axis of the dented electrode; therefore, the deeper the depth of the dented electrode, the smaller the toner cloud and the toner cloud traveled distance.

When the nesa glass was placed parallel to the dented electrode surface, the front of toner cloud seems to move with a constant speed. With the constant speed, Coulomb’s law and Newton’s law are applied for studying the interaction force between toner particles in this system and the effect of the dented electrode depth. Equation 4.19 which is derived from Equation 4.18, shows a simply relationship of the electric field (E) as a function of speed (v) and time (t).

$$F = m\vec{a} \tag{4.18}$$

$$q\vec{E} = m\vec{a} = m\frac{dv}{dt} \tag{4.19}$$

Figures 4-47 to 4-49 show the relationship between the 1/time of the front toner cloud moving from the origin to 0.025 m away, against the electric field. The results suggest that the time of the front toner cloud movement decreased with increasing the electric field between two electrodes. Similarly, the toner cloud also moved faster when the applied voltage increased in the shallower depth of the dented electrode. The 0.2 mm depth dented electrode gave the faster speed of toner cloud movement while the 0.5 mm depth dented electrode produced the slower speed.

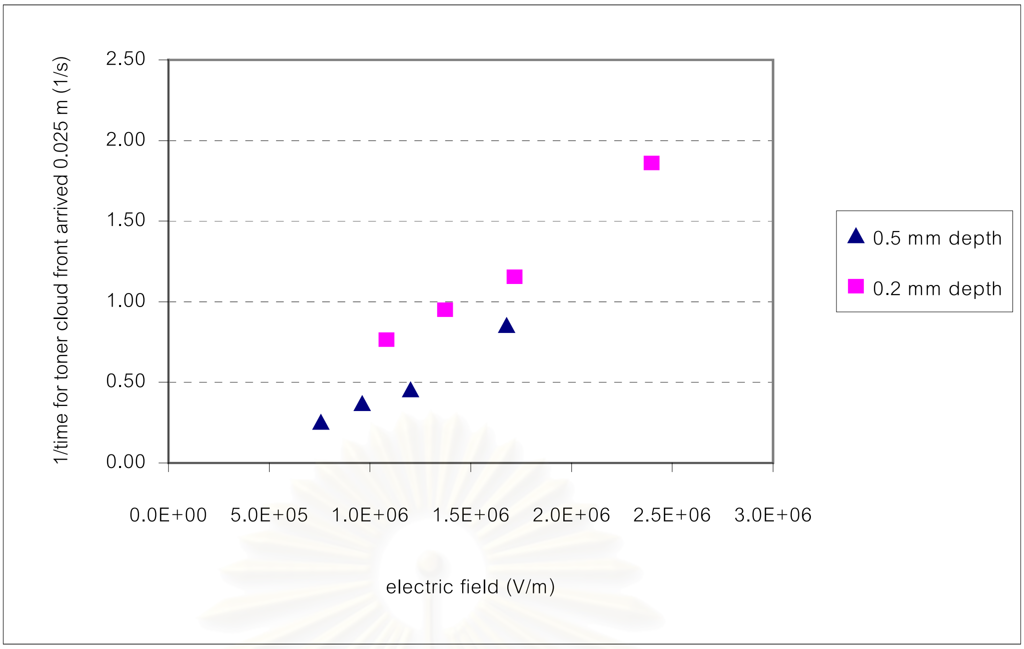


Figure 4-47 Dependence of 1/time for the front toner cloud traveled to 0.025 m on the electric field on the electrode of depth 0.5 and 0.2 mm, put toner of 3 mg at the center of the electrode.

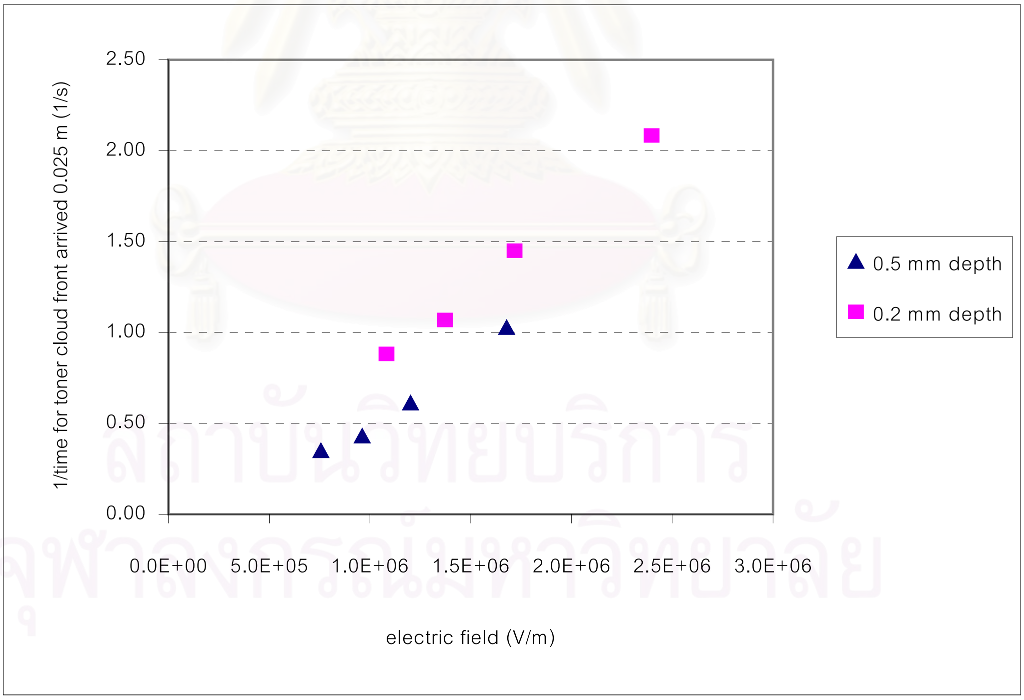


Figure 4-48 Dependence of 1/time for the front toner cloud traveled to 0.025 m on the electric field on the electrode of depth 0.5 and 0.2 mm, put toner of 4 mg at the center of the electrode.

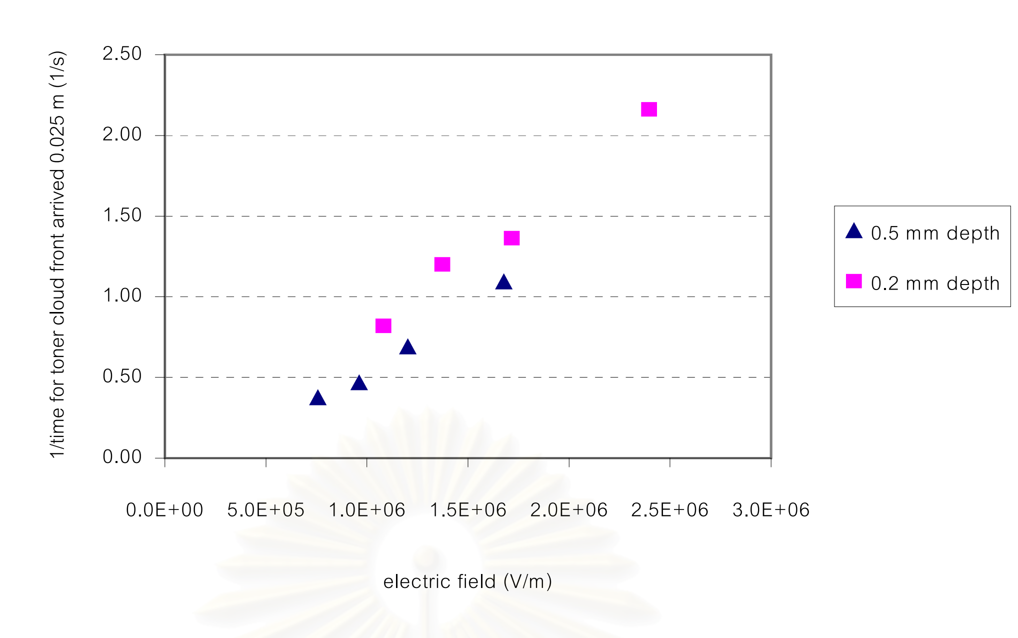


Figure 4-49 Dependence of 1/time for the front toner cloud traveled to 0.025 m on the electric field on the electrode of depth 0.5 and 0.2 mm, put toner of 6 mg at the center of the electrode.

4.1.4 Dependence of the toner cloud speed on the nesa glass slope

To elucidate the effect of the nesa glass slope over the width of printing area on the toner cloud motion, two values of slope are fixed in this experiment: 0.64 and 0.95 degree. It was expected that an increase in the slope would enhance the speed of toner cloud movement because the slope of ITO glass increased the impact angle of the toner particles, which induced more toner scattering than just moving up and down as in the case of setting the nesa glass parallel.

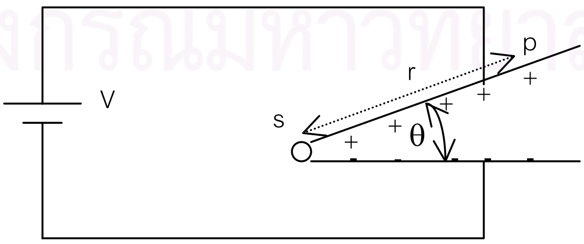


Figure 4-50 A simple set-up of two metal plates placed by making a joint angle θ, the applied voltage V, and an insulator, s, placed between the two metal plates to avoid short circuit.

From Figure 4-50, the larger the joint angle θ, the more the bending electric field. At the bending area caused by the electric field, toner motion path shifts because the conversational law forced the toner particles to scatter further to the direction of open end as shown in Figure 4-51.

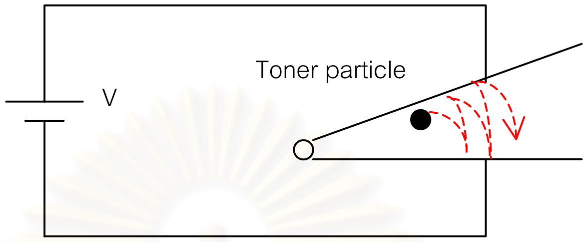
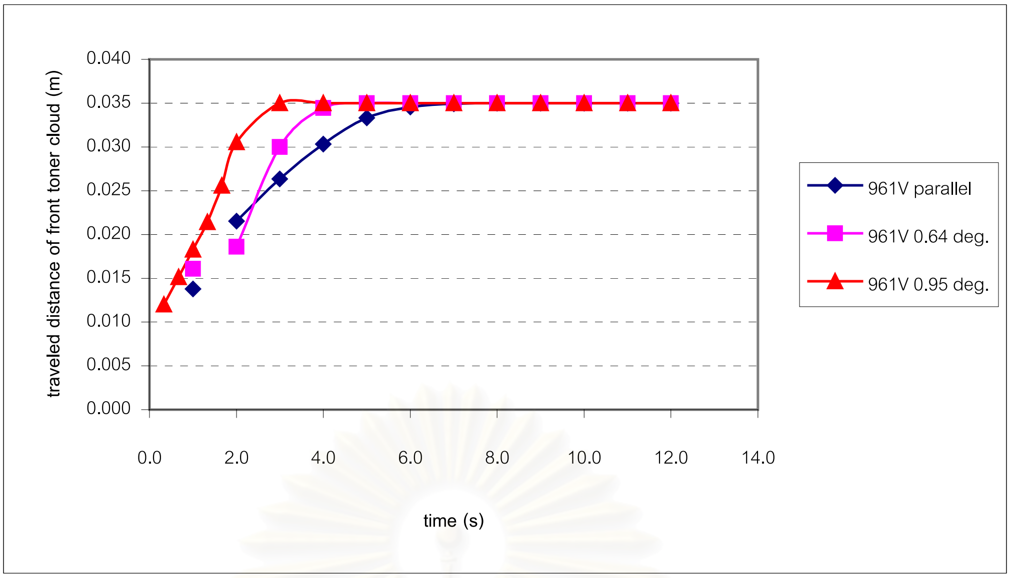


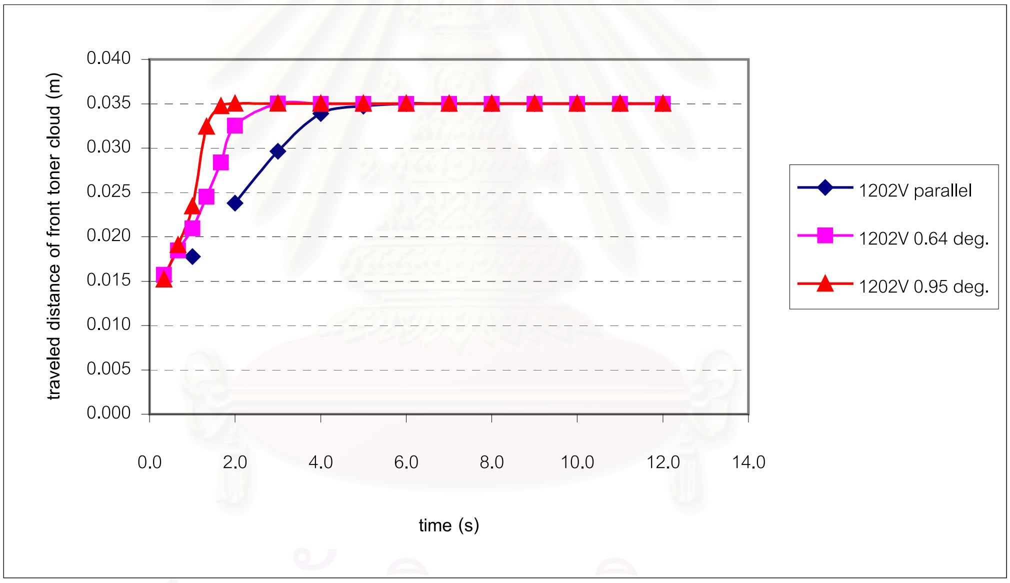
Figure 4-51 Shifts of a toner motion path under the bending electric field.

Figures 4-52 to 4-57 show the dependence of the front toner cloud displacement on the nesa glass slope with the amount of toner 3, 4 and 6 mg, which was put each at the center of the dented electrode of 0.2 and 0.5 mm depth with the applied voltage of 961, 1202 or 1678 V. It was observed that the higher the nesa glass slope, the faster the speed of toner cloud. However, in some cases, the experimental results did not show such a tendency. Perhaps when the nesa glass slope was increased, the distance between the upper and lower electrodes exceeded the limit of confinement of the toner cloud and then the toner cloud particles might leak and scattered outside the dented area. It might be caused by the absence of electrostatic force.



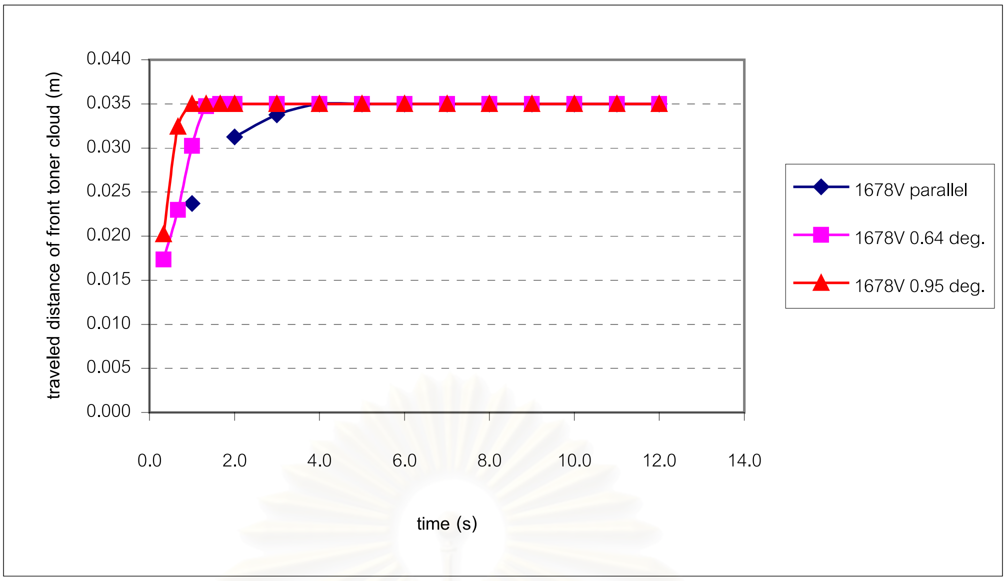
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
time (s)
traveled distance of front toner cloud (m)
961V parallel
961V 0.64 deg.
961V 0.95 deg.

a)



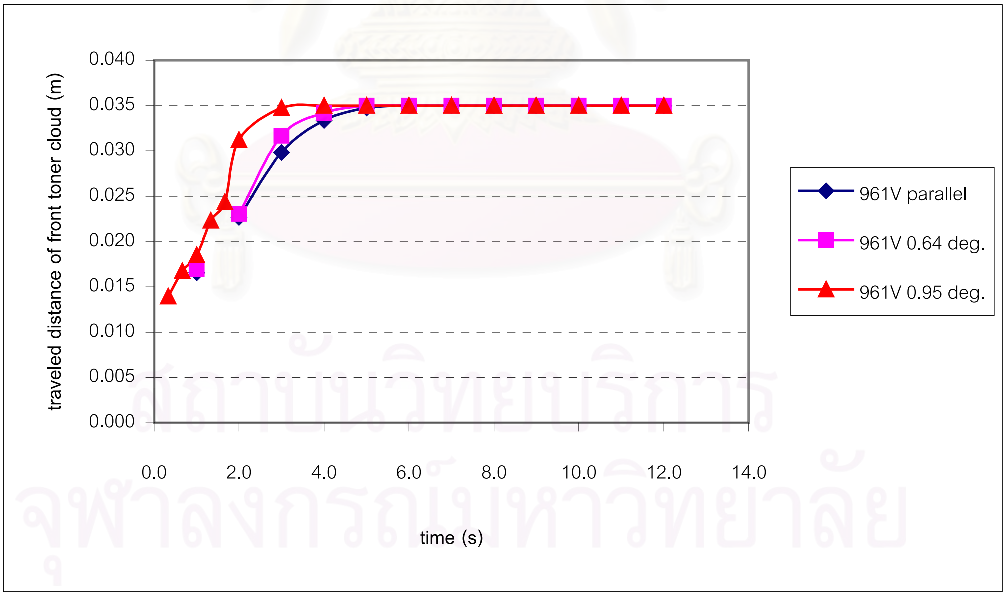
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
time (s)
traveled distance of front toner cloud (m)
1202V parallel
1202V 0.64 deg.
1202V 0.95 deg.

b)

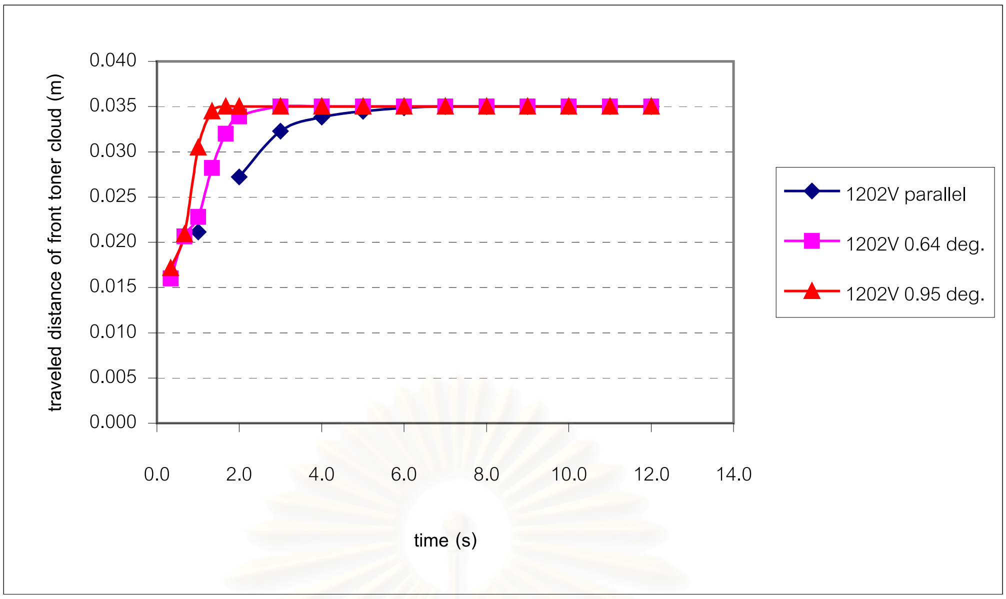


c)

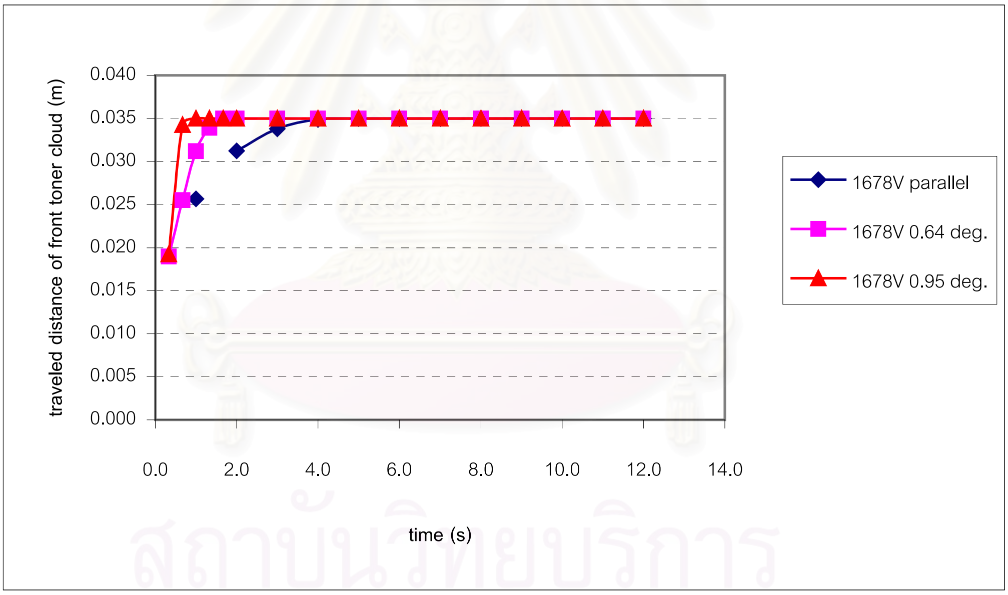
Figure 4-52 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 3 mg put at the center of 0.5 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V



a)

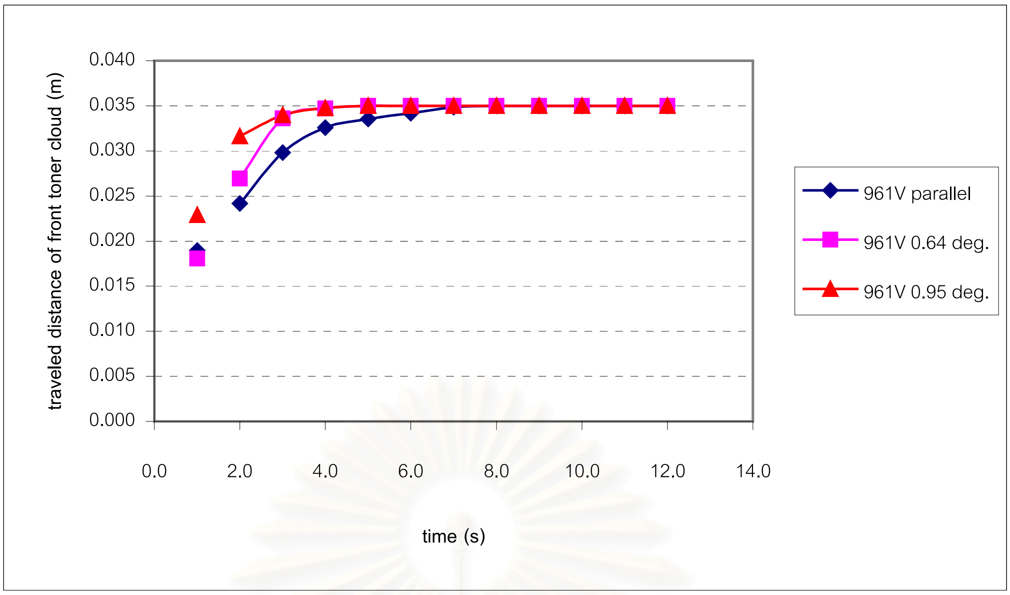


b)



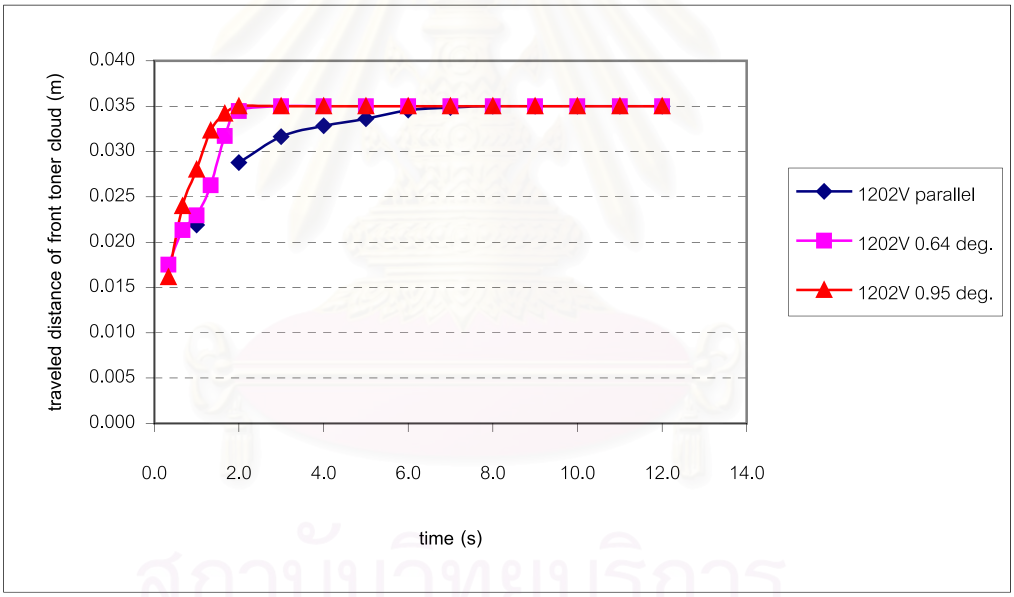
c)

Figure 4-53 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 4 mg put at the center of 0.5 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V



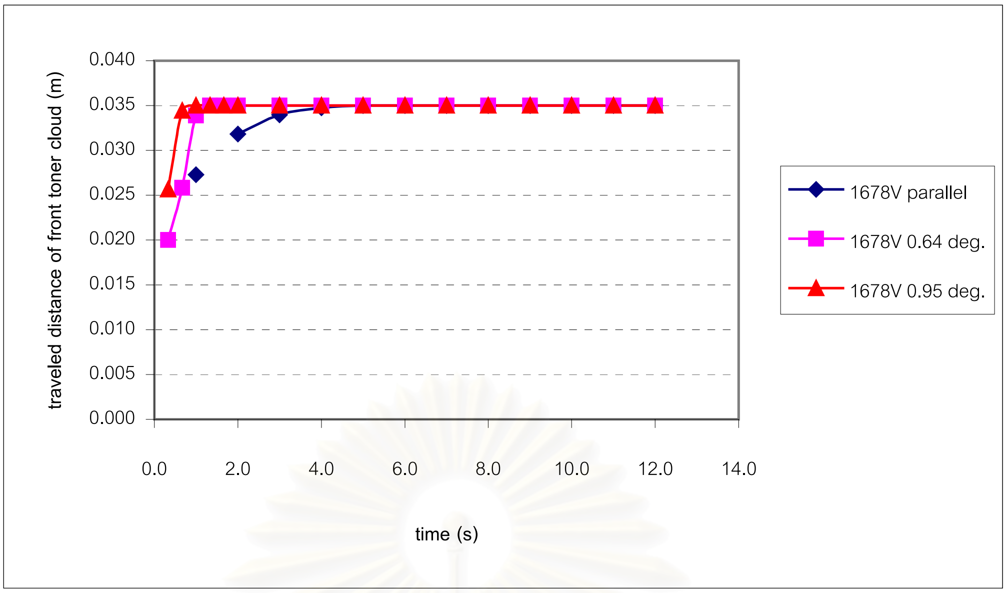
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
time (s)
961V parallel
961V 0.64 deg.
961V 0.95 deg.

a)



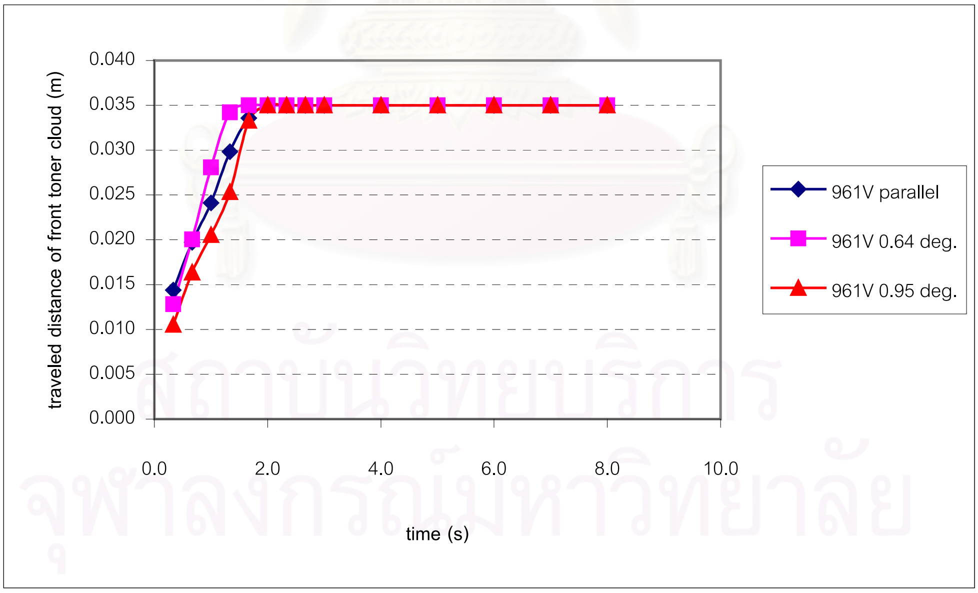
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
time (s)
1202V parallel
1202V 0.64 deg.
1202V 0.95 deg.

b)

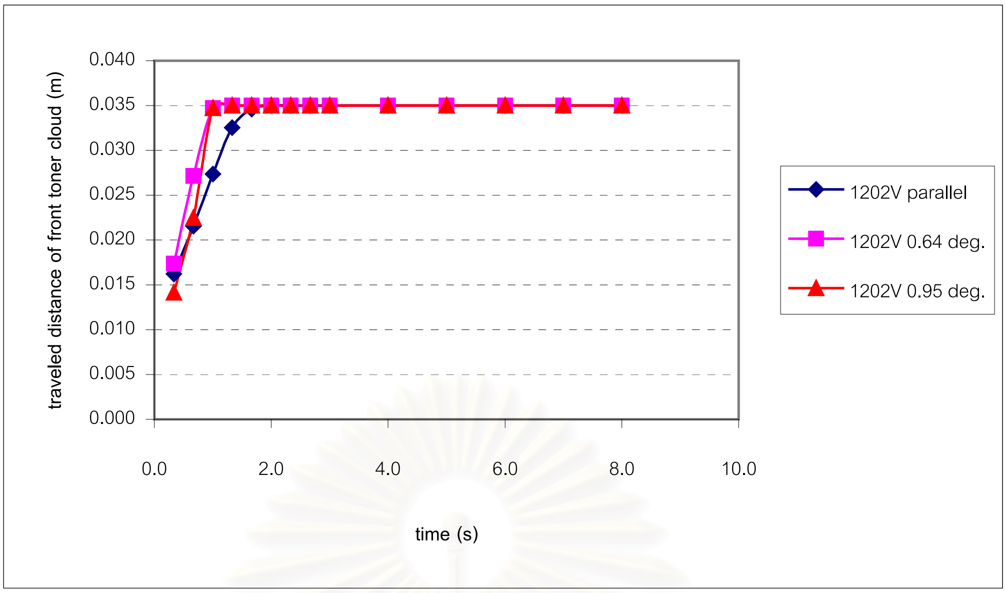


c)

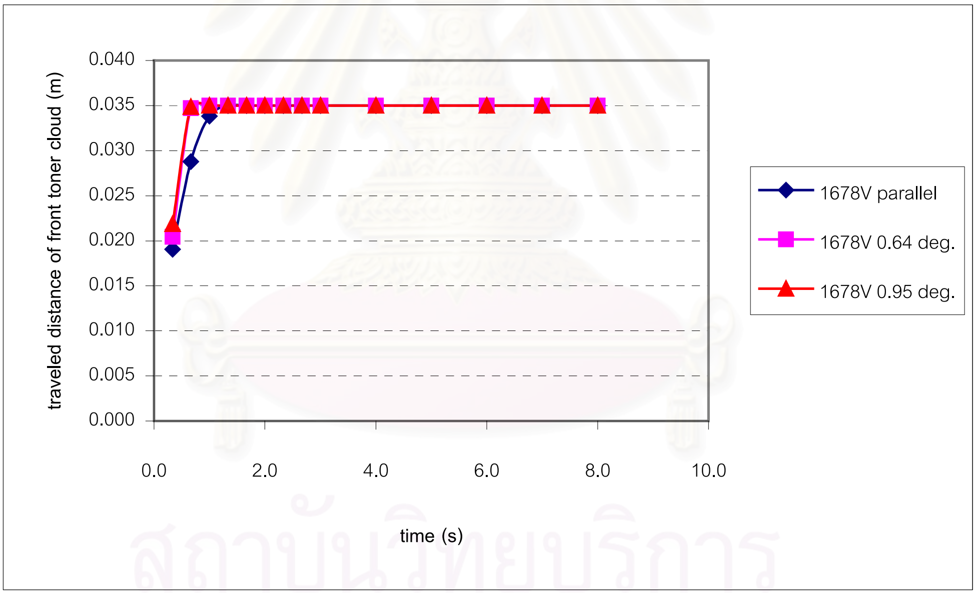
Figure 4-54 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 6 mg put at the center of 0.5 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V



a)

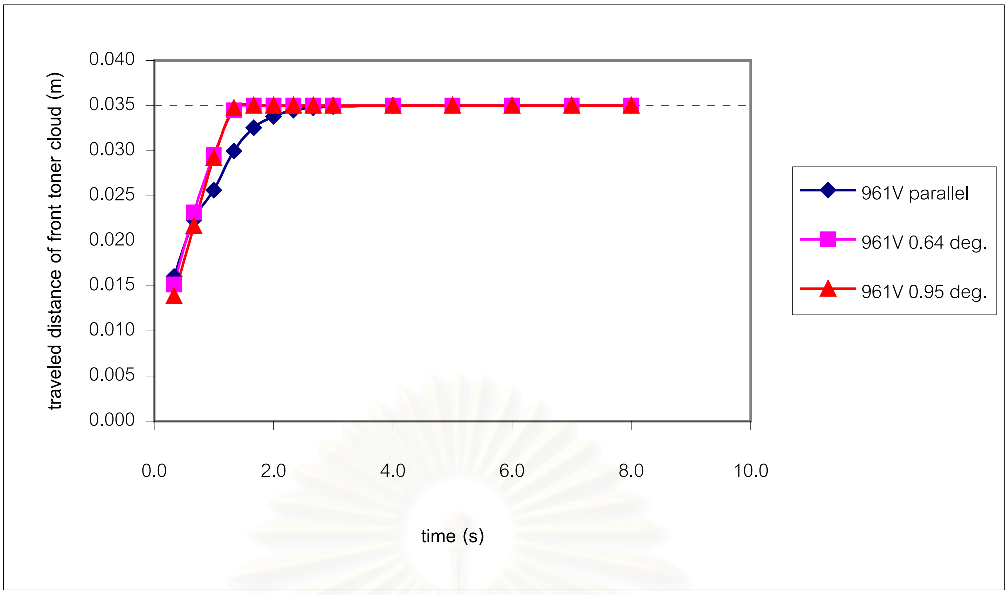


b)



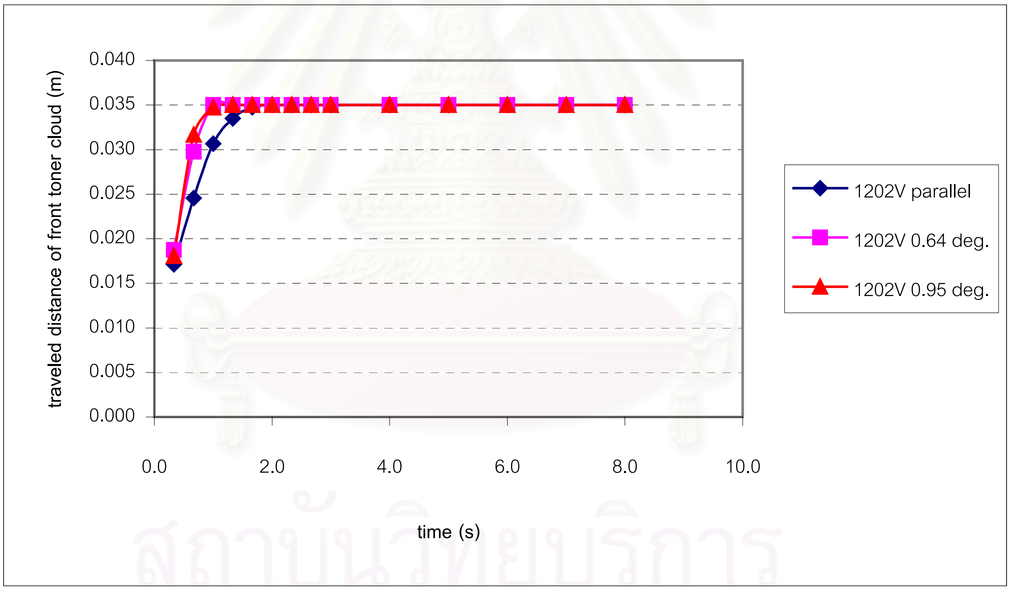
c)

Figure 4-55 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 3 mg put at the center of 0.2 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V



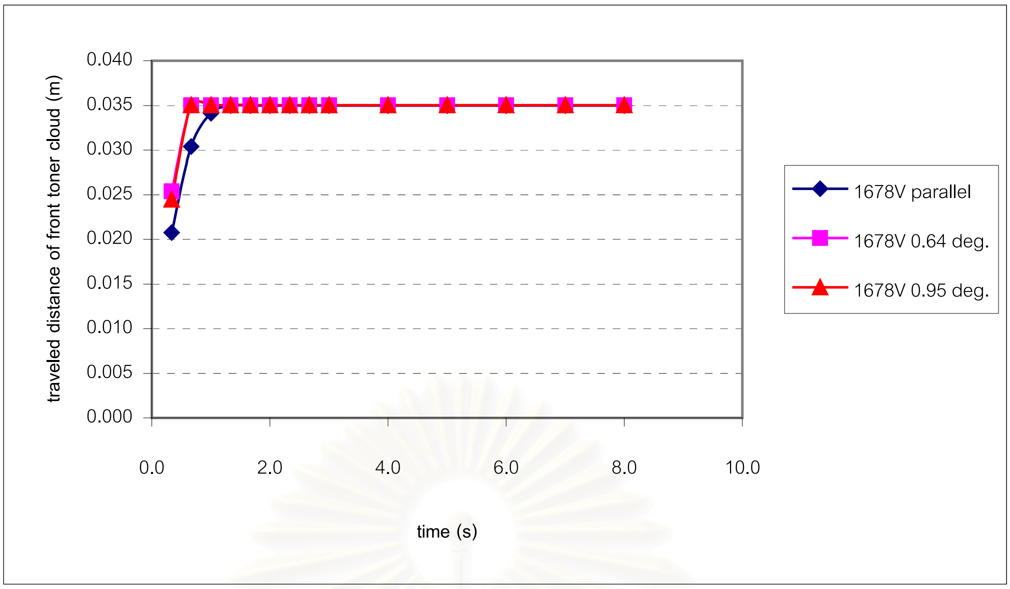
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.0
2.0
4.0
6.0
8.0
10.0
time (s)
961V parallel
961V 0.64 deg.
961V 0.95 deg.

a)



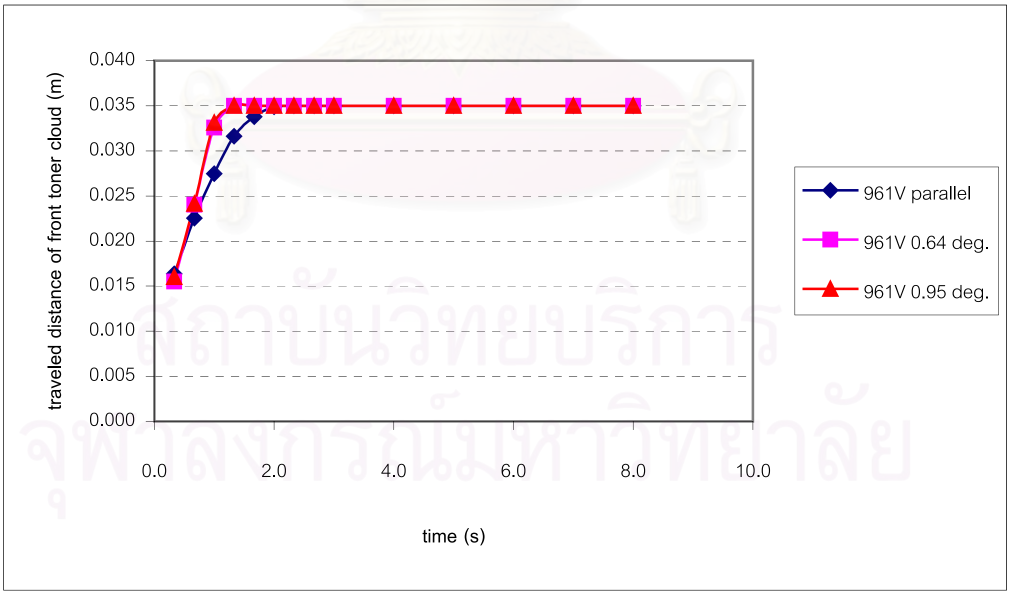
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
traveled distance of front toner cloud (m)
0.0
2.0
4.0
6.0
8.0
10.0
time (s)
1202V parallel
1202V 0.64 deg.
1202V 0.95 deg.

b)

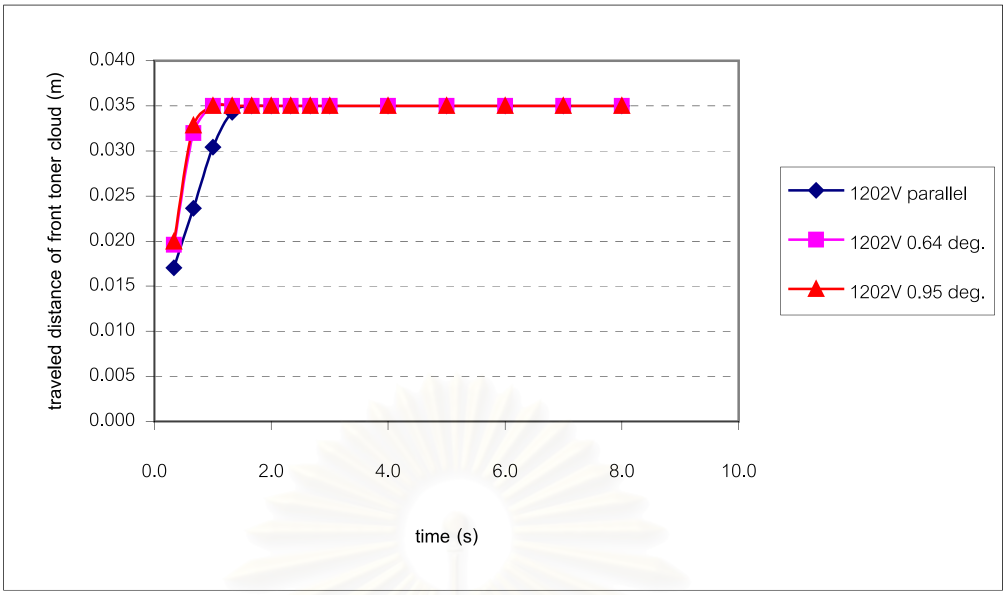


c)

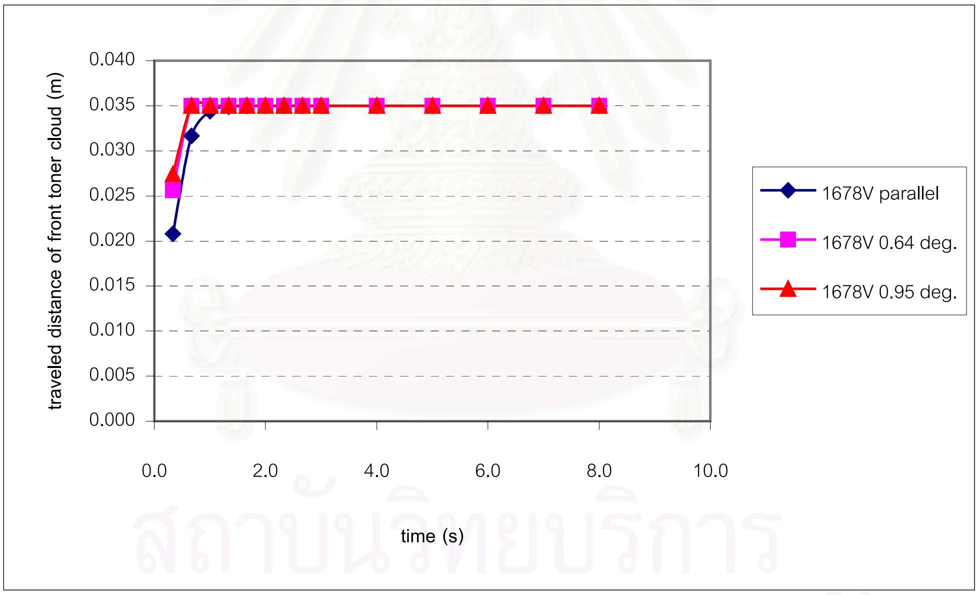
Figure 4-56 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 4 mg put at the center of 0.2 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V



a)



b)



c)

Figure 4-57 Dependence of the front toner cloud displacement on the nesa glass slope having the toner amount of 6 mg put at the center of 0.2 mm depth dented electrode with a) 961 V, b) 1202 V, and c) 1678 V

To confirm the experimental results, the toner particles are also supplied at the one end of the dented electrode to elucidate the effect of the nesa glass slope on the toner cloud motion. Figures 4-55 to 4-60 show the dependence of toner cloud traveled distance on the nesa glass slope with the toner amount of 3, 4 and 6 mg, put on the dented electrodes with the depth of 0.5 and 0.2 mm under the applied voltage of 757, 961, 1202 and 1678 V. The higher the nesa glass slope, the longer the toner cloud traveled distance at the same time for applying voltage or travelling.

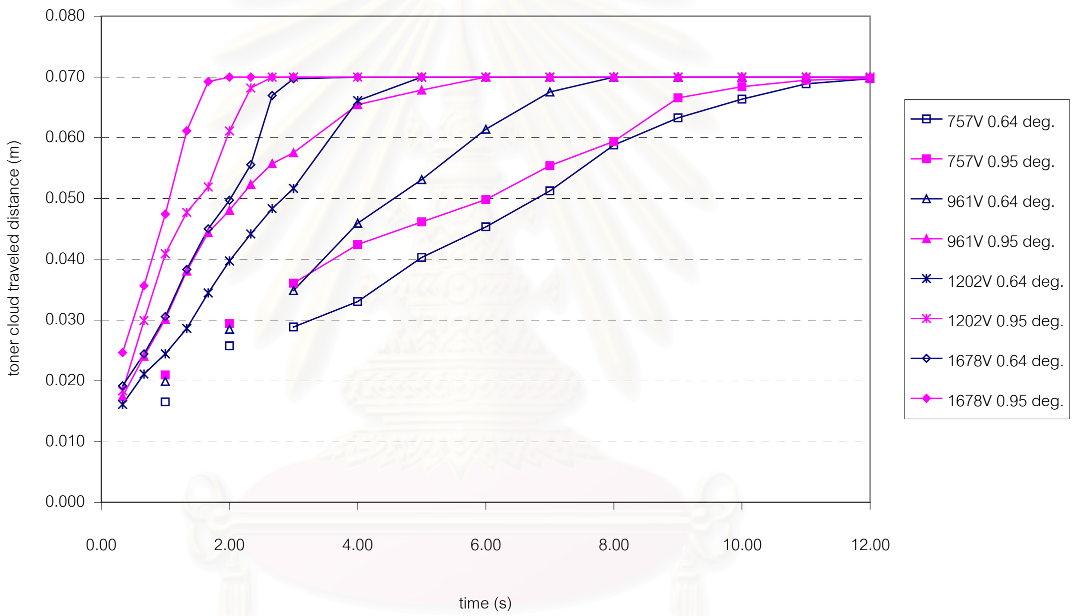


Figure 4-58 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 3 mg put at the one end of 0.5 mm depth dented electrode

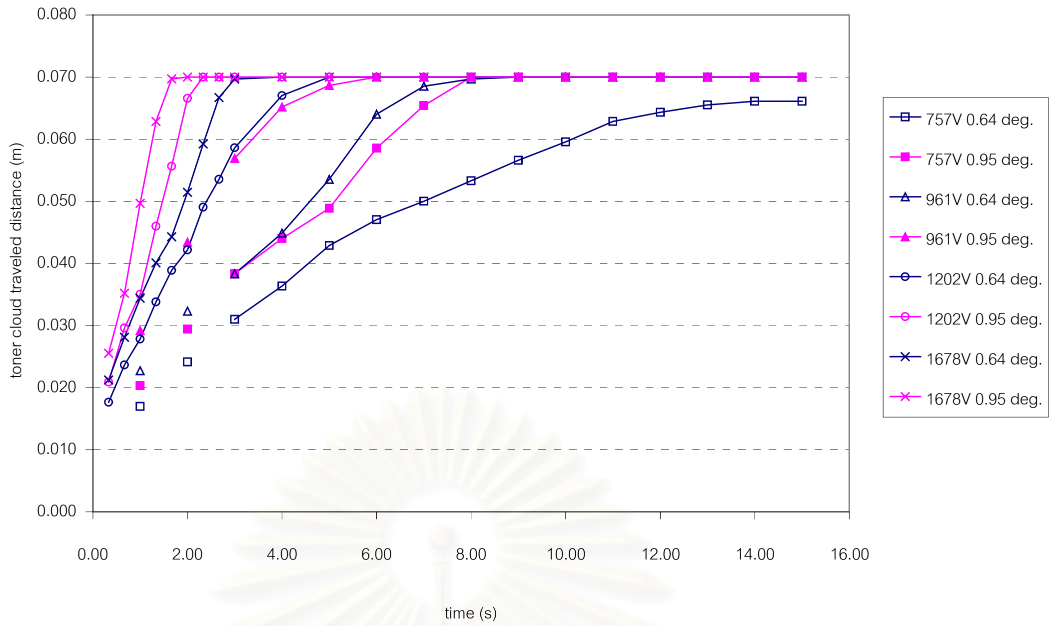


Figure 4-59 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 4 mg put at the one end of 0.5 mm depth dented electrode

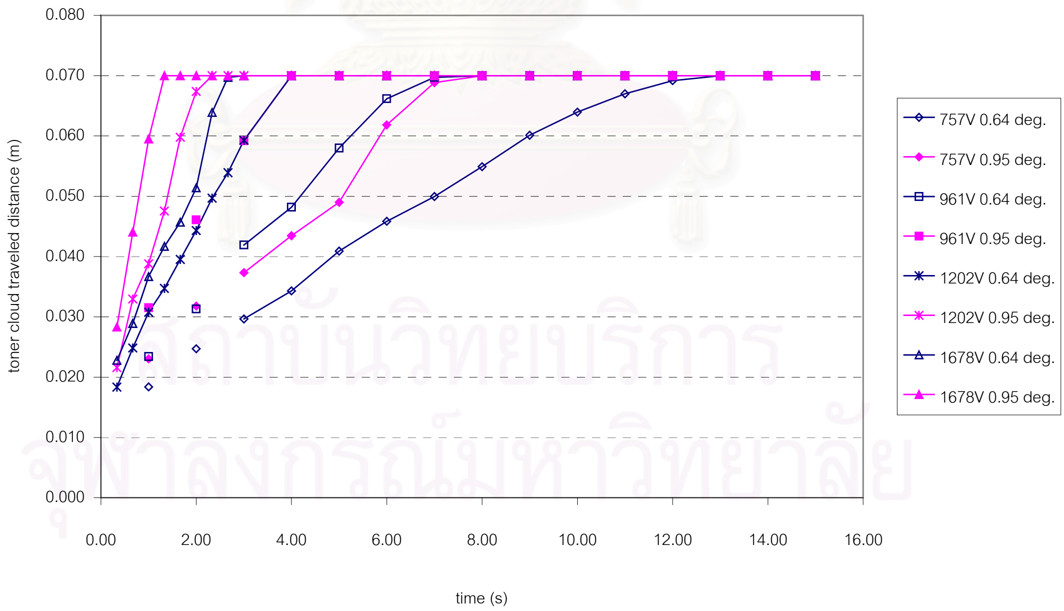


Figure 4-60 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 6 mg put at the one end of 0.5 mm depth dented electrode

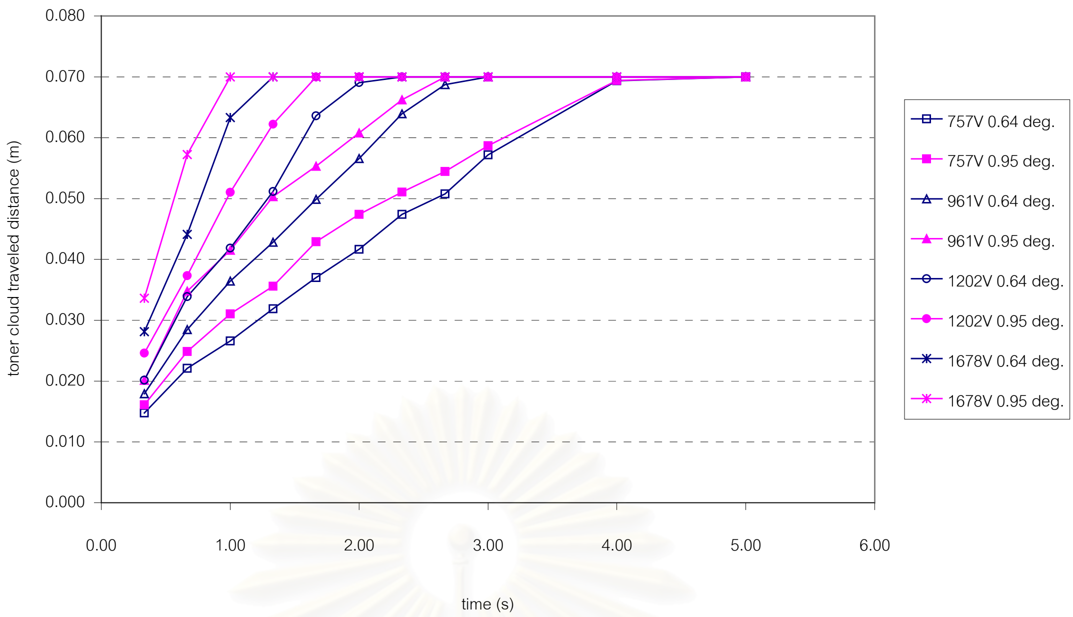


Figure 4-61 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 3 mg put at the one end of 0.2 mm depth dented electrode

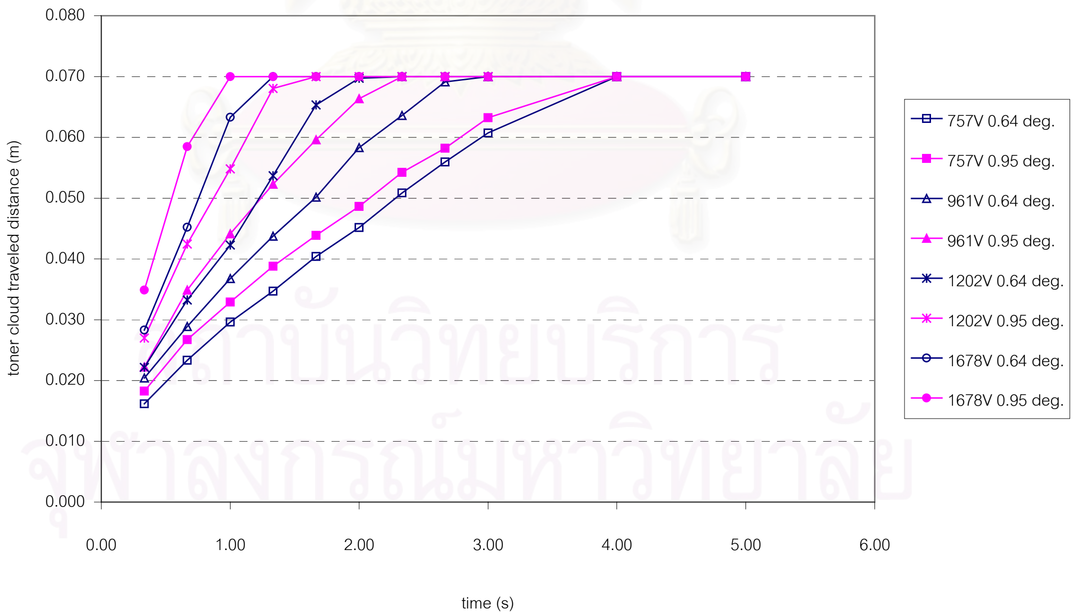


Figure 4-62 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 4 mg put at the one end of 0.2 mm depth dented electrode

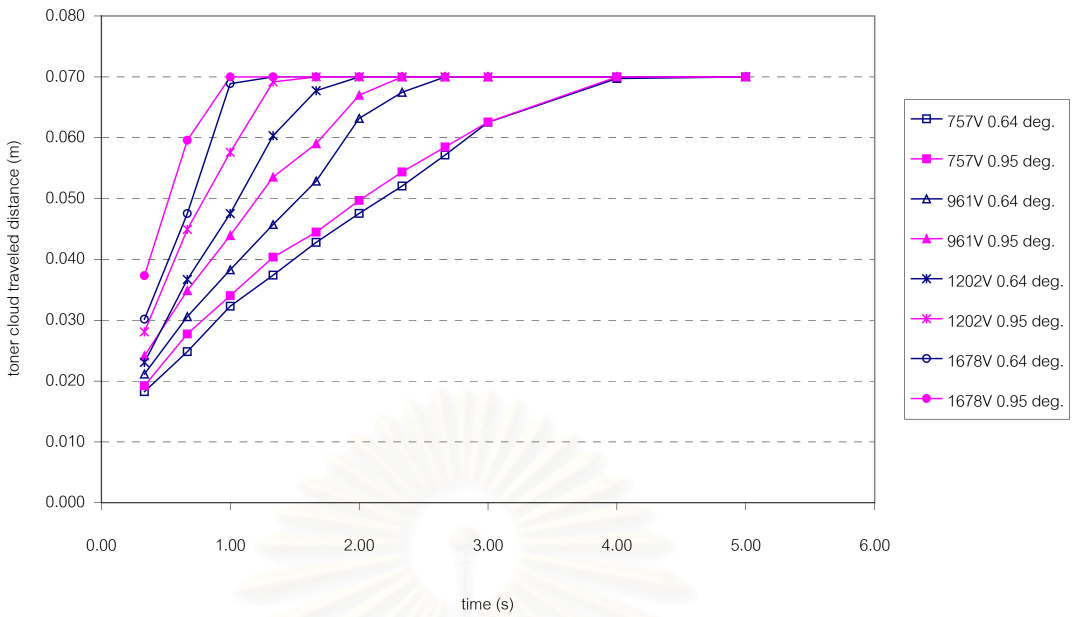


Figure 4-63 Dependence of the toner cloud traveled distance on the nesa glass slope at four levels of applied voltage for the toner amount of 6 mg put at the one end of 0.2 mm depth dented electrode

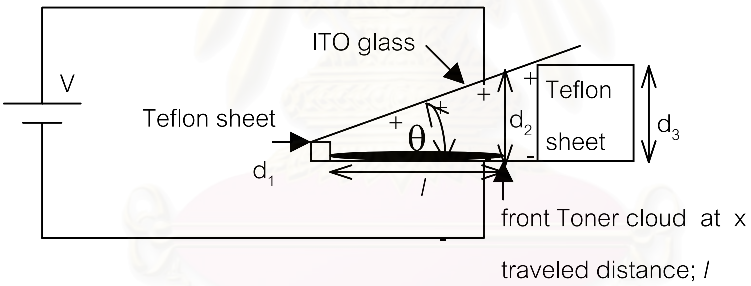


Figure 4-64 Schematic diagram of the experimental set-up for dependence of the front toner cloud traveled distance on the nesa glass slope with angle θ and applied voltage V, and Teflon sheet placed at both ends to avoid short circuit.

From Figure 4-50 and 4-64, the nesa glass was set with angle θ on the dented electrode, using Teflon sheet to avoid short circuit, the front toner cloud traveled under the applied voltage V to reach the point x at time t. Considering the point x, the space between the nesa glass and the dented electrode is d_2. With a very rough approximation, we consider the relationship of the electrostatic force acting on the toner motion as the increase in θ and V increase in the toner motion.

The relation is observed in Figure 4-63; an increase in the applied voltage and the nesa glass slope increased the speed of the front toner cloud movement as shown in Figure 4-65.

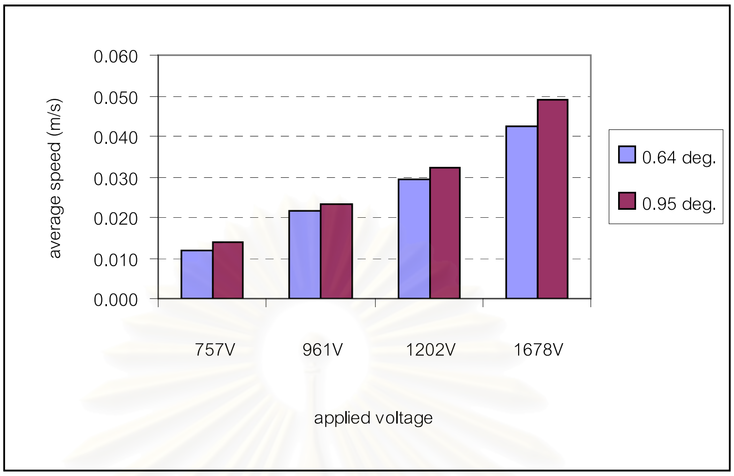


Figure 4-65 Dependence of the average toner cloud speed on the nesa glass slope of applied voltage for the toner amount of 6 mg put at the one end of 0.2 mm depth dented electrode

4.1.5 Dependence of toner cloud speed on the system slope

In this investigation, the TCB system was set at the slopes of 2.86 and 5.31 degrees while the ITO was placed parallel to the dented electrode. The distance between the two electrodes was 0.50 mm separated by the thickness of a Teflon sheet. To elucidate the effect of the system slope on the toner cloud speed, the applied voltages were 757, 961, 1202 and 1678 V. Tables 4-31 to 4-36 give the results of traveled distances, and Figures 4-66 to 4-71 illustrate the dependence of toner cloud speed on the system slope by the toner amounts of 3, 4 and 6 mg applied respectively to the electrode end of the dented electrode (0.2 and 0.5 mm depth). Unlike the nesa glass slope dependence, the higher the system slope, the lower the speed of toner cloud. This could be caused by the increasing gravity force. However, the insignificant results of the system slope between 0 to 5 degrees on the movement of toner cloud are the advantage for indeed designing this technique to the printing system. In the other words, the stability of the printing system is indeed required for a good printing outcome. It is anticipated that this technology can be realized in the near future.

Table 4-31 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.5 mm depth, toner 3 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0115	0.0127	0.0143	0.0146	0.0168	0.0158	0.0187	0.0184
0.67	0.0149	0.0151	0.0174	0.0163	0.0196	0.0181	0.0227	0.0225
1.00	0.0165	0.0165	0.0202	0.0181	0.0218	0.0204	0.0249	0.0268
1.33	0.0187	0.0180	0.0224	0.0201	0.0227	0.0222	0.0264	0.0286
1.67	0.0202	0.0189	0.0236	0.0210	0.0246	0.0233	0.0280	0.0298
2.00	0.0215	0.0195	0.0249	0.0219	0.0255	0.0242	0.0292	0.0306
2.33	0.0224	0.0201	0.0258	0.0225	0.0264	0.0251	0.0296	0.0318
2.67	0.0230	0.0207	0.0268	0.0233	0.0277	0.0257	0.0308	0.0330
3.00	0.0240	0.0210	0.0271	0.0239	0.0283	0.0265	0.0317	0.0335
3.33	0.0243	0.0216	0.0277	0.0248	0.0289	0.0268	0.0327	0.0344
3.67	0.0249	0.0216	0.0280	0.0254	0.0292	0.0277	0.0336	0.0353
4.00	0.0258	0.0219	0.0286	0.0263	0.0299	0.0283	0.0345	0.0362
5.00	0.0268	0.0227	0.0292	0.0268	0.0308	0.0289	0.0361	0.0382
6.00	0.0277	0.0230	0.0305	0.0274	0.0317	0.0298	0.0376	0.0400
7.00	0.0280	0.0233	0.0314	0.0283	0.0324	0.0312	0.0389	0.0414
8.00	0.0286	0.0236	0.0324	0.0283	0.0324	0.0321	0.0411	0.0420
9.00	0.0289	0.0242	0.0330	0.0286	0.0330	0.0327	0.0429	0.0429
10.00	0.0296	0.0245	0.0336	0.0292	0.0333	0.0333	0.0439	0.0435
11.00	0.0302	0.0248	0.0339	0.0295	0.0336	0.0341	0.0451	0.0443
12.00	0.0305	0.0248	0.0342	0.0295	0.0345	0.0344	0.0457	0.0449
13.00	0.0305	0.0248	0.0348	0.0295	0.0348	0.0347	0.0470	0.0449
14.00	0.0311	0.0248	0.0348	0.0295	0.0352	0.0347	0.0476	0.0449

An average of 3 times of measurements performed (m)

Table 4-32 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.5 mm depth, toner 4 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0162	0.0157	0.0178	0.0166	0.0213	0.0192	0.0222	0.0219
0.67	0.0201	0.0177	0.0222	0.0195	0.0263	0.0236	0.0286	0.0271
1.00	0.0224	0.0192	0.0257	0.0228	0.0306	0.0272	0.0328	0.0306
1.33	0.0239	0.0204	0.0286	0.0248	0.0335	0.0286	0.0349	0.0338
1.67	0.0251	0.0219	0.0303	0.0263	0.0353	0.0304	0.0366	0.0365
2.00	0.0260	0.0227	0.0315	0.0280	0.0376	0.0319	0.0387	0.0382
2.33	0.0272	0.0242	0.0327	0.0289	0.0394	0.0328	0.0411	0.0400
2.67	0.0281	0.0257	0.0335	0.0300	0.0411	0.0337	0.0431	0.0417
3.00	0.0289	0.0272	0.0344	0.0309	0.0429	0.0346	0.0478	0.0443
3.33	0.0298	0.0281	0.0353	0.0321	0.0438	0.0354	0.0529	0.0470
3.67	0.0310	0.0284	0.0362	0.0330	0.0446	0.0363	0.0567	0.0496
4.00	0.0319	0.0289	0.0376	0.0341	0.0455	0.0372	0.0597	0.0522
5.00	0.0343	0.0298	0.0403	0.0350	0.0510	0.0387	0.0632	0.0586
6.00	0.0366	0.0310	0.0429	0.0359	0.0548	0.0399	0.0670	0.0645
7.00	0.0393	0.0313	0.0467	0.0365	0.0580	0.0414	0.0688	0.0694
8.00	0.0402	0.0319	0.0490	0.0370	0.0613	0.0419	0.0700	0.0700
9.00	0.0411	0.0325	0.0525	0.0376	0.0639	0.0425	0.0700	0.0700
10.00	0.0414	0.0331	0.0554	0.0385	0.0665	0.0434	0.0700	0.0700
11.00	0.0416	0.0340	0.0589	0.0391	0.0683	0.0440	0.0700	0.0700
12.00	0.0419	0.0349	0.0613	0.0397	0.0700	0.0449	0.0700	0.0700
13.00	0.0428	0.0354	0.0633	0.0397	0.0700	0.0455	0.0700	0.0700
14.00	0.0431	0.0357	0.0645	0.0400	0.0700	0.0461	0.0700	0.0700

An average of 3 times of measurements performed (m)

Table 4-33 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.5 mm depth, toner 6 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0180	0.0176	0.0199	0.0213	0.0224	0.0243	0.0239	0.0259
0.67	0.0217	0.0220	0.0246	0.0261	0.0278	0.0290	0.0319	0.0325
1.00	0.0245	0.0242	0.0283	0.0289	0.0314	0.0325	0.0366	0.0356
1.33	0.0266	0.0260	0.0314	0.0314	0.0350	0.0369	0.0408	0.0400
1.67	0.0279	0.0282	0.0336	0.0336	0.0377	0.0391	0.0440	0.0457
2.00	0.0288	0.0295	0.0355	0.0355	0.0401	0.0416	0.0473	0.0523
2.33	0.0297	0.0307	0.0370	0.0367	0.0422	0.0448	0.0517	0.0596
2.67	0.0307	0.0317	0.0386	0.0380	0.0443	0.0476	0.0561	0.0643
3.00	0.0316	0.0329	0.0411	0.0395	0.0464	0.0505	0.0605	0.0691
3.33	0.0325	0.0339	0.0426	0.0414	0.0503	0.0552	0.0641	0.0700
3.67	0.0334	0.0348	0.0448	0.0433	0.0529	0.0577	0.0670	0.0700
4.00	0.0344	0.0358	0.0467	0.0455	0.0553	0.0586	0.0700	0.0700
5.00	0.0365	0.0377	0.0576	0.0502	0.0601	0.0618	0.0700	0.0700
6.00	0.0390	0.0389	0.0641	0.0568	0.0676	0.0656	0.0700	0.0700
7.00	0.0418	0.0405	0.0694	0.0606	0.0700	0.0700	0.0700	0.0700
8.00	0.0437	0.0417	0.0700	0.0637	0.0700	0.0700	0.0700	0.0700
9.00	0.0449	0.0430	0.0700	0.0669	0.0700	0.0700	0.0700	0.0700
10.00	0.0461	0.0442	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
11.00	0.0480	0.0452	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
12.00	0.0489	0.0468	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
13.00	0.0495	0.0471	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
14.00	0.0495	0.0477	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700

An average of 3 times of measurements performed (m)

Table 4-34 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.2 mm depth, toner 3 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0143	0.0147	0.0188	0.0176	0.0188	0.0209	0.0236	0.0248
0.67	0.0190	0.0191	0.0245	0.0245	0.0281	0.0296	0.0314	0.0326
1.00	0.0222	0.0230	0.0285	0.0290	0.0337	0.0356	0.0378	0.0383
1.33	0.0248	0.0257	0.0322	0.0323	0.0371	0.0389	0.0425	0.0422
1.67	0.0271	0.0284	0.0344	0.0350	0.0402	0.0425	0.0478	0.0458
2.00	0.0289	0.0308	0.0361	0.0380	0.0424	0.0452	0.0514	0.0506
2.33	0.0303	0.0335	0.0378	0.0404	0.0439	0.0473	0.0567	0.0550
2.67	0.0318	0.0350	0.0398	0.0422	0.0461	0.0497	0.0614	0.0598
3.00	0.0327	0.0371	0.0421	0.0443	0.0478	0.0524	0.0664	0.0631
3.33	0.0333	0.0383	0.0430	0.0458	0.0506	0.0547	0.0692	0.0655
3.67	0.0341	0.0398	0.0441	0.0479	0.0529	0.0574	0.0700	0.0679
4.00	0.0347	0.0410	0.0452	0.0503	0.0554	0.0601	0.0700	0.0694
5.00	0.0365	0.0431	0.0464	0.0562	0.0599	0.0649	0.0700	0.0700
6.00	0.0373	0.0452	0.0481	0.0619	0.0644	0.0691	0.0700	0.0700
7.00	0.0382	0.0467	0.0501	0.0664	0.0669	0.0700	0.0700	0.0700
8.00	0.0388	0.0485	0.0518	0.0691	0.0692	0.0700	0.0700	0.0700
9.00	0.0394	0.0497	0.0532	0.0700	0.0697	0.0700	0.0700	0.0700
10.00	0.0400	0.0503	0.0549	0.0700	0.0700	0.0700	0.0700	0.0700
11.00	0.0408	0.0509	0.0561	0.0700	0.0700	0.0700	0.0700	0.0700
12.00	0.0411	0.0515	0.0569	0.0700	0.0700	0.0700	0.0700	0.0700
13.00	0.0414	0.0521	0.0572	0.0700	0.0700	0.0700	0.0700	0.0700
14.00	0.0417	0.0521	0.0575	0.0700	0.0700	0.0700	0.0700	0.0700

An average of 3 times of measurements performed (m)

Table 4-35 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.2 mm depth, toner 4 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0190	0.0182	0.0210	0.0197	0.0233	0.0215	0.0273	0.0263
0.67	0.0239	0.0227	0.0277	0.0266	0.0304	0.0287	0.0355	0.0365
1.00	0.0274	0.0263	0.0331	0.0326	0.0354	0.0356	0.0415	0.0458
1.33	0.0306	0.0296	0.0374	0.0362	0.0405	0.0410	0.0485	0.0512
1.67	0.0335	0.0320	0.0395	0.0395	0.0441	0.0449	0.0542	0.0556
2.00	0.0368	0.0341	0.0426	0.0419	0.0486	0.0470	0.0603	0.0610
2.33	0.0394	0.0359	0.0461	0.0443	0.0534	0.0494	0.0685	0.0658
2.67	0.0423	0.0377	0.0481	0.0467	0.0585	0.0518	0.0700	0.0700
3.00	0.0440	0.0392	0.0521	0.0488	0.0616	0.0538	0.0700	0.0700
3.33	0.0458	0.0410	0.0562	0.0518	0.0649	0.0571	0.0700	0.0700
3.67	0.0487	0.0425	0.0611	0.0553	0.0700	0.0604	0.0700	0.0700
4.00	0.0505	0.0437	0.0663	0.0592	0.0700	0.0619	0.0700	0.0700
5.00	0.0580	0.0479	0.0700	0.0637	0.0700	0.0685	0.0700	0.0700
6.00	0.0662	0.0497	0.0700	0.0682	0.0700	0.0700	0.0700	0.0700
7.00	0.0700	0.0518	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
8.00	0.0700	0.0538	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0574	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0619	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0664	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0691	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700

An average of 3 times of measurements performed (m)

Table 4-36 The average traveled distance of the front toner cloud on the system slope and the applied voltage dependence (dented electrode 0.2 mm depth, toner 6 mg)

Time (s)	757V		961V		1202V		1678V	
	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.	2.86 deg.	5.31 deg.
0.33	0.0206	0.0186	0.0224	0.0224	0.0233	0.0250	0.0274	0.0290
0.67	0.0263	0.0244	0.0296	0.0291	0.0304	0.0340	0.0367	0.0416
1.00	0.0294	0.0275	0.0353	0.0355	0.0354	0.0393	0.0426	0.0494
1.33	0.0328	0.0312	0.0382	0.0400	0.0405	0.0459	0.0476	0.0580
1.67	0.0362	0.0336	0.0407	0.0445	0.0441	0.0527	0.0532	0.0640
2.00	0.0384	0.0357	0.0438	0.0491	0.0486	0.0569	0.0594	0.0688
2.33	0.0413	0.0388	0.0470	0.0533	0.0534	0.0611	0.0632	0.0700
2.67	0.0441	0.0406	0.0495	0.0573	0.0585	0.0664	0.0678	0.0700
3.00	0.0456	0.0422	0.0514	0.0600	0.0616	0.0700	0.0688	0.0700
3.33	0.0478	0.0440	0.0536	0.0624	0.0649	0.0700	0.0700	0.0700
3.67	0.0494	0.0452	0.0545	0.0648	0.0700	0.0700	0.0700	0.0700
4.00	0.0512	0.0480	0.0561	0.0670	0.0700	0.0700	0.0700	0.0700
5.00	0.0562	0.0501	0.0627	0.0700	0.0700	0.0700	0.0700	0.0700
6.00	0.0637	0.0531	0.0694	0.0700	0.0700	0.0700	0.0700	0.0700
7.00	0.0675	0.0571	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
8.00	0.0694	0.0602	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
9.00	0.0700	0.0620	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
10.00	0.0700	0.0632	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
11.00	0.0700	0.0645	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
12.00	0.0700	0.0663	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
13.00	0.0700	0.0675	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700
14.00	0.0700	0.0688	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700

An average of 3 times of measurements performed (m)

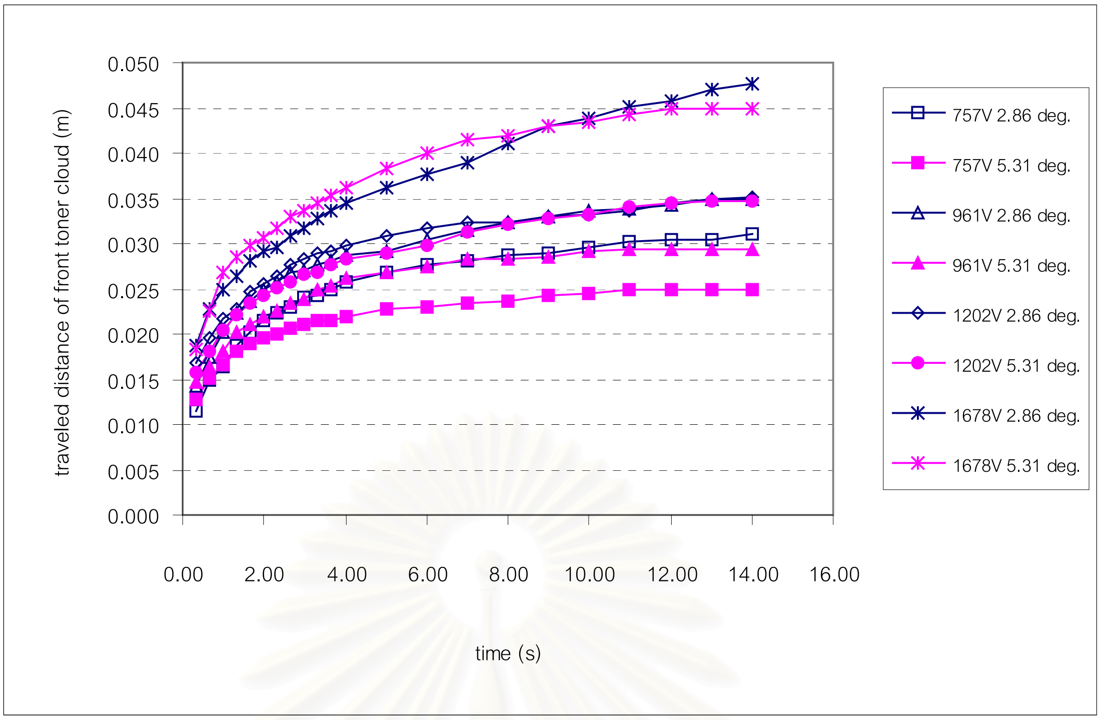


Figure 4-66 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 3 mg, dented electrode 0.5 mm depth)

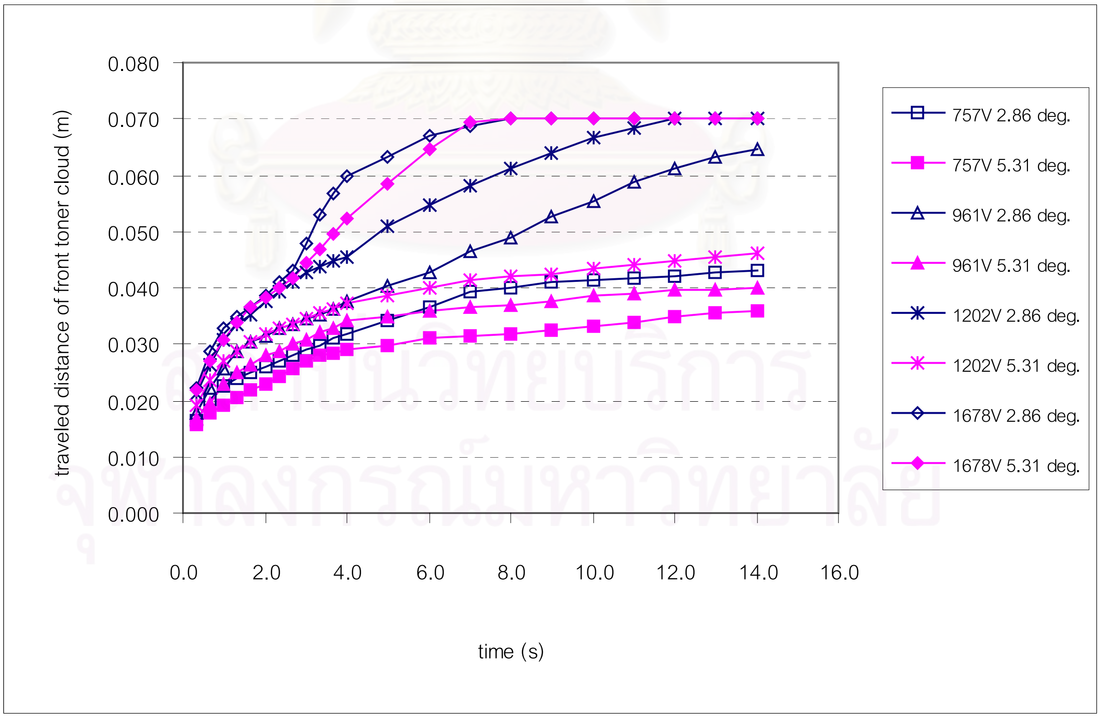


Figure 4-67 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 4 mg, dented electrode 0.5 mm depth)

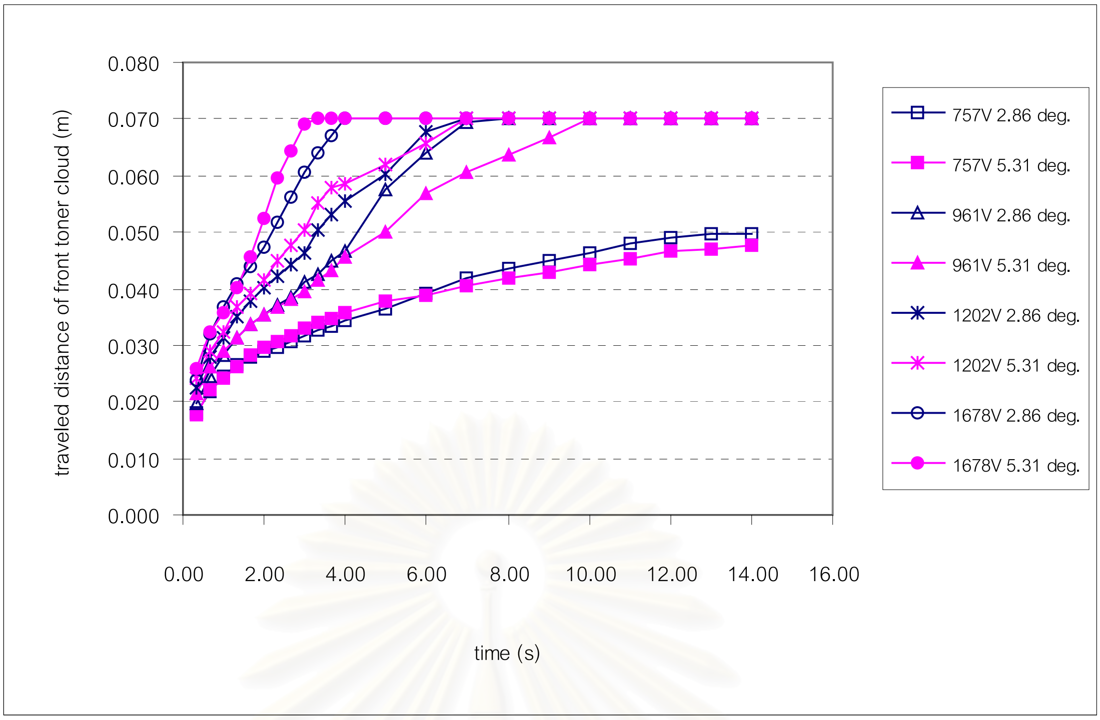


Figure 4-68 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 6 mg, dented electrode 0.5 mm depth)

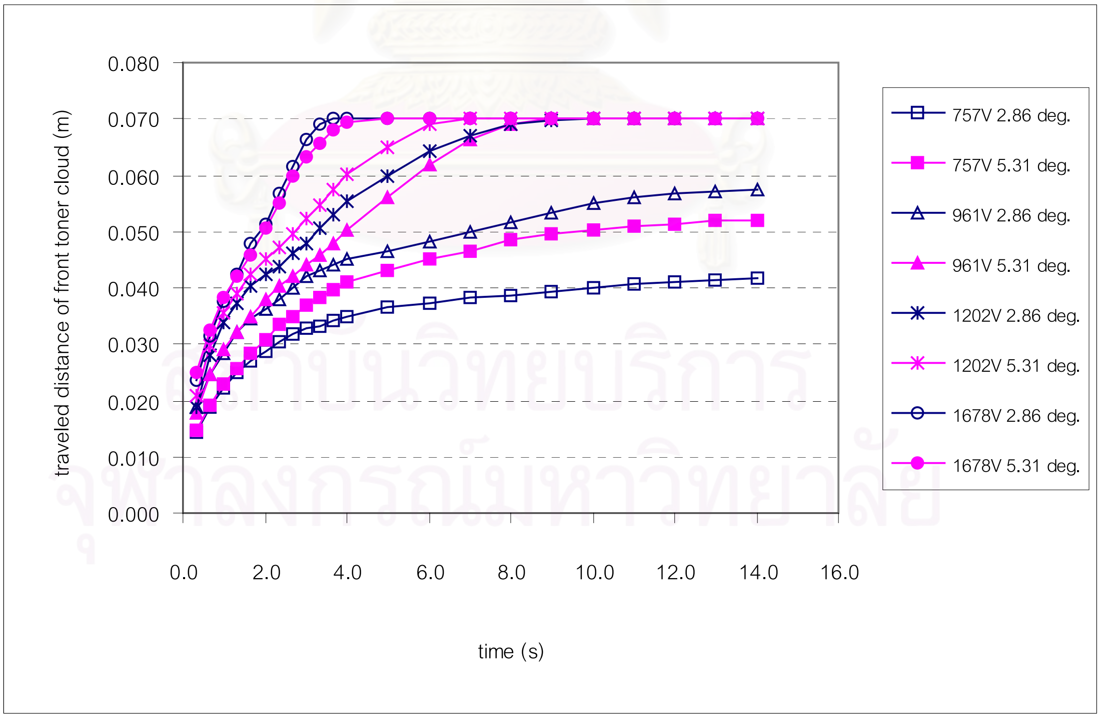


Figure 4-69 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 3 mg, dented electrode 0.2 mm depth)

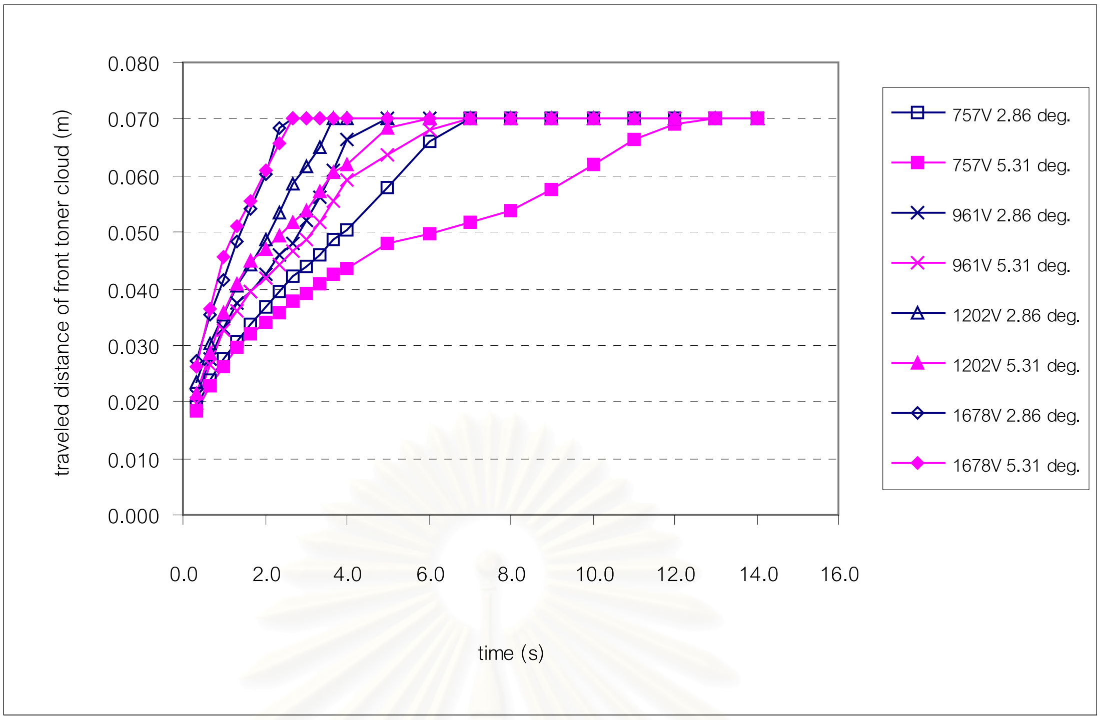


Figure 4-70 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 4 mg, dented electrode 0.2 mm depth)

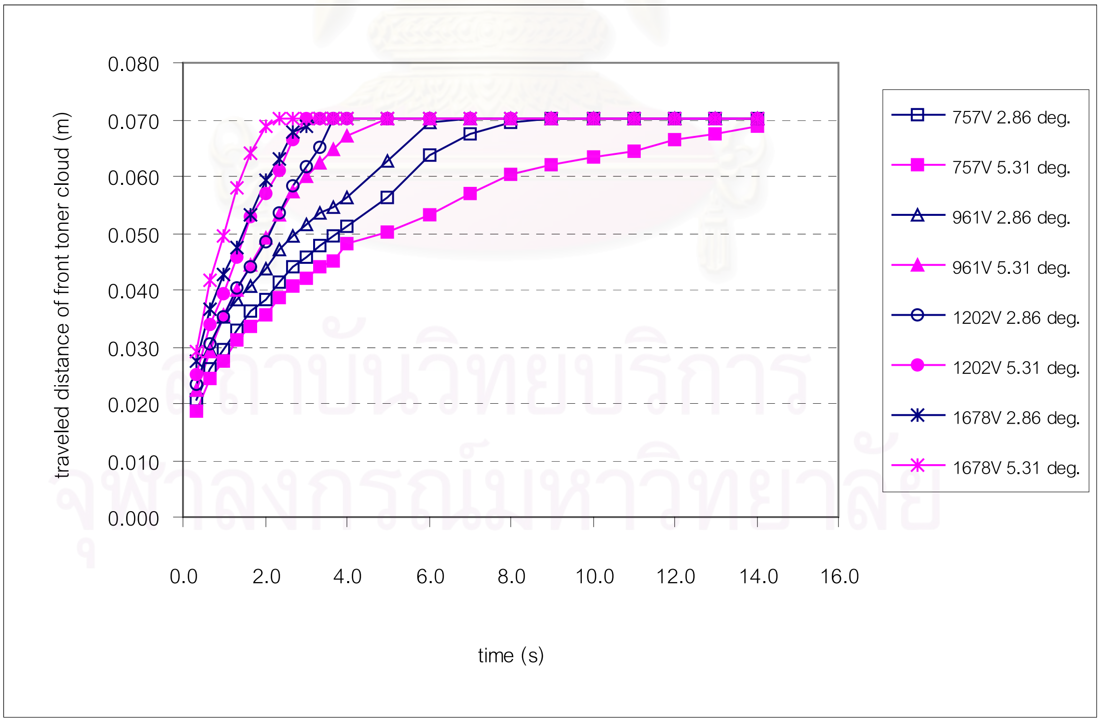


Figure 4-71 Dependence of the traveled distance of the front toner cloud on the system slope at four applied voltages (input toner 6 mg, dented electrode 0.2 mm depth)

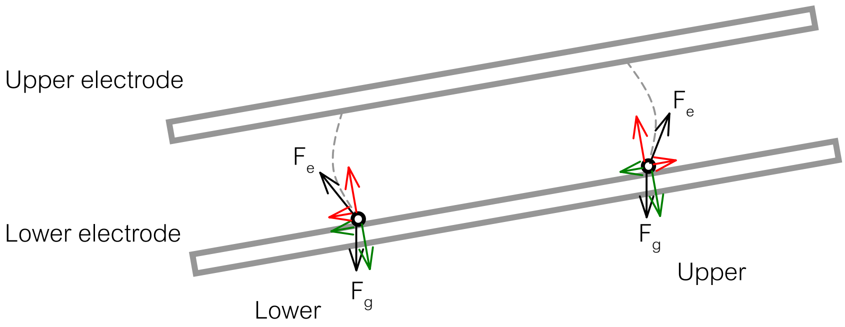


Figure 4-72 Schematic diagram of the electric force (F_e) and the gravitational forces (F_g) on the conductive toner particles in the inclined TCB system.

Figure 4-72 illustrates the electrostatic force and the gravitational force on the conductive toner particles in the TCB system, which is inclined to the ground. The setting of the upper and lower electrodes is parallel. Under the electric field, the toner particles tend to propagate slower along the advancing slope than those travelled down the descending slope. This phenomenon might probably be caused by the gravitational forces.

4.1.6 Dependence of the width of toner cloud on applied voltage

The confinement was also studied by observing the width of toner cloud through the upper transparent electrode, which was covered by a thin layer of ITO. The width of toner cloud is shown in Figure 4-73. The still pictures of the width of toner cloud were taken after 1 minute of applying voltage. In this case, the applied voltages were 521, 961 and 1202 V, the toner cloud approached the steady state in which the toner jumping current was constant within 1 minute. Tables 4-37 and 4-38 gave the results of the width of toner cloud confinement by the applied voltage in 0.2 mm and 0.5 mm depth dented electrodes, respectively. The higher the applied voltage, the smaller the width of toner cloud.

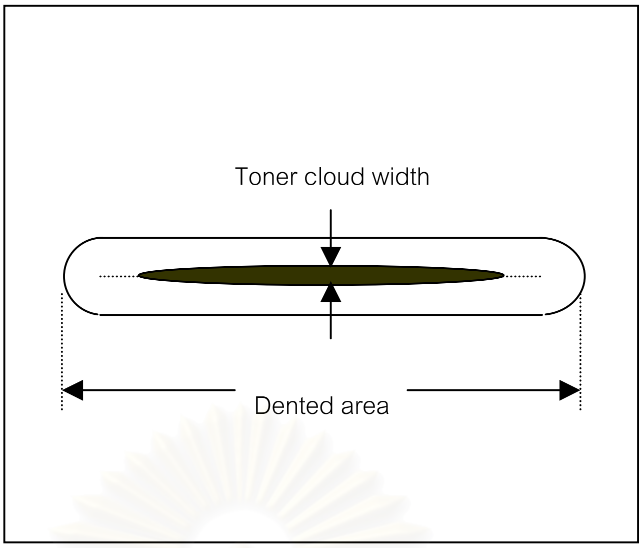


Figure 4-73 Top view of the toner cloud generation in the width of printing area.

Table 4-37 The average toner cloud width and toner width after applying the voltage on the applied voltage dependence (0.5 mm depth dented electrode)

Applied voltage (V)	Toner cloud width (m)	toner width after stopping the applied voltage (m)
521	0.0024	0.0011
961	0.0022	0.0008
1202	0.0021	0.0006

Table 4-38 The average toner cloud width and toner width after applying the voltage on the applied voltage dependence (0.2 mm depth dented electrode)

Applied voltage (V)	toner cloud width (m)	toner width after stopping the applied voltage (m)
521	0.0023	0.0014
961	0.0022	0.0008
1202	0.0020	0.0005

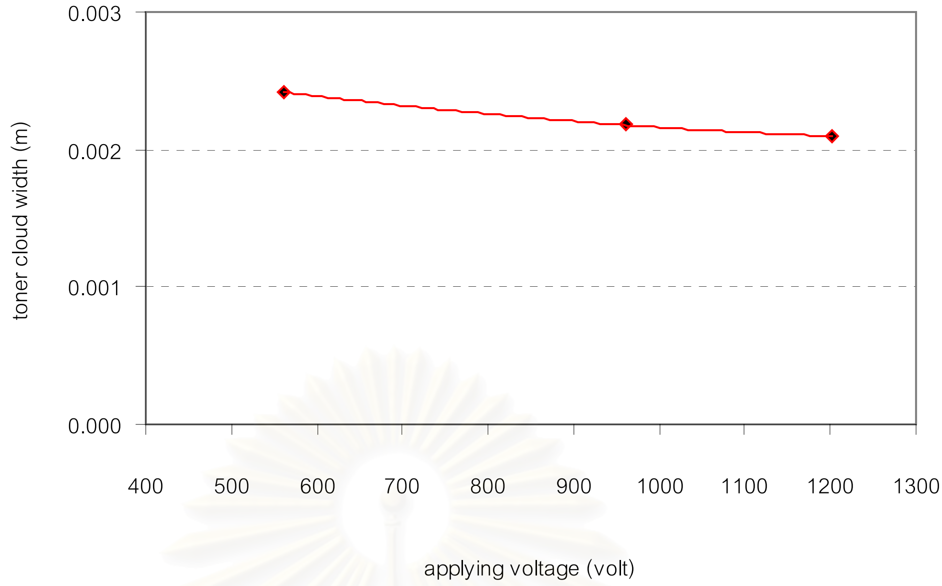


Figure 4-74 The average toner cloud width on the applied voltage dependence (0.5 mm depth dented electrode)

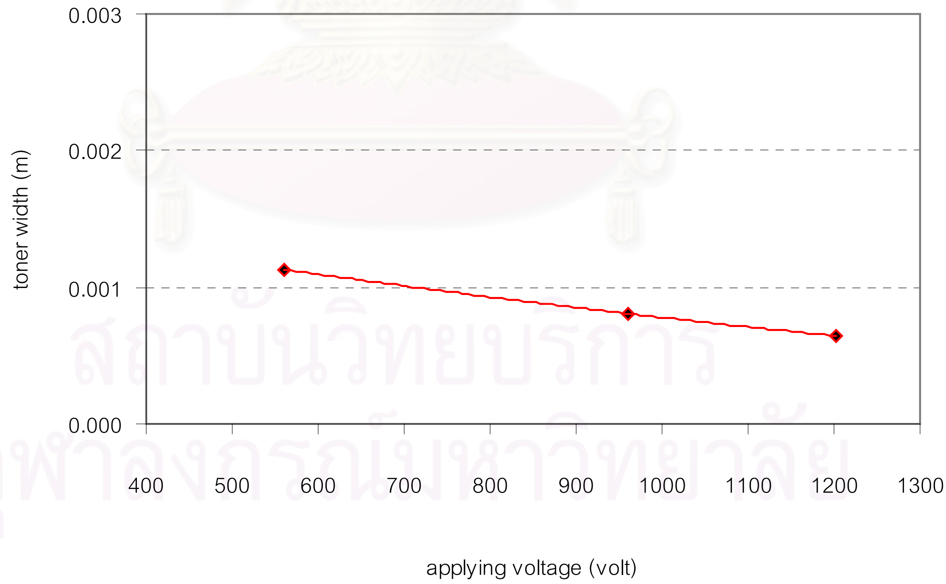


Figure 4-75 The average toner width after stopping the applied voltage on the applied voltage dependence (0.5 mm depth dented electrode)

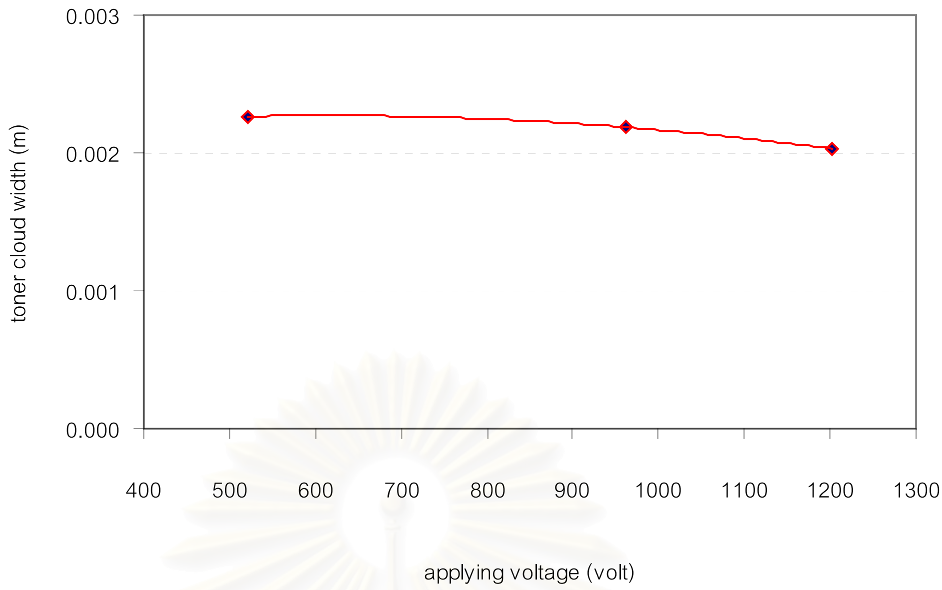


Figure 4-76 The average toner cloud width on the applied voltage dependence (0.2 mm depth dented electrode)

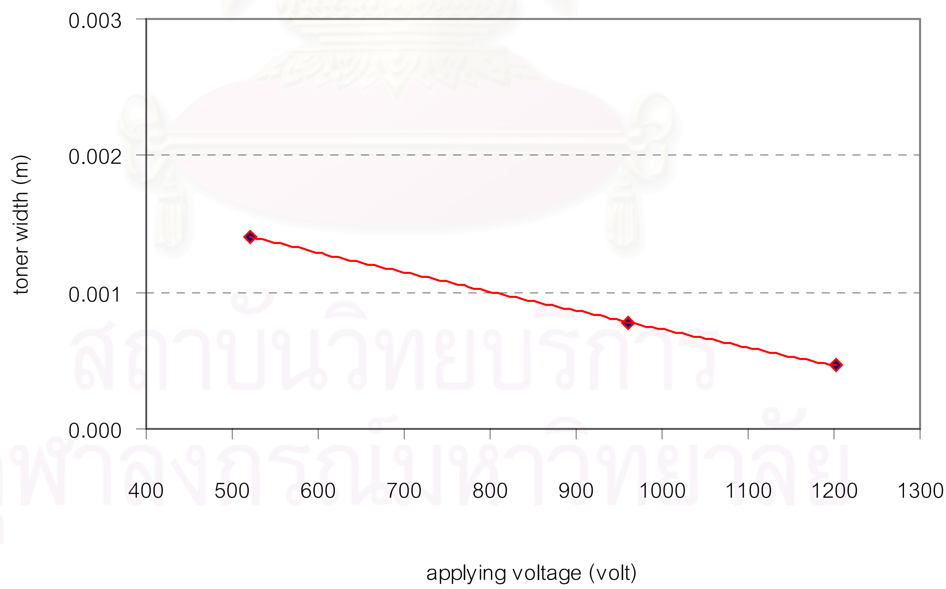


Figure 4-77 The average toner width after applied voltage cut off on the applied voltage dependence (0.2 mm depth dented electrode)

4.2 Determination of Toner supplying

Since the control of toner supply is important in printing and other applications such as electronic printing. The dented electrodes, which are dented into two-overlapped cone shapes, were used to elucidate the possible toner transferring method. There are 3 dented electrodes, OLDE_01, OLDE_02 and OLDE_03, used in this case. The toner 0.5 mg were used at various applied voltages of 521, 757 and 961 V. The results are shown in Figures 4-78 to 4-81. At the fixed toner amount of 0.5 mg and applied voltage, the time of toner transfer with OLDE_01 dented electrode is shortest compared to others. Therefore, the higher level of applied voltage creates the shorter time of toner transferring. We anticipated that the distance between the center of the higher cone shape dented electrode and the center of the lower cone shape dented electrode might be the controlling factor. The two overlapped cone shape dented electrode with the shorter distance between the center of two dented electrodes can transfer the toner particles faster than the longer distance between the center of two dented electrodes. Also that the shallower of the higher cone shape dented electrode, the higher toner transferring speed.

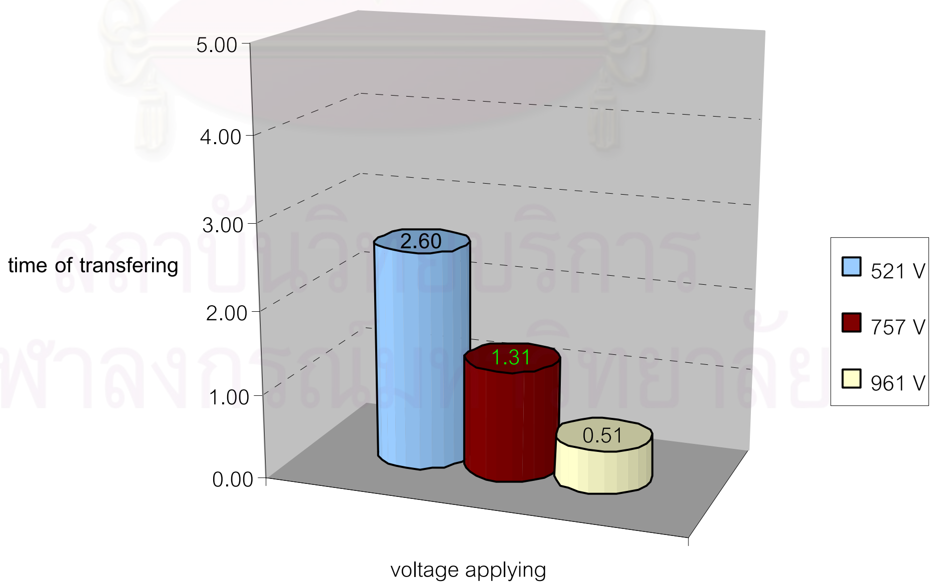


Figure 4-78 The toner transferring time on the applied voltage of OLDE_01 dented electrode (diameter of two cones: 5, 3 mm)

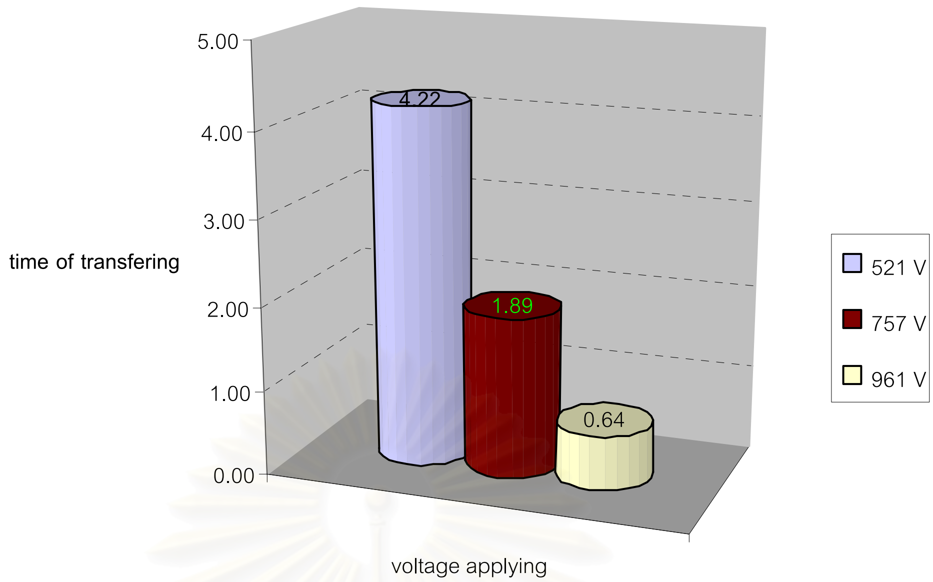


Figure 4-79 The toner transferring time on the applied voltage of OLDE_02 dented electrode (diameter of two cones: 5, 5 mm)

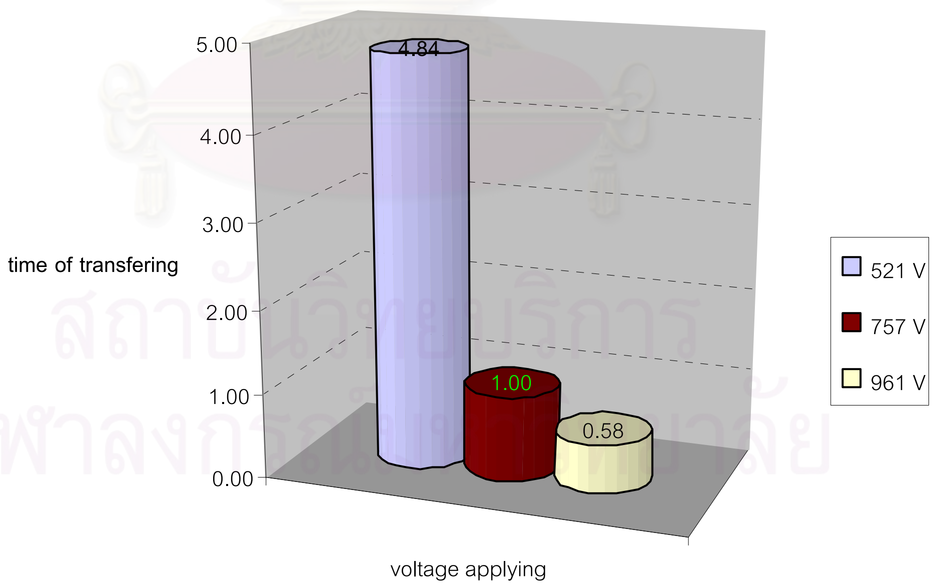


Figure 4-80 The toner transferring time on the applied voltage of OLDE_03 dented electrode (diameter of two cones: 5, 4.5 mm)

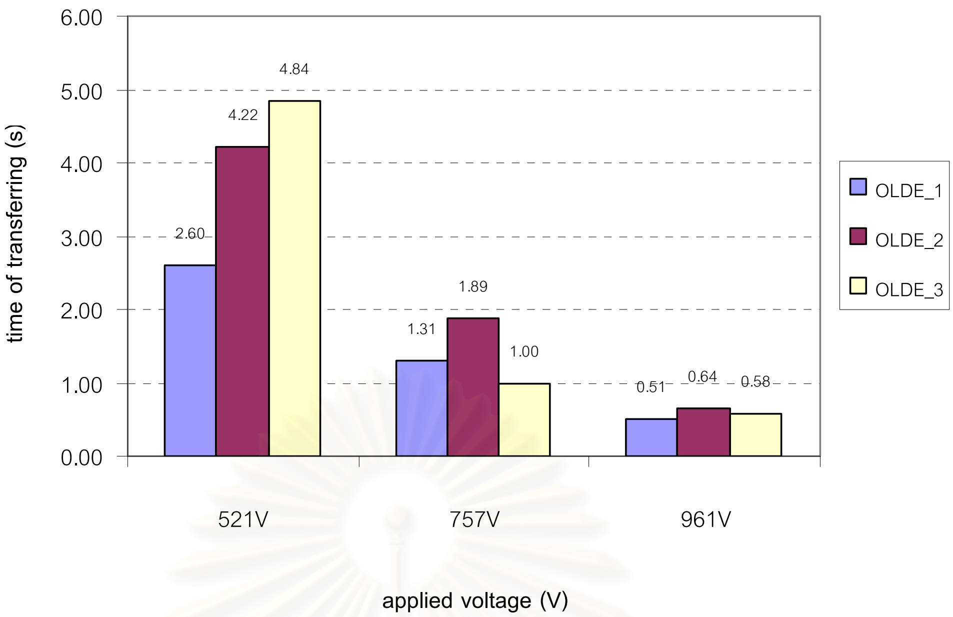


Figure 4-81 Summary of the toner transferring time on the applied voltage of 3 electrodes

Considering the depth of higher cone shape and lower cone shape, as shown in Figure 4-82, we anticipated that the wall of the overlapping of the two cone shape dented electrodes produced the blocking. The wall blocked movement of some toner particles and delayed the toner transfer. The shallower wall will promote the faster toner transfer. That is, the shorter wall height between the two electrodes enhances the toner supplying to the lower electrode.

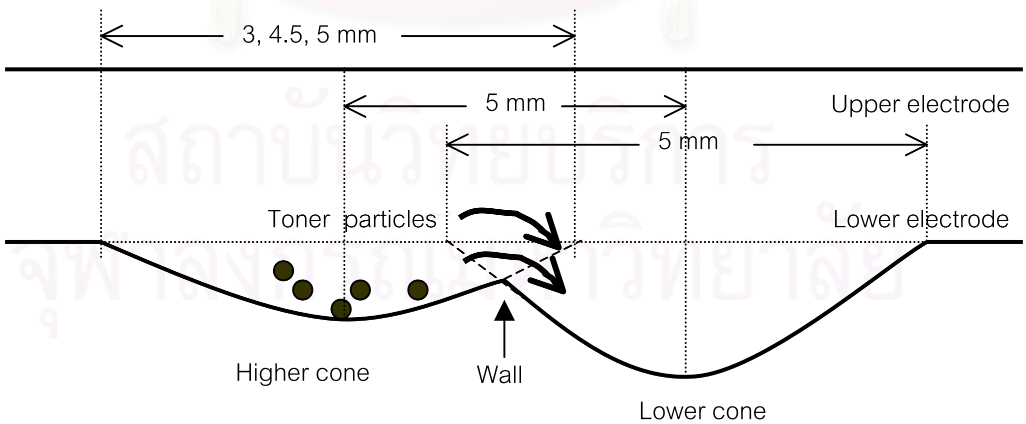


Figure 4-82 Schematic diagram of the toner transferring from the higher cone shape dented electrode to the lower cone shape dented electrode

4.3 Morphology of the Toner Particles

The toner used in this experiment is a mono-component toner made by the crushing method and the average diameter is around 11.25 μm. The micrograph of the toner observed by scanning electron micrography (SEM) is shown in Figure 4-83. The toner shape is irregular resulting from the crushing method. In addition, the specific gravity (ρ) is 1.9 g/cm^3 and the resistivity (η) is 1.55×10^{10} Ωcm.

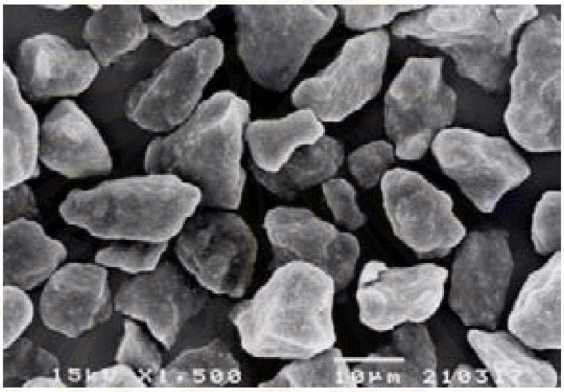


Figure 4-83 Electron micrograph of the toner particles

CHAPTER 5

CONCLUSIONS AND SUGGESTION

This research studied the conductive toner cloud generation in the width of printing area using the lower electrode, which was dented to a wide chamber shape and another electrode of the ITO glass for observing the toner motion between the electrodes. The conductive toner was sprayed freely on the dented electrode and the voltage was applied to the electrodes. The conductive toner cloud was generated and measurement on the traveled distance of the front toner cloud at the toner cloud state was carried out, then the front toner cloud velocity was computed. Furthermore, we investigated the dependence of the front toner velocity on various influencing factors. These factors were the applied voltage (500–1700 Volts), the toner amount (3, 4 and 6 mg), the depth of the dented electrode (0.2 and 0.5 mm), the slope of the ITO glass (0.64 and 0.95 degree), and the slope of the system (0-5 degree). In addition, the two-overlapped cone shape dented electrode was elucidated for the toner transport phenomenon.

Conclusions

When a certain value of the electric field was applied between the electrodes, the conductive toner that sprayed on the wide chamber shape dented electrode starts to move up and down between the electrodes by the electrostatic force. The conductive toner moves to the width direction. The mechanism of the motion was discussed from the following viewpoints: 1) The toners move with the random scattering direction because the toner particles have an irregular shape and the average diameter is around 11.25 μm, which could be explained by random walk model. 2) The toners scattered during their jumping, which occurred by direct collisions between toners and Coulomb's repulsion between the same polarity toner. We can observe that the conductive toner cloud propagates along the width of the dented electrode like a black cloud through the ITO glass.

An investigation of the dependence of the toner cloud speed on five levels of the applied voltage was carried out. It was found that an increase in the applied voltage leads to the faster toner cloud speed.

The toner cloud speed extent increases with increasing toner amount. On the other hand, the toner cloud speed decreases with the increasing depth of dented electrode. For the slope of the ITO glass, the toner moves to the direction of wider space between the electrode and ITO glass. The toner cloud speed is not significant to the system slope between 0-5 degrees.

In addition, the effect of applied voltage was also studied for toner cloud confinement in the wide chamber shape dented electrode. It was found that the width of toner cloud depends on the applied voltage. When the applied voltage increased, the width of toner cloud decreased. Furthermore, the two-overlapped cone shape dented electrode can be used for toner transport to the printing system.

In conclusion, we achieved the conductive toner cloud generation in the width of printing area and also the toner transportation for the printing system. This information could possibly be applied to improve the dot formation mechanism in a modern electrostatic toner cloud beam printer.

Suggestions

Although we achieved many important features necessary of the toner cloud beam printer, some parameters for conductive toners, involving toner cloud generation and transportation are not yet thoroughly investigated. A few parameters worth while to be mentioned below:

a) Optimum toner characteristics,

- conductivity
- shape and size

b) Adhesion force between the toner and the electrode,

c) Effect of ambient humidity and temperature,

These parameters indeed affect the extent of toner cloud generation, toner cloud movement, uniformity of toner clouds, and toner transportation.

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