Development of Water-Based Ink System for Braille Printing

Saurabh Varma

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DEVELOPMENT OF WATER-BASED INK SYSTEM FOR BRAILLE PRINTING

by

Saurabh Varma

A Thesis Submitted to the Faculty of The Graduate College in partial fulfillment of the requirements for the Degree of Master of Science Department of Paper and Printing Science and Engineering

Western Michigan University Kalamazoo, Michigan December 2002
DEVELOPMENT OF WATER-BASED INK SYSTEM FOR BRAILLE PRINTING

Saurabh Varma, M.S.
Western Michigan University, 2002

The most commonly used system of writing by and for blind persons is called Braille, named after its French inventor, Louis Braille (1809-1952). Braille is comprised of a rectangular six-dot cell on its end, with up to 63 possible combinations using one or more of the six dots. Braille is the only reliable method of literacy for blind persons, because it enables them to read and write by touch.

Currently, Braille is printed by special embossers that serve as a printing press. These embossers create Braille output when it is attached appropriately to computers. The speed of these generators ranges from 25 characters per second to 60 characters per second. This study is focused on a novel based Braille printing ink. A water-based ink system was developed with appropriate physical properties, to enable the creation of raised Braille dots on the surface of paper without the use of an embosser. The ink utilizes a thermally activated blowing agent, which releases CO₂ gas into the deposited ink layer during drying. The CO₂ gas raises the ink layer to heights acceptable for the blind to distinguish by touch. The height of the dot can be controlled by the amount of blowing agent added. The work shows promise as an alternative printing method to embossing.
ACKNOWLEDGMENTS

This thesis has been conducted in partial fulfillment of the requirements for the degree of Master of Science in Paper and Imaging science and Engineering. The author would like to thank Dr. Margaret Joyce, Dr. Dan Fleming, and Dr. Alexandra Pekarovicova for their valuable suggestions and support in completing this thesis.

Saurabh Varma
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CHAPTER I

INTRODUCTION

The demand for inkjet printing is increasing day by day in the market. Inkjet printers are now plentiful and popular. They provide a cheap and convenient way of printing the colorful images that computers can generate, as well being able to print images that are generated by scanners and digital cameras. Thus, their use as a Braille printing device would offer an inexpensive way for the blind to print stored or download images and information from their computers.

The most critical component of inkjet printing is the ink. Ink chemistry and formulations not only dictate the quality of the printed image, but they also determine the drop ejection characteristics and the reliability of the printing system. Many different types of inks have been developed and used in inkjet applications. The ink composition provides good printing properties, water fastness, light fastness and storage stability. Whatever technology is applied to the printer hardware, the final product consists of ink on paper, so these two elements are especially important when it comes to producing quality results. The quality of output from inkjet printers has greatly improved over the years. Excellent, near-photographic quality can now be produced with the right combination of ink and paper.

Braille is a system of touch reading for the blind, which employs embossed dots evenly arranged in quadrangular letter spaces or cells. In each cell, it is possible to place six dots, three high and two wide.
By selecting one or several dots in characteristic position or combination, 63 different characters can be formed. To aid in describing these characters by their dot or dots, the six dots of the cell are numbered 1, 2, 3, downward on the left, and 4, 5, 6, downward on the right, thus:

```
1 0 0 1
2 0 0 5
3 0 0 6
```

Figure 1: Braille Dots Arrangement

The 63 possible characters have a systematic arrangement and are universally grouped in a table of seven lines, as follows:

<table>
<thead>
<tr>
<th>1st Line</th>
<th>2nd Line</th>
<th>3rd Line</th>
<th>4th Line</th>
<th>5th Line</th>
<th>6th Line</th>
<th>7th Line</th>
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<tbody>
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Figure 2: Braille Characters

These dots or characters, which are read by finger touch, must be of a minimal standard height (recommended height being 0.019 inches) for touch sensitive reading by the blind. Braille is read by blind persons by running their fingers along the raised dots of a series of Braille characters. Such persons can also write Braille by means of a six-key writing machine known as a "Braillewriter" or by means of a stylus disposed on a pocket-size metal or plastic slate. Braille books are generally printed by
utilizing metal press plates. The Braille characters for the book are stamped on both sides of the paper utilized to fabricate the book by a method known as "interpointing". The characters are arranged so that dots impressed upon one side of a book page do not interfere with those printed on the other side of the page. Computers have been used to increase the speed of production of Braille books in recent years. In such systems, the computer converts ordinary punched cards prepared by a typist on a keypunch machine into cards punched with a Braille code. A machine is then utilized to automatically produce metal plates from the Braille-coded cards for printing of the Braille book. Currently, the various means for Braille printing are either very labor intensive, or require expensive machinery and processing.

Recently, machines using a duplicating engine to provide substitutes for the printing plate have been developed for printing of Braille and other raised lettering and graphics in a thermographic process. These machines, however embody sophisticated technology, are very expensive, and are accordingly not amenable for use in common desktop publishing applications. Even with the sophistication of the machines, simultaneous printing of raised and non-raised portions is still not possible, such as the printing of regular text with corresponding clear raised Braille print thereon⁴.

The objective of this research is to develop a water-based ink system for Braille printing to enable the printing of Braille dots and images by commercial printing processes, i.e., rotogravure, flexo, or inkjet printing. The preferred method would be inkjet to enable the use of inexpensive commercial printers in the home or office by the blind end-user.
CHAPTER II

LITERATURE REVIEW

A recent patent by Thermotek Inc. uses a two-step process to dispense a thermographic powder as to a wet ink film printed with an inkjet printer and heating device to create raised lettering or graphics. The thermographic dispenser and heating device is connected to the output of the inkjet printer.

The main problem occurring with the current invention for inkjet printed Braille images is that it requires a two-step process requirement to generate the raised dots. In this method, the Braille image is created on the surface of the paper using a forming toner, which contains thermoexpansive cell particles and binder. The image or text is first printed on special paper with an inkjet printer by usual means. The printed sheet is then conveyed into a toner bath where the toner particles adhere to the wetted imaged areas. The un-adhered toner in the non-imaged areas is then lightly shaken off the sheet and the paper dried at high temperatures to expand and fuse the toner particles to the sheet. Unfortunately, the size of the toner particles prevents their direct application with the inkjet nozzle. Thus, a better ink system is needed to enable conventional inkjet printers to be used. Adding water-soluble foaming agents into the ink along with precipitating materials that expand to form a raised image may be one way to eliminate the necessity of sprinkling the expanding powder in a two step process. The process may further be improved by using surface tension and viscosity modifiers in the ink to control the shape of the ink droplets exiting the nozzle, as well as how the ink flows on the medium rather than relying the properties of the paper to control the shape of the ink droplet. If a thermoexpansive foaming agent is used, the
ink is not practical for use on a thermal inkjet printer. Instead, a piezo-printer should be used. In this project, water-based inks will be formulated and used because they are capable of receiving various additives that assist ink drying, ink hold out, ink laydown, and printability on various substrates. Also, similar water-based formulations offer the possibility of printing Braille on a flexographic press.

**Inkjet Printing**

Inkjet printing is a radical departure from the conventional printing and reprographic technologies. It relies on ejection of uniformity shaped droplets of aqueous dye solutions that from the image on the paper. Inkjet printers have made rapid technologies advances in recent years. Six and seven color inkjet printers have been around from recent years now and have succeeded in making color inkjet printing an affordable option.

Inkjet printers have one attraction over laser printers; they produce colors at a much lower price, and that is what makes them so popular with home users. The down side is that although color inkjets are generally cheaper to buy than lasers, they are more expensive to maintain. Cartridges need to be changed more frequently and the special coated paper required for producing high-quality output is very expensive. When it comes to comparing the cost per page, inkjets work out about ten times more expensive than laser printers.

Research in inkjet technology is making continual advances, with each new product on the market show improvements in performance, usability, and output quality. As the process of refinement continues, the price of inkjet printers continues to fall, making them more competitive with laser printers.
Inkjet printing, like laser printing, is a non-impact method. Ink is emitted from the nozzles as they pass over the media to be printed. Liquid ink in various colors is squirted at the paper to build up an image. A print head scans the page in horizontal strips or rasters, using a motor assembly to move it from left to right and back, as another stepping motor assembly rolls the paper in vertical steps. A strip of the image is printed, and then the paper moves on, ready for the next strip. On ordinary inkjets, the print head takes about half a second to print a strip across a page. Since A4 paper is about 8.5in wide and inkjets operate at a minimum of 300dpi, this means there are at least 2,475 dots across the page. The print head has, therefore, about 1/5000th of a second to respond as to whether or not to print a dot. The nozzles used in inkjet printers are hair fine and on early models they became easily clogged. On modern inkjet printers this is rarely a problem, but changing cartridges can still be messy on some machines. Another problem with inkjet technology is a tendency for the ink to smudge immediately after printing, but this, too, has improved drastically during the past few years with the development of new ink compositions.

Most desktop inkjet printers use thermal technology, whereby heat is used to fire the ink onto the paper. There are three main stages with this method. The drop injection is initiated by heating the ink to create a bubble until the pressure forces a droplet from the chamber. The bubble then collapses as the element cools, and the resulting vacuum draws ink from the reservoir to replace the ink that was ejected. This is the method favored by Canon and Hewlett-Packard. Thermal technology imposes certain limitations on the printing process in that whatever type of ink is used; it must be resistant to heat because the firing process is heat-based. The ink
must also have been sufficient vapor pressure to form a large enough bubble. The use of heat in thermal printers creates a need for a cooling process as well, which levies a small time overhead on the printing process. Thermal inkjet printers have small resistors built into each nozzle of the printhead. When an electrical current is applied to these resistors, they heat up, thus heating the ink in the nozzle, causing it to vaporize locally and form a bubble. This bubble provides the force needed to eject the ink from the nozzle onto the paper.

![Diagram of thermal or bubble jet process](image)

**Figure 3: Thermal or Bubble Jet Process**

Epson’s proprietary inkjet technology uses a piezo crystal at the back of the ink reservoir. Piezo-electric inkjet printers harness the piezo-electric technology, which causes certain crystalline materials to change shape when a voltage is applied across them. In these printers, each nozzle of the printhead is housed inside an integrated piezo crystal. A small electrical current makes the crystal contract slightly, squeezing ink out of the nozzle onto the paper. The piezo crystal acts like a loudspeaker cone is that it flexes when an electric current flows through it. So,
whenever a dot is required, a current is applied to the piezo element causing the element to flex and in so doing, forces a drop of ink out of the nozzle.

There are several advantages to the piezo method. The process allows more control over the shape and size of ink droplet release. The tiny fluctuations in the crystal allow for smaller droplet sizes and hence higher nozzle density. Also, unlike in thermal technology, the ink does not have to be heated and cooled between each cycle. This saves time, and the ink itself is tailored more for its absorption properties than its ability to withstand high temperatures. This allows more freedom for developing new chemical properties in the inks. The piezo pressure is also suitable for a wider class of inks because it is not sensitive to vapor pressure\textsuperscript{8}.

\[\text{Figure 4: Piezo Electric Process}\textsuperscript{8}\]
Alternative Impact Printing Methods

Screen Printing

Screen printing, is an ancient practice. Its concept is simple - a cut stencil is placed beneath a fine screen through which paint flows. The stencil's holes allow paint through to print onto paper placed directly below. As a whole, screen printing is one of the least expensive methods of printing. There are approximately ten or fifteen different methods of screen printing, ranging from basic stencil printing to intricate and complex methods of photo printing. A variation on basic stencil printing is tusche stenciling. This method is the most adaptable and responsive for fine-art printing. It closely approximates the feel and response of freehand drawing. Tools involved are lithographic tusche (a greasy black fluid resembling India ink), lithographic crayon (a thin crayon used like a pencil), brush (any kind), glue, and kerosene. The identifying feature of this method is that once the drawing is made on paper, the tusche stops out the drawing and is dissolved.

Film stenciling involves a more extensive list of materials, including lacquer stencil film (made of lacquer and glassine backing paper), adhering & removing thinners, film stencil knife, soft flannel cloth, clear fill-in lacquer and a gooseneck lamp. In general technique, this method is similar to the stencil method. Lines are cut from the film and it is then placed under the screen to be printed. It is extremely suitable for concise sharp lines and mass rather than the intricacy of textural effects which can be achieved with tusche printing. Six different types of fabric can be used in the screen, each creating individual effects on the overall print. Organdy and silk
are the two most basic fabrics and are used mostly in conduction with the less complex forms of printing. They do not require a professional to be stretched and therefore make it easier for anyone to use. Monofilament nylon fabric and polyester are tightened more stringently, but are stronger and more durable than the natural fibers. Finally, stainless steel and nickel plated polyester each are used to achieve a grainier texture in the ink, and should be handled by professionals because they are easily ripped or creased\textsuperscript{10,11}.

Figure 5: Screen Printing
Flexographic Printing

Flexography is the fastest growing conventional printing process, especially in packaging such as corrugated containers and flexible films. It has also made significant advances in publication printing, particularly newspapers. Because the quality of flexo printing has improved so much, it is now used extensively for printing process color, as well as spot color, on a wide variety of substrates. It is used extensively for printing tags and labels. Flexography was originally called “aniline” printing because of the aniline dye inks that were originally used in the process. The aniline dyes were made from coal tar and were banned from food packaging by the FDA because of their toxicity\textsuperscript{12,13}.

The flexographic process is like letterpress in that images are created from a raised inked surface. Flexo plates, whether molded from rubber or imaged from photopolymer, are generally made from flexible materials. Flexo inks generally are low viscosity, highly fluid and quick drying, although there is a trend toward higher viscosity inks. The inks are made from a dispersion of resins, solvents, color and additives, which are organic or aqueous based\textsuperscript{14}.

In the simplest and most common form, the flexo process consists of four components;

1) Fountain roll,

2) Ink-metering (anilox) roll,

3) Plate cylinder and impression cylinder.
These are illustrated in the Figure 6 (the fountain roll is generally covered with rubber).

![Diagram of Flexographic Printing Process]

**Figure 6: Flexographic Printing Process**

From above it rotates in a reservoir of ink to pick-up and delivers a relatively heavy flow of ink from the fountain. The anilox roll is usually chrome or ceramic plated and is covered with tiny engraved cells. The number of cells varies from 80 to 1000 cells per linear inch. The roll of the anilox is to supply a fine film of ink to the printing plates. Thus, the fountain and anilox rolls are set to rotate against one another with the least amount of pressure required to form a puddle behind the nip. The anilox roll is often used with a (reverse angle) doctor blade to wipe excess ink for the roll.

The plate cylinder is usually steel and installed between the anilox roll and the impression cylinder. Printing plates are attached to the plate cylinder with sticky back (a special double sided tape). The plates raised surface picks up ink from the
anilox and transfers it to the substrate. The impression cylinder is smooth, highly polished and supports the substrate when it contacts the plate. Its speed must match that of the plate cylinder, the anilox roll and the substrate.

Rotogravure Printing

Rotogravure printing has a significant advantage relative to other printing processes for medium to long runs. The origins of gravure printing were with the creative artists of the Italian Renaissance in the 1300s. Fine engravings and etchings were cut by hand into soft copper. The engraved surface consisted of channels or sunken areas. The Italian word intaglio (in-tal-yo) means engraved or cut in. Intaglio refers to a method of printing whose image carrier consists of lines or dots recessed below the surface. Intaglio reproduces an original design by pressing paper into the recesses. The first intaglio plate was used for printing in Germany in 1446 about the same time as Gutenberg. Unfortunately, the intaglio process was not compatible with Gutenberg’s letterpress, so it wasn’t adopted by early printers. The modern gravure printing press resulted from the invention of photography and the adoption of rotary printing from cylinders. William Henry Fox Talbot invented the halftone screen in 1860, as a method of breaking up continuous tone images into a series of discrete dots. This method is used to reproduce photographic images in all printing processes. Auguste Godchaux received a patent for a reel-fed rotary gravure perfector press in 1860. This press was still in use in 1940. The process was refined by the German Karl Klic (Klietsch) and the Englishman Samuel Fawcett. Klic and Fawcett didn’t have patents on their process, so they tried to keep the process secret. They sold prints
Gravure can produce very high quality multicolor printing on a variety of substrates. Its success results from the simplicity of the process. Having fewer variables to control ensures consistent print quality throughout a run. Each print unit has 4 basic components; an engraved cylinder, the ink fountain, the doctor blade and the impression roller. Gravure transfers ink from small wells or cells that are engraved into the surface of the cylinder. This is illustrated in the figure below. The cylinder rotates through a fountain of ink. The ink is wiped from the surface by a doctor blade. The cup-like shape of each cell holds the ink in place as the cylinder turns past the doctor blade\(^{15}\).

\[\text{Figure 7: Rotogravure Printing}\^{15}\]
The formation of nearly perfect cells or wells is accomplished by the gravure engraver. The gravure cell is characterized by 4 variables; depth, bottom, opening and bridge. The depth of the cell is measured from the bottom of the cell to the cylinder surface. The opening is described by shape and cross sectional area. The bridge is the surface of the cylinder between cells. The doctor blade rides along the cell bridges or ridges (also called walls).

**Water Based Ink System**

Water based inks can be used for conventional printing by either the flexographic or gravure process as well as inkjet. A water based ink contains a pigment, a dispersant for dispersing the pigment, a water-soluble organic solvent, a resin, surfactant, water, and other additives such as defoamer. The dispersant used is at least one compound selected from a molecule having a hydrophilic part and a hydrophobic part. The chemistry of oligomeric dispersant is such that the hydrophilic group can interact with the water molecules, soluble solvent, and anchoring group capable of interacting with the pigment. The composition of the ink must provide good printing properties, water fastness, light fastness and storage stability. Water based inks, while being more environmentally sound in that there is little need for petroleum-based solvents in the printing process, have several problems associated with their usage. The most noticeable of these is the significant increase in chemical additives required. Water based inks require increased energy for drying and there are occasional difficulties in controlling the amount of ink spread. For conventional printing paper curl and shutting down of presses for short periods of time for more
frequent cleaning all contribute to the difficulties in using these inks. Another
disadvantage is that dried ink on the press and rollers can be very difficult to remove.

Two entirely different types of ink are used in the inkjet printers: one is slow
and penetrating and takes about ten seconds to dry, and other is a fast drying ink that
dries about 100 times faster. Theses inks are available in both solvent-based and
water based systems. Most industrial and wide format applications use solvent-based
while home office printers are almost exclusively water-based. As more and more
inks are mixed for high graphic color printing, the need for the inks to dry as quickly
as possible to avoid bleeding increases.\textsuperscript{16}

As mentioned, the ink used in desktop inkjet technology is water-based. The
composition of water based inks is summarized in Table 1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deionized water</td>
<td>Aqueous carrier medium</td>
<td>60 to 90</td>
</tr>
<tr>
<td>Water-soluble solvent</td>
<td>Humectant, Viscosity control</td>
<td>0.5 to 30</td>
</tr>
<tr>
<td>Dye or pigment</td>
<td>Provides color</td>
<td>1 to 10</td>
</tr>
<tr>
<td>Surfactant</td>
<td>Wetting, penetration</td>
<td>0.1 to 10</td>
</tr>
<tr>
<td>Biocide</td>
<td>Prevents biological growth</td>
<td>0.05 to 1</td>
</tr>
<tr>
<td>Buffer</td>
<td>Controls pH of ink</td>
<td>0.1 to 0.5</td>
</tr>
<tr>
<td>Other additives</td>
<td>Chelating agents, defoamer, solubilizer, etc</td>
<td>Less than 1</td>
</tr>
<tr>
<td>Resins</td>
<td>Film formation</td>
<td>1 to 2</td>
</tr>
</tbody>
</table>

Table 1: Composition of Water-based Ink\textsuperscript{16}
One of the major goals of inkjet manufacturers is to develop the ability to print on almost any media. The secret to this is ink chemistry, and most inkjet manufacturers will protect their formulas. Companies like Hewlett-Packard, Canon and Epson invest large sums of money in research to make continual advancements in ink pigments, quality of light fastness and water fastness, and suitability for printing on a wide variety of media.

For practical use of inkjet printing, the most important factor is high reliability. Ink must satisfy a variety of requirements in current drop on demand type inkjet printers with multiple nozzle arrangements. The list of important properties is below:

1) Ink composition that does cause nozzle clogging.
2) Long shelf life without causing bleeding.
3) Ink must not have any chemical effect on nozzles of the printer.
4) Printing must be acceptable on plain paper.
5) Ink must be water resistant and weather proof.
6) Ink must produce high quality printing on selected substrates.

Water based inks are capable of receiving various additives that assist ink drying, ink hold out, ink lay down and printability on various substrates. For conventional printing the press crew uses these additives in different ratios and formulas depending on the desired finished product. Complete water based ink systems do not have the vapor recovery concerns that the alcohol and solvent-based
ink systems have. This is a strong consideration in selecting water based ink systems.\textsuperscript{16}

**Chemistry of Foam**

The science of "Foam" seems simple but is actually a very complicated and well-studied chemical concept because of its importance to several processes including the manufacture of plastics, glass and certain food products.

Foam is the dispersion of gas as bubbles in a liquid. It is the result of a heterogeneous 2-phase system: a liquid phase and a gas phase. Foams are produced only in systems possessing the proper combination of interfacial tension, viscosities, volatility, and composition. The most important factor to foam stability is interfacial tension. The force keeping the chemicals separated is the interfacial tension. Associators (specifically surfactants) lower interfacial tensions by making dissimilar chemicals more compatible. Consequently, associators can stabilize foam. Foam is distinguished by two characteristics: volume and longevity. The volume of foam is dependent on the volume of the gas phase and solution. Ultimately, volume is driven by the quantity of air successfully incorporated into the solution. The longevity (or stability) of the foam is dependent on the size of the bubbles. The smaller the bubbles, the lower the interface tension and hence the more stable the foam and the longer it lasts. The larger the bubbles, the higher the interfacial tension and the more unstable the foam and the quicker it collapses.\textsuperscript{17}

Foaming agents, emulsifiers, and dispersants are surfactants which suspend respectively, a gas, an immiscible liquid, or a solid in water or some other liquid. A surfactant is an amphiphilic molecule that consists of a hydrophobic (water hating)
and a hydrophilic (water loving) part. This opposing hydrophobicity gives rise to a wide range of properties that include foaming, emulsification, wetting, adsorption, micellisation, etc. These properties can be grouped into three general properties (i.e. self-assembly, adsorption, and the formation of mesophases). Surfactants are ionic, non-ionic or zwitterionic. They are commonly used to make products such as soap, detergent, shampoo, shaving cream, toothpaste, cosmetics and ointments\textsuperscript{18}.

Self-assembly

When surfactant molecules are dispersed in water they dissolve until they reach the critical micelle concentration (CMC). At the CMC the surfactants aggregate together to form a micelle where the hydrophobic tails are protected from the water by the hydrophilic part of the molecule. The process is known as self-assembly. Micelles are spherical, cylindrical or planar.

Adsorption

Surfactants adsorb to surfaces. This is probably their most important property and is used in almost all of the industries that use surfactants. They adsorb at the solid-solution interface, at the air-solution interface and at the liquid-liquid interface. Some common examples of this in the home are shaving cream (surfactant at the air-solution interface) and ointment (which is really oil emulsified in water with the surfactants keeping it all together).

Mesophases

Surfactants form liquid crystals at high enough concentrations. The most common are cubic phases, hexagonal phases and lamellar phases where the
surfactants form strange microscopic structures that have a stunning affect on the macroscopic behavior of the system.

Foaming Agents

Chemical foaming agents considered for this thesis are:

a) “HYDROCEROL” chemical foaming and nucleating agent by Clariant Company

b) “CELOGEN” foaming agent by Uniroyal Chemicals

c) Detergent composition comprising acrylic acid-based polymer and amino tricarboxylic acid-based compounds.

d) Sodium salts of fatty acids.

HYDROCEROL is a chemical foaming agent by Clariant Company. This may be the best foaming agent because it is a foaming agent that has thermoplastic properties and decomposes at higher temperatures to form various gases that expand thermoplastics, resulting in a fine cellular structure. Hydrocerol is used as a foaming agent in thermoplastic resins for the following reasons:

- Weight reduction
- Raw material savings
- Thermal and acoustic insulations
- Elimination of warpage and sink marks
- Increase in wall stiffness
- Surface textures
The second foaming agent to be considered is CELOGEN, a foaming agent that is generally used for density reductions of up to 50% in rigid PVC and polystyrene. CELOGEN is currently being used in conventional free-foam extrusion and the celuka or inward foaming process. The celuka process used for producing rigid PVC and foam profiles was originally developed and patented by Ugine Kuhlman of France. This process utilizes a die with an internal torpedo or mandrel. The die is directly connected to a shipping/calibrating device that immediately begins to cool the profile as it moves from the die. The presence of the torpedo in the die causes foaming to occur in the inward direction towards the core after the melt passes around the torpedo. Combined with the cooling provided by the shaping device, this leads to a thicker, well-defined foam skin. These processes are generally thicker in cross section than free foam products and have more shiny skins. Their greater thicknesses provide higher rigidity.

Foam extrusion involves mixing the appropriate CELOGEN products with the resin, and extruding this blend using process conditions somewhat different than those used with unfoamed material. The techniques used to produce expanded plastics, although different, do apply to essentially all combinations of polymer and foaming agent.
CHAPTER III

PROBLEM STATEMENT

In this thesis the aim is to develop a water based ink system for Braille printing. To create a Braille printed image on the surface of the paper, a three-dimensional image on the surface of the paper needs to be created. A three-dimensional image is essential because images and text are interpreted by feel of the fingers. The three-dimensional images are used not only for language information but also image information such as a map, etc., and are indispensable for a blind person. Past work has shown this to be possible using a forming toner, which contains a binder resin and foaming agent. To prevent the collapse of the raised toner image, it was found that the foaming agent should react in such a manner that it is not substantially exposed to the surface of the toner. Microcapsule particles containing a low-boiling point substance such as isobutene, and having a shell material of the microcapsule shell made from vinylidene chloride and acrylonitrile were found to work well. An image forming toner was successfully created using an ordinary electro photographic copying machine to create a three-dimensional image with sufficient thickness for recognition as Braille types and of good adhesion to plain paper.

A study of recent patent by Thermotek Inc. shows that Braille printing is possible in two-steps using inkjet printing. This method creates a Braille image on the paper surface using a forming toner, which contains thermoexpansive cell particles and binder. The image or text is first printed on special paper with an inkjet printer by usual means. The printed sheet is then conveyed into a toner bath where the toner
particles adhere to the wetted imaged areas. The un-adhered toner in the non-imaged areas is then lightly shaken off the sheet and the paper dried at high temperatures to expand and fuse the toner particles to the sheet. The main problem occurring in the Braille printed image by using inkjet printing is generation of raised dots. In Braille printing a three dimensional image on the surface of the paper will be created through a forming toner and some expanding cell particles, which will contain at least a binder resin and a foaming agent in such a manner that the foaming agent is not substantially exposed to the surface of the toner. By adding water-soluble foaming agents into the ink along with precipitating materials that expand to form a raised image, necessity of sprinkling the wetted ink with the expanding powder can be eliminated. This process can also be improved by using surface tension and viscosity modifiers, which control the shape of ink droplets exiting the nozzle, as well as how the ink flows on the medium. This foaming agent will foam under heating, thus it will not be practical to use with a thermal inkjet printer. Instead, a piezo printer will be better used. Water-based inks will be used in this project because they are more appropriate for use in the home/office environment. Similar water-based formulations may be used to print Braille with impact printing method such as screen printing, gravure or flexography.
CHAPTER IV

EXPERIMENTAL PLAN

Materials and Chemicals

Polyvinylacetate binder (PVAC), Aldrich Chemical Company

$\text{AL(OH)}_3$, Aldrich Chemical Company

Kaolin, Hydrocarb 60, Huber Corporation

Hydroxyethylcellulose (HEC), Aldrich Chemical Company

$(\text{NH}_4)_2\text{HPO}_4$ and thiourea, Aldrich Chemical Company

Silica, Aldrich Chemical Company

Carnuba wax, Michem Wax Company

Diazoaminobenzene or Azodicarbonamide, Aldrich Chemical Company

Urea, Aldrich Chemical Company

Resins, Johnson Polymers

Hydrocerol (Foaming agent), Clariant Paper Chemicals

Lecithin Oil (emulsifier), Central Soya Company

Substrates

Special coated paper supplied by Dearfield Paper Company with a Parker Printsurf roughness value of 1.4 microns, paperboard with a Parker Printsurf roughness value of 0.89 microns and glass plate.

Preparation of Ink Formulation

The formulations were prepared at different percentage of total solids. The pigment slurry was prepared by dispersing pigments in water with a high shear Cowles
disperser. After dispersing the pigments, all the required chemicals were added slowly into the coating slurry, while still agitating the solution. After 30 minutes of mild mixing, the formulation was ready for testing on a paper sample.

**Method of Application**

The ink formulations were applied with a very thin pipette to different substrates respectively. The volume of the drop was in a range of 50-100 micro liters. The sample were dried in an oven and under an IR dryer at 130 °C. During drying the ink droplet was observed to produce an acceptable Braille dots.

**Measurement of Dot Geometry**

Contact angle and height of Braille dots were measured using a First Ten Angstrom dynamic contact angle instrument. The change in height was measured with time by taking a video image of the dots/dried with a hot air gun, as it was difficult to dry the sample using an oven or IR dryer during making a movie of the sample.
CHAPTER V
RESULTS AND DISCUSSIONS

The study was initiated using the water-based ink formulation parameters outlined in Table 2.

Table 2: Starting Water Based Ink Formulation.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>% wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyvinylacetate binder (PVAC), Aldrich Chemical Company</td>
<td>5-15</td>
</tr>
<tr>
<td>AL(OH)₃, Aldrich Chemical Company</td>
<td>10-40</td>
</tr>
<tr>
<td>Kaolin, Hydrocarb 60, Huber Corporation</td>
<td>60-90</td>
</tr>
<tr>
<td>Hydroxyethylcellulose (HEC), Aldrich Chemical Company</td>
<td>1-1.5</td>
</tr>
<tr>
<td>(NH₄)₂HPO₄ and thiourea, Aldrich Chemical Company</td>
<td>0.2-2.0</td>
</tr>
</tbody>
</table>

The formulations were prepared at 30%, 40%, 50%, 60% and 70% total solids. The pigments were prepared by dispersing kaolin and aluminum hydroxide in water with a high shear Cowles disperser. The pigments were dispersed at 90:10 kaolin to aluminum hydroxide ratio to obtain a pigment dispersion of 60% solids. After dispersing the pigments, 1.5% wt. of HEC, 1% wt. of (NH₄)₂HPO₄ and 0.5% on wt. of dry solids of thiourea were added slowly to the coating slurry, while still agitating the solution. Finally, 10% wt of PVAC added to the coating slurry. After 30 minutes of mild mixing, the formulation was ready for testing on a paper sample. The ink formulation was applied with a very thin pipette to a paper sample and the sample dried in an oven at 130 °C. During drying, the ink droplet was observed to determine if sufficient foaming agent and pigment was added to produce an acceptable Braille
dots. An acceptable dot was required to have good rise and stability. The process was then repeated adjusting the solids level of the coatings to determine the influence of solids on the height and stability of the Braille dots. Due to the lack of success of being able to form a sufficiently raised dot on the paper surface, adjustments were made to the formulation to alter the ratio of kaolin to aluminum hydroxide. The ratio was altered from 90:10 to 80:20 to increase the packing fraction and entrap more gas in the smaller void spaces. Again the solids of the formulation were adjusted from 30-70% solids. The ink formulations were again tested on paper, without success. Similar approaches were taken, altering the kaolin to aluminum hydroxide from 80:20 to 75:25 to 60:40 ratios, but failed to produce an acceptable Braille dot. The cause of the failure was believed to be due to the lack of sufficient blowing agent in the formulation to release enough gas during drying to sufficiently raise the ink droplet. Another possibility was that the particle sizes of the pigments being used were too large. Assuming that the particle size was causing the problem, it was decided that use of a pigment with small particle size, i.e. very fine silica would be more appropriate rather than using kaolin, which has bigger particle size. A new formula was proposed on the basis of a new pigment as shown in Table 3.

Table 3. Silica Based Ink Formulation

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>% wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVAC, Aldrich Chemical Company</td>
<td>5-15</td>
</tr>
<tr>
<td>Silica, Aldrich Chemical Company</td>
<td>50-90</td>
</tr>
<tr>
<td>Hydroxyethylcellulose, Aldrich Chemical Company</td>
<td>1-1.5</td>
</tr>
<tr>
<td>(NH₄)₂HPO₄ and thiourea, Aldrich Chemical Company</td>
<td>0.2-2.0</td>
</tr>
</tbody>
</table>
The formulations were prepared as before using silica as the pigment at 30%, 40%, 50%, 60% and 70% total solids levels. All coatings were prepared by varying the percentage of blowing agents in the formulation. After 30 minutes of mixing, all formulations were tested on a paper sample. The ink formulations were applied with a very thin pipette to a paper sample and the sample dried in an oven at 130 °C to observe, if sufficient blowing agent was added to produce an acceptable Braille dots. Again, all formulations failed to produce an acceptable Braille dot on the surface of paper. The possible cause of the failure of all these formulations was the generation of foam during preparation of the formulations. This was caused by the instability of the foaming agent to heat generated during the shearing process. Although, shearing the mixture in a temperature controlled vessel was considered, this would not be practical for commercial application, so this formulation was abandoned. After failure of all the above formulations and reviewing the noted observations, a new formulation was proposed. The decision was made to abandon the ink jet approach and try a hot melt ink formulation. Hot-melt printing involves applying heat and/or pressure to transfer ink, solid at room temperature, to a target substrate in a discrete pattern to create an image liquid in the moment of printing. The process can use either impact methods, such as hot-stamp printing, or non-impact methods, such as thermal transfer or hot stick printing. Conventional hot melt inks that are used in a heat transfer layer of a thermal transfer recording material are composed from 4 main components. Also, an ink binder comprising a wax with a melting point in the range of 50°C to 90°C is a necessary constituent in a hot melt ink formulation.
1. Wax
2. Blowing agent
3. Activator
4. Resin

The hot melt ink consists of a semi crystalline vehicle, composed of resins, waxes, and optionally, low molecular weight components like higher fatty acids or higher alcohols. Stearic acid and/or lauric acid and their hydroxylated derivatives can be selected as higher fatty acids and stearyl alcohol and/or 12-hydroxystearic acids can be chosen as higher alcohols. These vehicles, when solidified, form large spherulitic structures. Control of the spherulite size during solidification is very critical for the image quality and durability. Large spherulites lead to hazy and brittle prints. The spherulite size should be the same order as the wavelength of the visible light. Vehicles must give homogeneous dispersion of pigments or dyes, good flow properties, sharp melt/solidification properties, ink transparency, negligible sublimation of material, competitive cost, good edge definition and dot size, abrasion resistant images on thermoplastic materials. Vehicles that could be commercially viable include solid waxed base carriers. Melt onset starts around 60 °C and melting point maximum is at 6-8 degrees more. A very sharp melting point can be achieved, which, if desired, can be manipulated within a small temperature range. Since they are totally solvent free, such vehicles have an advantage over existing conventional ink bases. Hot melt vehicles is especially suitable for dyes with a highly oleophilic character. Waxes are another very important component of hot melt inks. They can be
used alone or in the form of a mixture of two or more waxes, and should be contained in the ink composition in an amount ranging from 5 to 95% by weight as the total weight of the wax component. If the wax component is less than 5% by weight, properties of other additives may dominate and hence the ink composition may have a higher or intermediate melting point, which will tend to make the ink composition not melt sharply at ink jetting temperature. If the wax is more than 95% by weight, the ink composition may have an insufficient melt viscosity, so that it may adhere to printing substrate with difficulty. Waxes are usually selected from the family of petroleum waxes, synthetic hydrocarbon waxes, higher fatty acids, higher alcohols, and their derivatives, modified waxes with primarily or secondary hydroxyl group, grafted with allyl alcohol or alkoxylated. Natural plant can also be used. Petroleum waxes consists of paraffin wax and microcrystalline wax. The most important synthetic hydrocarbon waxes are a polyethylene wax and a Fisher-Tropsch wax. The main representatives of plant waxes are candelilla wax and carnuba wax.

It is possible to formulate a hot melt ink that has a good print quality, has superior transparency, adhesion and heat resistance, and can form sharp colors most suited for the hot melt inkjet recording. Polymers used ink phase change or hot melt inks generally have melting points in the range of about 60°C to 140°C. The polymer should be thermally stable in a molten state, so that gaseous products are not generated or deposited on the printer device. Two or more polymers can be combined to bring special properties of each one. To be able to combine otherwise non-compatible polymers, these are chemically reacted to form hybrid polymers to achieve specific printer, substrate or end-use requirements. This allows the unique
property enhancing attributes of two incompatible polymers to be exploited in the same ink composition. Hybrid polymers can be used as a sole polymer of the ink formulation or in a combination with other polymers, including other hybrid polymers. Examples of suitable polymers for ink compositions include, but are not limited to, one or more of the following: alkyd resins; amides; acrylic polymers; benzoate esters; citrate plasticizers; cumarone-indene resins; dimer fatty acids; epoxy resins; fatty acids; ketone resins; maleate plasticizers; long chain alcohols; olefin resins; petroleum resins; phenolic resins; phthalate plasticizers; polyesters; polyvinyl alcohol resins; rosins; styrene resins; sulfones; sulfonamides; terpene resins; urethanes; vinyl resins. The structure of cellular gas-filled polymers can be formed using two possible ways. Either by foaming a polymer system, by introducing gas-filled microspheres into a system, or by extracting material by a post-treatment which results in the cells or pores formation. The various compounds used for foaming polymers may be classified in several ways. The most general classification scheme is based on the mechanism by which gas is liberated by blowing agents (BAs). Chemical blowing agents are individual compounds or mixtures of compounds that liberate gas as a result of chemical reactions, including thermal decomposition, or as a result of chemical reactions of CBAs or interactions of CBAs with other components of the formulations. Physical blowing agents are compounds that liberate gases as a result of physical processes as evaporation or desorption, at elevated temperatures or reduced pressures. PBAs do not undergo chemical transformation themselves, and most are liquids. It was decided to use an Organic-blowing agent in this formulation; blowing agents of this type have the advantages that, the reaction that
liberates gas is irreversible. Also, the compounds can be used that have the
temperature of maximum gas liberation close to the flow temperature range of the
polymer composition being foamed. In addition, the blowing agents can be mixed
uniformly with the rest of the components. A new formula was proposed and is given
in Table 4 on the basis of the above theory, which satisfies all the above requirements
and it was assumed that this formulation would have sufficient properties to produce
Braille dots with acceptable height on the surface of paper.

Table 4: Hot Melt Ink Formulation

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>% wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carnuba wax, Michem Wax Company</td>
<td>60-80</td>
</tr>
<tr>
<td>Diazoaminobenzene or Azodicarbonamide, Aldrich Chemical Company</td>
<td>5-20</td>
</tr>
<tr>
<td>Urea, Aldrich Chemical Company</td>
<td>5-20</td>
</tr>
<tr>
<td>Resins, Johnson Polymers</td>
<td>5-20</td>
</tr>
</tbody>
</table>

The formulations were prepared at 30%, 40%, 50%, 60% and 70% total solids. The formulations were prepared by melting carnuba wax (60-80%) on a heater with appropriate quantity of wax in the container, keeping in mind that temperature of the heater should not exceed 100 °C. After melting the wax, blowing agent (5-20%) was mixed with melted wax at a temperature below 100 °C. The reaction between wax and blowing agent takes place at around 130 °C. This temperature is achieved during the drying process of the sample, so it can release gas only during the drying phase of the printing process. After mixing the blowing agent with wax solution, an activator and an acrylic polymer were added to the formulations, which are necessary constituents of the hot melt ink formulation. After a few minutes of mixing, the
formulation was ready for testing on paper. The ink formulation was applied with a very thin pipette to a cardboard paper sample and the sample dried in an oven at 130°C to observe if sufficient blowing agent was added to produce an acceptable Braille dot. The process was then repeated adjusting the solids level of the blowing agent to determine the influence of solids on the height of Braille dots. Due to the lack of success of being able to form a sufficiently raised dot on the paper surface, adjustments were made to the formulations to alter the percentage of blowing agent. It was determined that a minimum of 25% blowing agent was needed to create a good Braille dot. Unfortunately, all the dots quickly collapsed after rising and the adhesion of the dots to the surface was poor. The cause of the failure was believed to be due to the poor wetting of the melted wax to the paper sample. The wax spread on the surface, but did not stick. On the basis of the old formulations, a new water based ink formulation was proposed (Table 5), using Hydrocerol as the foaming agent. Hydrocerol was selected based on its ability to decompose at processing temperatures suitable for a modified inkjet and flexographic printing application.

Table 5: Water Based Ink Formulation

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>% wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVAC, Aldrich Chemical Company</td>
<td>5-15</td>
</tr>
<tr>
<td>Clay, Hydrocarb 60, Huber Corporation</td>
<td>50-90</td>
</tr>
<tr>
<td>Hydroxyethylcellulose, Aldrich Chemical Company</td>
<td>1-1.5</td>
</tr>
<tr>
<td>(NH₄)₂HPO₄ and thiourea, Aldrich Chemical Company</td>
<td>0.2-2.0</td>
</tr>
<tr>
<td>Hydrocerol (Foaming agent), Clariant Paper Chemicals</td>
<td>5-25</td>
</tr>
</tbody>
</table>
The formulations were prepared at 30%, 40%, 50%, 60% and 70% total solids. The formulations were prepared by dispersing kaolin in water with a high shear Cowles disperser. After dispersing the clay, HEC, (NH₄)₂HPO₄ and thiourea were added slowly to the coating slurry, while still agitating the solution. Finally, PVAC and foaming agent were added to the coating slurry. After 30 minutes of mixing, the formulation was ready for testing on a paper sample. The ink formulation was applied with a very thin pipette to a glass slide and the sample dried in an oven at 130 °C to observe if sufficient foaming agent was added to produce an acceptable Braille dot. The process was then repeated adjusting the solids level of the foaming agent to determine its influence on dot height. The addition of 25 % foaming agent worked well. Braille dots were created on the surface of the paper during drying phase, but the dots collapsed within a minute and contained unactivated microcapsules at the air/ink film interface. The presence of unactivated microcapsules at the surface was the result of the poor dispersion of the foaming agent. The hydrophobicity of the wax encapsulated particles made it near impossible to disperse the foaming agent. High shear was needed to disperse them, which then, caused them to break. This resulted in the premature foaming of the product and a lot of undesirable foam in the coating. At low shear they floated on the surface. To alleviate this problem, a search was made to find an emulsifier that could provide the desired surface-active property to enable two different substances like oil and water to easily blend together. Lecithin oil supplied by Central Soya Company (Fort Wayne, IN), was found to successfully disperse the Hydrocerol into the aqueous ink formulation. Lecithin is a complex, naturally occurring mixture of phospholipids that most often
comes from soybean oil. Lecithin is a mixture of surface-active agents. Most of the surfactant properties of lecithin can be attributed to the phospholipids. Phospholipids contain a hydrophobic portion with an affinity for fats and oils, and a hydrophilic portion with an affinity for water. The characteristic of blending different substances makes lecithin an invaluable low-cost, functional ingredient in foods, nutritional products, many industrial applications and in animal feeds, too. Lecithin promotes formation of stable oil-in-water and water-in-oil emulsions by reducing the surface tension between immiscible liquids\textsuperscript{31}. Using the lecithin oil as an emulsifier, many formulations were prepared. The best formulation is shown below in Table 6.

Table 6: Oil Based ink Formulation

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>% wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVAC, Aldrich Chemical Company</td>
<td>5</td>
</tr>
<tr>
<td>Clay, Hydrocarb 60, Huber Corporation</td>
<td>50</td>
</tr>
<tr>
<td>(NH\textsubscript{4})\textsubscript{2}HPO\textsubscript{4}, Aldrich Chemical Company</td>
<td>5</td>
</tr>
<tr>
<td>Thiourea, Aldrich Chemical Company</td>
<td>5</td>
</tr>
<tr>
<td>Hydrocerol (Foaming agent), Clariant Paper Chemicals</td>
<td>35</td>
</tr>
<tr>
<td>Lecithin Oil (Emulsifier), Central Soya Company</td>
<td>15</td>
</tr>
</tbody>
</table>

The formulation was prepared at 55% total solids level. The formulations was prepared by mixing the foaming agent (Hydrocerol) in the lecithin oil with slow, mild agitation. A solution of clay was prepared separately at 70% solids. The clay was mixed slowly into the oil/foaming agent paste. The lecithin oil was successfully able to disperse the Hydrocerol into the aqueous solution without premature foaming as
experienced before. After mixing the clay into the paste of foaming agent and lecithin oil (NH$_4$)$_2$HPO$_4$ and thiourea, were added slowly to the formulation, under agitation. Finally, the PVAC was added. After 30 minutes of mixing, the formulation was ready for testing on the paper sample. The pH and viscosity of the formulation was 7.9 and 1480 cp (100 rpm and number 3 spindle). The ink formulation was applied with a very thin pipette to a glass slide and the sample dried in an oven at 130°C to observe, if sufficient foaming agent was added to produce an acceptable Braille dots. The process was then repeated adjusting the solids level of the foaming agent to determine its influence on drop height. Of all the formulations tested, this one showed the most promise. The height of the drop could be varied with the amount of blowing agent added and good drop height was obtained. The heights of the drops were measured using a First Ten Angstrom dynamic contact angle instrument. The change in height was measured with time by taking a video image of the dot as it was dried with a hot air gun. The frames of the video were then analyzed using the instrument software to measure the change in dot height with time.

The dots again failed to be stable. They deflated within 1.5 minutes for most of the samples, indicating that more binder or a different binder is needed to form a tougher film layer. The adhesion of the dot to the glass surface was good. It could not be easily scratched off.

Although few positive results were found, much was learned during the formulation process. The type and amount of foaming agent is key to successfully forming a Braille dot. The best foaming agent found was Hydrocerol. The most distinguishable dots were formed with its use. However, Hydrocerol is nothing more
than sodium carbonate encapsulated in wax, thus, could not be dispersed in water without the aid of an emulsifying agent. Lecithin oil was found to work well with the Hydrocerol. By making a paste of the Hydrocerol in lecithin oil, the foaming agent could be dispersed into the ink formulation. The lecithin oil also acted to protect the Hydrocerol capsules from breaking under mild shear conditions. The Hydrocerol was activated upon heating of the ink droplets on the glass slide. It is believed that the heat from the oven or blow dryer used, caused the wax layer to melt, exposing the sodium carbonate to the free water in the ink formulation. The reaction of the water with the sodium carbonate resulted in the emission of $\text{CO}_2$ gas, resulting in the rise of the ink droplet. The height of the ink drop was found to be dependent on the amount of Hydrocerol added. Figures 8 show the increase in ink drop height with amount of foaming agent. Figures 9 show the increase in ink drop height with time. These results compare well with the measurements performed on the dots created using the two-step inkjet toner process\textsuperscript{32} and also with standard specification of dot height of 0.019 inches. A comparison of the dots produced by both methods is shown in Figure 10. The increases in heights of the dots shown are given in the Figure 11. Figures 12, 13, 14, 15 in the appendices section of the report shows the wetting property of the substrate with time (Dearfield coated paper sample) using two commercially available ink samples. Figures 16, 17, 18, 19 in the appendices section of the report shows the effect of ink drop height of the paper substrate with time (Dearfield coated paper sample) using two commercially available ink samples.
Figure 8: Increase in Ink Drop Height with Amount of Foaming Agent

Figure 9: Increase in Ink Drop Height with Time
Dot Produced by Two Step Process

(a): Dot Height- 0.4812 mm.

Dot Produced by Final Formulation (Table 6)

(b): Drop height- 0.9823 mm.

Figure 10: Comparison of the Dots Produced by Both Methods (At Equal Magnification)
Figure 11: Increase in Ink Drop Height (Pictures at 21, 34, and 71, 79, 104, 116, 129, 145 Seconds Respectively)
CHAPTER VI

CONCLUSIONS

1. Hydrocerol was the best foaming agent found, however use of an emulsifier is required to disperse Hydrocerol in an aqueous medium.

2. By altering the amount of foaming agent in the formulation, the height of the ink drop can be controlled.

3. A rise in ink drop has been observed successfully with time, which means that Braille printing can be done in a single step process, however additional studies are needed to improve the stability of the dots, which deflated with time.
CHAPTER VII

RECOMMENDATIONS

The ability to produce dots of similar or higher height than the two step printing process, without the need of the toner adhesion and shaking step, makes this a much simpler process for impact printing methods such as screen printing, flexography or rotogravure. Although water-based, the large particles of the clay pigment would prevent its use as an inkjet ink printing device. With the foaming agent particles in the 1-2 micron range, the inkjet nozzles would clog. The application of this formulation by conventional printing methods completely depends on the stability of the microencapsulated foaming agent to shear. It is unsure whether the microcapsules would also be able to withstand the shear forces exerted between the nips of a press. Additional studies are needed to improve the stability of the dots formed by the later process. The film forming polymers addition into the formulation will improve stability and body of the dots.
BIBLIOGRAPHY


19. Hydrocerol chemical foaming agents, [www.clariant.masterbatches.com](http://www.clariant.masterbatches.com)

20. CELOGEN Foaming agents and foam extrusion, [www.uniroyalchemical.com](http://www.uniroyalchemical.com)


Figure 12: Contact Angle Measurement of the Paper Substrate with Time using HP Clear Ink

Figure 13: Contact Angle Measurement of the Paper Substrate with Time using Canon Clear Ink
Figure 14: Contact Angle Measurement of the Paper Substrate with Time using HP Black Ink

Figure 15: Contact Angle Measurement of the Paper Substrate with Time using Canon Black Ink
Figure 16: Dot Height Measurement of the Paper Substrate with Time using HP Clear Ink

Figure 17: Dot Height Measurement of the Paper Substrate with Time using Canon Clear Ink
Figure 18: Dot Height Measurement of the Paper Substrate with Time using HP Black Ink

Figure 19: Dot Height Measurement of the Paper Substrate with Time using Canon Black Ink