CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Theoretical Background

2.1.1 Overview of Inkjet Printing

Inkjet printing is currently experiencing tremendous growth. It is a non-impact means of generating images, which involves directing small droplets of ink in rapid succession, under computer control, onto the substrate. There are a number of types of inkjet printing methods. Two of the principal types are the continuous jet method and the impulse or drop-on-demand method, although only the latter is considered here. In this method pressure on the ink is applied to form a droplet when it is needed to form part of the image. An array of nozzles is used to generate the image and the printhead is required to be as close as possible to the substrate surface so as to produce an accurate image.[1]

Inkjet printing requires the use of inks, which meet stringent physical, chemical and environmental criteria. Inkjet printing inks are very low viscosity fluids as is required by the non-impact method of ink delivery. They have a remarkably simple composition consisting of a solvent, almost invariably water and a colorant together with other additives for specific purposes. In contrast to most other printing inks, the colorants used are mainly dyes because pigments, even when an extremely fine particle size is used, have a tendency to block the nozzles. Initially, the dyes used in inkjet printing were water soluble dyes selected from the range of the conventional dyes used in textile application classes, notably from the acid, direct, or reactive dye application classes, or from food dyes, this last group offering the particular advantage of clearly-established non-toxicity.

2.1.2 Principle of Inkjet Printing

A digital printing system for application on textiles is an integration of four components, namely the inkjet head, ink chemistry, media and the color management software. For each component, various technologies and suppliers exist. Based on choices of level of technologies available today, two major types of system, namely the Continuous Inkjet (CIJ) and the Drop-on-Demand (DOD), have emerged. The most important features of the inkjet printer are the printing head and the nozzles. In case of both these technologies, numerous nozzles are used for each color.[2]

2.1.2.1 Continuous Inkjet (CIJ)

In the continuous inkjet system shown in Figure 2-1, ink is forced at high pressure through a small nozzle, from 10 μm to 100 μm in diameter. The emerging stream of ink breaks into small droplets. In the non-stimulated case, the jet stream is allowed to spontaneously form droplets at a non-uniform rate due to the surface tension of the liquid stream. However, this drop formation is usually forced by stimulating the reservoir at high frequency by a piezo transducer. This causes the jet to break up in a regular and controlled manner.[3]

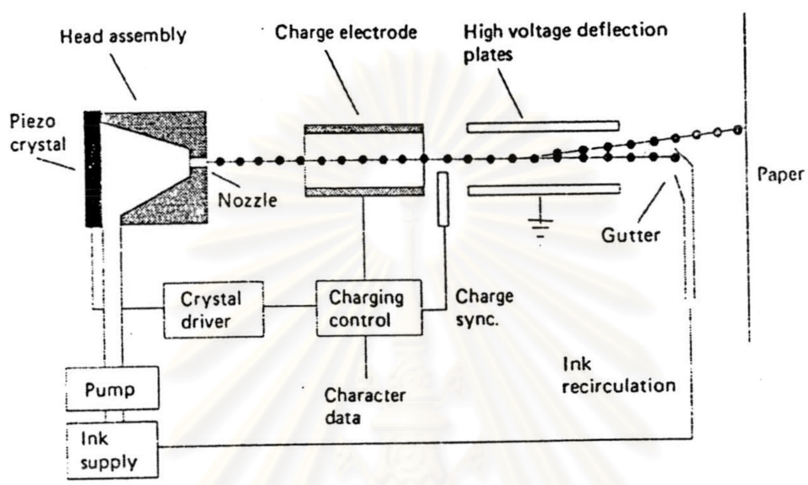

Figure 2-1 Continuous inkjet printhead

After creation, the drops need to be selectively controlled so that images can be formed. Electrical defection of the drops is the most frequently used technique. A variable electric charge is imparted to the drops by placing a charge electrode near the point of jet break up. The charged drops are then defected when they subsequently pass through an electric field created by applying a high voltage between a pair of electrode plates.

2.1.2.2 Drop-On-Demand

The basic concept of drop-on-demand or impulse inkjet printing is to project a drop of ink from an orifice onto the substrate as shown in Figure 2-2. The drop is emitted by means of binary pulse acting on a mechanism, which delivers the energy to produce such drops. In use, a succession of such drops is ejected in response to a succession of drive pulses. The drops are projected onto a substrate to form a predetermined dot matrix. The ink is contained in a chamber: at rest, the forces of hydrostatic pressure cause the ink to form a concave meniscus. One end of the chamber may in the form of a diagram, the other end opening as an orifice. Depending on the manufacturer of the product and the application, the opening may vary from about 40 μm to about 100 μm. An electrical driving pulse acts on the chamber, causing the volume of ink to decrease, thus emitting a drop of ink from the orifice at a relatively high velocity. The frequency at which the drops are emitted varies greatly depending on the manufacturer of the system. However, operating frequencies in general vary in the range of 2-8 kHz. The velocity of the drops usually ranges between 1 and 3 m s^{-1}. Most of the inks used in this technology are water based and have dye as the colorant. The viscosity of these inks varies from about 1 cP up to about 18 cP. [4]

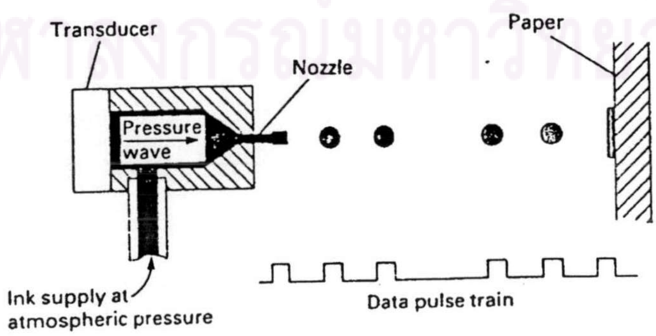

Figure 2-2 Drop-on-demand printhead

2.1.3 Properties of Inkjet Inks

Inks for digital printing require a special control on parameters like viscosity, conductivity, surface tension, chemical stability, physical stability, pH and foam-free properties. Without the color chemistry base and in-formulation technology, the particle size distribution required for such inks is not possible. A further requirement is an ideal combination of ink and substrate. [4]

2.1.3.1 Viscosity

The viscosity of the ink is of primary importance. A humectant such as glycol is the primary constituent that affects this parameter. In an inkjet system, the amount of humectant will affect the degree of crusting caused by dye precipitation. Too much humectant would greatly hinder the flow of ink through a 10 μm nozzle. The drop-on-demand printers require a more viscous ink. This is because, instead of high pressure, the drop-on-demand system uses an acoustic wave, usually produced by a piezoelectric transducer, to emit and propel an ink drop.

2.1.3.2 Specific Gravity

The specific gravity of the fluid is needed to determine the weight of the mass to be propelled (ink drop) for a velocity control, and to determine other physical properties.

2.1.3.3 Surface Tension

Surface tension is one of the primary factors determining where the actual drop will form in continuous inkjet printers. In drop-on-demand printers, it helps to regulate control of the concave meniscus to hold ink in the system. Once the ink has been deposited onto the printing substrate, the interaction of the surface dynamics of both ink and paper plays a major role in how the final form of the dot will appear.

2.1.3.4 Optical Density

The optical density is used in the quantitative evaluation of the contrast of the ink against a known value, that is, the print medium

2.1.3.5 Dielectric Properties

The dielectric properties are also primarily important to the continuous flow plotters. The ink drops must be able to accept an applied voltage that will determine where the drops are to be placed. In the Hertz technology, drops are not required to be part of a character receive charge of 200 V. On their way to the printing medium, they pass through a high voltage field of approximately 2000 V. Because of like charges repel, these droplets are deflected into a waste receptacle. The drops intended to be part of the plate do not receive a charge. Therefore, when they go through the high voltage field, there is no effect on their trajectory, and they become part of a printed character.

2.1.3.6 pH

The pH of the ink is critical for several reasons. First of all, the solubility of the dye is greatly affected by pH. The hue of some dyes will change if they go from a low to high pH value. There must be a correlation between the pH values of the ink and of the printing media; otherwise, the archival quality of the print may deteriorate. For example, the ink is as acidic as the paper is, the resulting highly acidic state will cause degradation of the paper and this the finished print. With a low pH ink, therefore, it is advisable to use a high pH paper.

Another reason for controlling pH of the ink is that the orifice of some inkjet systems may be made of a material that is affected by pH. If this is the case, the pH of the ink should be close to neutral to prevent any corrosion.

2.1.3.7 Tristimulus Values

Quality control specification for colored inkjet inks should include color measurements. This will help to ensure that the color or shade of an ink is consistent from batch to batch. A colorimeter or spectrophotometer can take the values. The Hunter Lab scale is probably the most commonly used. L is related to lightness or darkness of a color, a is related to redness (if a positive value is given) or greenness (if a negative is given), and b is related to yellowness (if a positive value is given) or blueness (if a negative is given).

Another widely used standard is promulgated by International Commission on Illumination (Commission Internationale de l'Eclairage: CIE), the tristimulus values. This system measures color in the CIELAB coordinates L*,a*,b*. When the results of the data are properly interpreted and used as a quality control tool, color consistency of manufactured inks can be assured.

2.1.4 Composition of Pigmented Inkjet Inks

2.1.4.1 Pigment

A wide variety of organic and inorganic pigments, alone or in combination, may be selected to make the ink. The pigment particles are sufficiently small to permit free flow of the ink through the inkjet printing device, especially at the ejecting nozzles that usually have a diameter ranging from 10 μm to 50 μm The particle size also has an influence on the pigment dispersion stability, which is critical throughout the life of the ink. Brownian motion of minute particles will help prevent the particles from flocculation. It is also desirable to use small particles for maximum color strength and gloss. The range of useful particle size is approximately 0.005 μm to 15 μm. Preferably, the pigment particle size should range from 0.005 μm to 5 μm and, most preferably, from 0.005 μm to 10 μm.[4]

2.1.4.2 Dispersant

Dispersants are materials that can bind the pigment with one part of a molecule, while the other is attracted to the vehicle. A dispersant typically coats the pigment particles and then attracts a coating of the vehicle, which allows the coated particles to disperse easily in the vehicle. Clumping and agglomeration of the pigment particles are therefore minimized due to a steric or electro-steric repulsion caused by the protective coverage.

2.1.4.3 Water

The majority of inks used in inkjet printers is water-based inks. Exceptions are the inks used in the hot melt or phase change inkjet systems or solvent inks, which are primarily used in commercial inkjet applications. In water-based inks, the liquid portion of the ink, which is referred to as the vehicle, is mostly comprised of water. Water to be used in the makeup of an ink should be as chemically pure as possible. It should be free of calcium, chlorides, sulfates, and heavy metals or contain only minimum trace amounts. The water should be distilled or deionized.

2.1.4.4 Humectants

Humectants are added to inks for two purposes: first to retard the evaporation of the ink in the printhead, and second to act as a dye solubilizer. Some typical humectants, used either alone or in combination with one another, are diethylene glycol, glycerol, and poly(ethylene glycol). These chemicals belong to a family called poly(hydric alcohols). If the ink undergoes evaporation, several conditions may occur. The viscosity of the fluid may be increased, thus altering the parameters of the ink.

The proper choice of the grade and quantity of the humectant to be used in the formulation is one of the biggest challenges facing the ink chemist. If the quantity is too high, the ink may take too much time to dry on the printed substrate, even on heavily coated papers. If the quantity is decreased, the ink delivery system may fail as a result of orifice clogging. There is a fine line in determining the percentage of humectant added to the ink formulation that will allow maximization of the ink system so that neither type of failure should occur.

2.1.4.5 Bactericides and Fungicides

Organic compounds in the ink are perfect media for the growth of both bacteria and fungi. Once a colony of either organism has become established, it is a possible source of orifice clogging. To prevent this problem, a bactericide and/or a fungicide must be added to the ink formulation.

2.1.4.6 Surfactants

The choice of surfactant is highly dependent on the type of substrate to be printed. The printing speed of inkjet printers is currently limited by the relatively slow rate at which ink penetrates the substrate. The addition of surfactants to inkjet inks permits the ink to wet rapidly into a variety of substrates without introducing potentially toxic and destabilizing additives. The drying time is reduced from about 70 seconds required for non-surfactant containing inks to as little as 5 seconds for inks containing surfactants. Moreover, the addition of surfactants permits inks suitable for high speed printing without the necessity for the addition of relatively large quantities of solvent, which may injure the ink stability, materials of construction of the ink cartridge, or possibly introduce toxicity or flammability.

The surfactant selected for the ink composition needs to be compatible with the other components, particularly the polymer and surfactants have to be of the same type, i.e., anionic or cationic. Non-ionic surfactants can be used with either type of polymer. A concentration of surfactant of about 0.1% to about 10.0% of the total ink composition is effective, with about 0.5% to about 3.0% being preferred.

2.1.5 Pigmented Inkjet Inks for Textiles Printing

Developing inks with proper rheology and fixation properties is a critical factor in the application of jet printing to textiles. Inks must have physical properties suitable for drop formation while being capable of producing sharp, dense and permanent images. Inkjet printing inks also must be chemically stable, compatible with the materials it contacts as well as meet all of the requirements of a specific inkjet printer type. Rheology and conductivity requirements differ between drop-on-demand and continuous inkjet printers. Ink colorants must have the proper affinity for the substrate and have good fastness properties under expected end-use conditions. Some additional properties required for inkjet inks are:[5]

- Steady ejection of a homogenous droplet reproducible in size, speed and direction;
- Ejection in response to a signal with no clogging at any time;
- Fast wetting;
- High concentration;
- Low fluctuation of ink properties with temperature change;
- Long shelf life.

In pigment printing, insoluble pigments, which have no affinity for fiber, are fixed on to the textile with binding agents in the pattern required. This description is perhaps oversimplified, but it does obviously set pigments apart from dyes that are absorbed into the fiber and fixed there as a result of reactions specific to the dye.

Successful pigment printing systems are based upon three equally important components:

- pigment dispersions;
- binder and crosslinking agents;
- thickeners and auxiliary agents giving the required rheology.

2.1.5.1 Pigment Dispersions

Most of the pigments used in textile printing are synthetic organic materials, except for carbon black, titanium dioxide of the rutile and anatase types, copper and aluminium alloys, and sometimes iron oxide and titanium dioxide coated glimmer. When choosing synthetic pigments, the price, the fastness properties, the brilliance and the coloring power of the many products available are taken into consideration.

Among the organic pigments in use, the following types are important:

- azo pigments;
- naphthalene, perylenetetracarboxylic acid, anthraquinone, dioxazine and quinacridone pigments;
- halogenated copper phthalocyanine derivatives.

The chosen pigments are treated in a disintegrator or grinding mill using surfactants. The pigments are treated until they have been reduced to the optimum particle size-in the region of 0.03 μm to 0.5 μm. If the pigment is not fine enough, the prints are dull and gray: a particle size of less than the wavelength of visible light, however, results in a loss of covering power and color intensity.

2.1.5.2 Binder System

The binder film in a pigmented print is a three-dimensional structure, the third dimension of which is of rather less importance than the other two. The binder which is a film forming substance made up of long-chain macromolecules, when applied to the textile together with the pigment, produces a three-dimensionally linked network.

The links are formed during some suitable fixing process, which usually consists of dry heat and change in pH value, bringing about either self-crosslinking or reaction with suitable crossliking agents. The degree of crosslinking should be limited, to prevent the macromolecules becoming too rigidly bonded, thus preserving some extensibility. The important criteria, which ensure that the pigment within the crosslinked binder film is fast to wear and cleaning, are elasticity, cohesion and adhesion to the substrate, resistance to hydrolysis, as little thermoplasticity as possible and absence of swelling in the presence of dry-cleansing solvents. The binder used are all addition polymers, preferably copolymers such as the structure in Figure 2-3

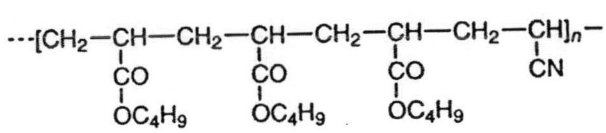

Figure 2-3 Copolymer binder

The technique used is that of emulsion co-polymerization, which leads to a product containing 40-45% binder dispersed in water. These dispersion binders look like milk, are comparatively readily produced, and can be easily transported for use. Moreover, they have the advantage of high concentrations of active binding substances, together with low flammability because they contain no organic solvents. Depending upon the properties required in the binding film (softness, elasticity, plasticity, solvent stability, light and weather fastness), binders can be tailor-made by choosing suitable base products. Typically, unsaturated monomers are used, such as vinyl chloride, dichloroethene, acrylic acid, methacrylic acid, acrylamide, acrylonitrile, acrylic acid esters, vinyl ethers and vinyl esters, styrene and diolefins like butadiene.

The monomers are dispersed using suffient amounts of suitable surfactants, and polymerisation is initiated by means of free radicals originating from redox reactions such as that between potassium persulphate and sodium bisulphite. These are added to the monomers, producing more radicals that also have the capacity to accumulate monomers. As a result of this reaction, macromolecules in a chain form are produced. Their growth is limited either by the combination or disproportionation of two radicals, or by chain transfer to a monomer or to another macromolecule to give branching. The addition of regulating substances can influence, if necessary, the length of the polymer chain, in order to give the required properties to the end product or to prevent premature crosslinking. The size of dispersed polymer particles is determined for the most part by the type and amount of surfactant present during polymerization, and in the case of mechanically stable dispersion the binder particle is in the region of 120-300 nm.

While the prints are being dried, a film is formed from the dispersed binder. Its formation takes place in two stages: flocculation (or coagulation) and coalescence.

During the first stage of film formation, water and surfactants are removed from the binder by absorption and evaporation. The dispersed solid coagulates to form a gel like layer of very tightly packed 'balls', which have only poor solidity and adhesive properties. If the mechanically more stable, more redispersible, dispersion binders are used, these coagulated particles can be brought back to their original form by rubbing them with water.

During the second phase, the gel particles flow together to form a continuous film. The lowest temperature at which a film can be formed depends upon chemical constitution, but for pigment printing it is usually around 5°C. The speed at which the film is formed depends upon the range of particle size. Poly(butyl acrylate), for instance, can form a film at 0°C, whereas the more polar polyacrylonitrile is a very poor film former even at high temperature. For pigment printing, such a film would require to be softened by copolymerization with, for example, butyl acrylate, in a ratio of butly acrylate: acrylonitrile in the range 3:1 to 5:1. The higher the ratio, the softer the film becomes, but at the sane time it becomes more thermoplastic and develops poorer fastness to dry cleaning.

Binder systems for w/o pigment printing have been based on the reaction products of polyols with saturated and unsaturated mono- and di-carboxilic acids, combined with the hydrophobic butyl ethers of urea- or melamine-formaldehyde condensates. More recently, emulsion copolymers based on butadiene have been added to improve the dry-rubbing fastness of the print.

2.1.6 Pigment Dispersion Technique

Dyes, mainly acidic dyes, are used as colorants for inkjet inks, but they are usually inferior in light-fastness and water-resistance. So, especially for industrial application, pigments began to be used. In consumer use, carbon blacks are also used. For inkjet ink application, the dispersions of pigments are required to be excellent in dispersibility and dispersion stability. The dispersion should be stable for more than one year, and particle size of dispersions should be smaller than 100 nm in average to be comparable to dyes in color vividness. Pigments are dispersed in water with dispersants in general procedures, but such dispersions are not always sufficient in dispersibility and dispersion stability.[6]

The main objective of pigment dispersion is to separate clustered particles and keep them permanently isolated from each other.[7] As a general rule, particles are associated in the form of clusters due to their high surface force (high free energy per mass unit). The size of primary or individual particles is generally sufficiently small and thus appropriate for its utilization in industrial process.[8]

The level of dispersion required in inkjet system is determined from the fluidity of ink on the device, and from the storage stability on the market. The fluidity of the ink to optimize the inkjet device is to have the low viscosity and to show a Newtonian flow at the required pigment concentration. The required level of storage stability of the ink is the same as the aqueous pigmented ink.

The principle of finely dispersed pigment particle is to keep the dispersed state in a vehicle such as, smaller particle size, smaller difference of the specific density between pigment and vehicle, and adsorption of the dispersing agent on the surface of the pigment to decrease the excess surface energy.

For dispersing the pigment particles to a required level, for these reasons, it is necessary to select the suitable pigment, dispersing apparatus, and dispersing agent.

Stability of adsorption depends on the selection of the dispersing agent, optimum amount of dispersant, ionic repulsive force effect, steric hindrance effect and stabilization of the dissociated state by controlling the added salts, ions, impurities inside and from outside. These factors affect the sizes of the hydrostatic, and electrostatic radius of the particle in the vehicle. As important as dispersion is, the process of dispersion stabilization, dispersion stabilization is by one of two basic mechanisms, steric stabilization or charge stabilization.

Steric stabilization is usually dominant in solvent-based systems and is achieved through the adsorption of solvated resin onto the pigment surface thereby producing a steric barrier to flocculation. Charge stabilization is the common method of achieving stable dispersions in water-based systems. It involves the adsorption of an ionized species (usually a dispersant) onto the pigment surface. Pigment particles with similar electrical charges will repel each other and thus resist flocculation.[9]

There are many pigment dispersion techniques to overcome the coagulation problem of inkjet ink, such as, polymer dispersion, surfactant dispersion, microencapsulation and surface modification. These techniques have been developed for the next generation inkjet ink, which provides a significant improvement over the existing inks.

2.1.6.1 Microencapsulation Technique

Microencapsulation technique is described by structure of microencapsulated pigments, which have a thick encapsulation of polymer layer containing the pigment particles. Encapsulation polymers were synthesized using automated polymerization reaction apparatus. Dispersions were prepared by means of paint shaker or beads mill. General procedure was as follows:[6]

- Pigment encapsulation polymer (solution of 2-butanone), base (usually sodium hydroxide), and deionized water were pre-mixed.
- The mixture was dispersed by means of dispersing apparatus.
- 2-butanone was distilled off, and diluted hydrochloric acid was added to the dispersion to deposit the polymer on the pigment surface.
- The mixture was filter off, and washed several times by deionized water.
- Base was added to repulse the filter cake. Coarse particle sizes were eliminated from the dispersion by centrifugation.

2.1.6.2 Surface Modification Technique

Many of the inorganic fillers and pigments manufactured for incorporation in paints, plastics, and other organic media are treated with organic reagents to modify the surfaces in the compounding processes. Surface modifications may be used for a variety of reasons that include improvement of the dispersion of the minerals in organic media and modification of the rheology of mineral dispersion. The surface modification dispersion technique is the technique related to chemical bonding and the number of functional groups of the surface of the pigment. The various surface modifying reactions and interactions are such as

- Modification by adsorption of acids, bases, salts and neutral compounds.
- Modification by ion exchange.
- Modification by the adsorption of polymers and the dispersion of minerals.
- Modification by encapsulation polymerization.

Surface modified organic pigments offer great freedom to the inkjet ink formulators or developers by providing dispersions with high surface tension, low viscosity, good solvent compatibility, and excellent colloidal stability.[10,11]

Cabot Corporation progresses the utilized proprietary technology to modify the pigment surface by attaching functional groups. A wide variety of functional groups enable to modify the surface of pigments. A new generation of inkjet colorants has been using its proprietary diazonium chemistry (Figure 2-4) to generate pigments with reactive precursors. The secondary and tertiary reactions of these precursors yield products with both unique and useful properties.

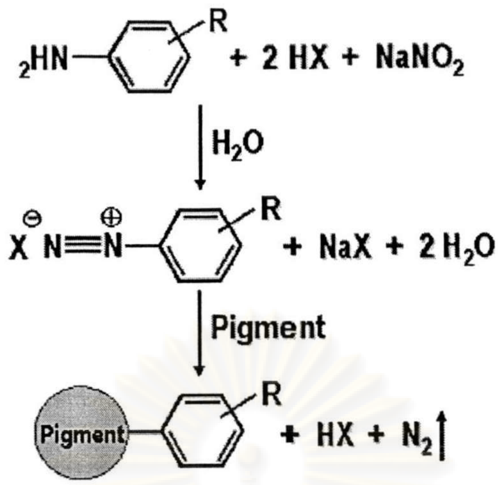

Figure 2-4 Surface treatment via diazonium chemistry

The reactive precursors as a chemical "hook" in order to do secondary and tertiary surface chemistry (Figure 2-5). The reactive group introduces the desired properties. Therefore it is now possible to attach groups that are not compatible with diazonium chemistry. There are many variants to this chemistry, dependent on the initial treatment path such as condensation reactions, coupling reactions, addition elimination reactions, displacement reactions, etc.

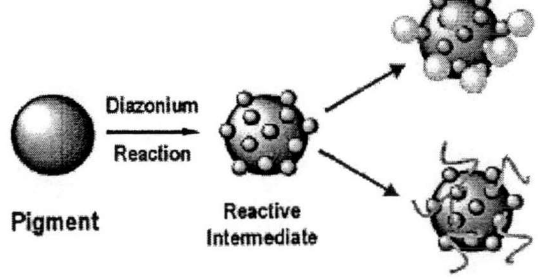

Figure 2-5 Secondary surface chemistry

A preferred reactive precursor group attached, using water based diazonium chemistry is the aminophenyl sulfoethylsulfato group (APSES). This reactive moiety is often used as the active portion of reactive dyes for textile applications. Using APSES as an electrophilic base, it is possible to attach a variety of nucleophilic materials to the surface of the modified colorant. The nucleophile type and level can be varied based on the requirements of the specific application. Dispersions from this class of materials yield inkjet dispersions with improvements in water fastness, smear resistance, rub resistance, and media independent properties.

2.1.7 Silk Fabric

Silk is a natural protein fiber excreted by the moth larva Bombyx mori, better known as the common *silkworm*, The silk is formed by the polymerization of amino acids with the general formula of $NH_2CHRCOOH$, by means of peptide links (-CO-NH-) to give long-chain molecules. Silk is a fine continuous monofilament fiber of high luster and strength and is highly valued as a prestige fiber.[12]

Silk is essentially used in very expensive luxury goods. It has been able to withstand competition from synthetic fibers in many high-quality textile applications because of its excellent dyeing characteristics, high moisture and absorbency, and heat-preserving property. It has one major drawback that it does not blend easily with other fibers.[13]

Physical Properties

Silk fibers are strong, with moderate degrees of recovery from deformation. Silk fibers are moderately stiff and exhibit good to excellence resiliency and recovery from deformation, depending on temperature and humidity conditions. Silk has a specific gravity of 1.25 to 1.30 and a moisture regain of 11% under standard conditions. Silk is soluble in hydrogen bond breaking solvents such as aqueous lithium bromide, phosphoric acid, and cuprammonium solutions. It exhibits good heat insulating properties and is little affected by heat up to 150°C. Silk has moderate electrical resistivity and tend to build up static charges.

Chemical Properties

Silk is slowly attacked by acids but is damaged readily by basic solutions. Strong oxidizing agents such as hydrochloric acid rapidly discolor and dissolve silk, whereas reducing agents have little effect except under extreme conditions. Silk is resistant to attack by biological agents but yellows and loses strength rapidly in sunlight.

End-use Properties

Appearance : The smooth, translucent surface of silk gives it a high luster, while the triangular shape of the fiber provides highlights that cause silk fabrics to sparkle.

Comfort : The hand of silk is usually considered to be the most pleasant of all of the fibers. It is often described as smooth, crisp, soft, and dry. The pleasant hand comes about through a combination of smooth surface, fineness of fiber, and ability to absorb moisture. The smooth, fine yarns do not trap air well and the protein structure of silk allows a high level of moisture absorption and good wicking. Thus, silk garments are comfortable on all but the most hot and humid days.

Maintenance : The smooth surface of silk fibers prevents dirt from attaching itself readily, so silk fabrics do not soil easily. Fibroin is destroyed by strong acid and alkalies, and even weak alkali in long contact with the fiber will cause some damage. Silk fabrics have good dimensional stability and usually will not shrink or stretch. The resiliency of the fiber assures that it will not wrinkle readily. Silk is damaged by high temperatures and will yellowing.

Durability : Silk is a moderately strong fiber with good resistance to abrasion. It decomposes in strong sunlight and when exposed to atmospheric fumes. The sensitivity of silk to perspiration is of greater concern. Silk has a dry tenacity of 2.8 g d^{-1} to 5.2 g d^{-1} and a wet tenacity of 2.5 g d^{-1} to 4.5 g d^{-1}.

2.1.8 CIELAB Color Space

The general use of chromaticity diagrams has been made largely obsolete by the advent of the CIE color spaces: CIELAB and CIELUV. These spaces extend tristimulus colorimetry to three-dimensional spaces with dimensions that approximately correlate with the perceived lightness, chroma, and hue of a stimulus. This is accomplished by incorporating features to account for chromatic adaptation and nonlinear visual responses. The main aim in development of these spaces was to provide uniform practices for the measurement of color differences, something that can not be done reliably in tristimulus or chromaticity spaces.

The CIE 1976 (L* a* b*) color space, abbreviated CIELAB, is defined by Equations (2-1) through (2-5) for tristimulus values normalized to the white that are greater than 0.008856.[14]

$$L^* = 116(Y/Y_n)^{1/3} - 16 \quad (2\text{-}1)$$

$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \quad (2\text{-}2)$$

$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \quad (2\text{-}3)$$

$$C^*_{ab} = \sqrt{(a^{*2} + b^{*2})} \quad (2\text{-}4)$$

$$h_{ab} = \tan^{-1}(b^*/a^*) \quad (2\text{-}5)$$

where

X, Y and Z = the tristimulus values

X_n, Y_n, and Z_n = the tristimulus values of the reference white

$L*$ = lightness

$a*$ = redness-greenness

$b*$ = yellowness-blueness

$C*_{ab}$ = chroma

$h*_{ab}$ = hue

The $L*$, $a*$, and $b*$ coordinates are used to construct a Cartesian color space.

2.1.9 Textile Print Quality

Digital printing on textiles is viewed by many as a key to reviving the competitive edge of the textile printing industry. Digital printing has the potential to shorten the lead-time from design to production, speed up production of samples, and reduce production lot size and hence inventory cost. The leading digital printing technology for textiles today is inkjet printing, and the most notable applications are in proofing and sample production. To achieve this objective, significant improvements are needed in production speed, equipment and operating costs, and print quality.[15]

Print quality in inkjet printing is strongly dependent on the interactions between the ink and the media. In inkjet printing on paper, the significance of ink-media interactions is well recognized and has been extensively researched. Inkjet printing on textiles, however, is a different matter. While the impact on print quality of the fibrous structure of textiles is no surprise, a true understanding of ink-fabric interactions and their effects on print quality remains a wide open field for both academic and industrial research.

Print quality issues in digital printing of textiles fall into several main categories: 1) appearance-related issues including line definition, text quality, resolution, image noise, optical density, tone reproduction and gloss; 2) color-related issues including color gamut, color matching and color registration; 3) permanence issues including lightfastness and water fastness; and 4) usability issues including the presence of defects and "hand". Not surprisingly, many print quality issues are common to both conventional and digital printing techniques. However, digital printing introduces a number of problems of its own, for example, jaggies (digital artifacts in edges), banding (lines of missing color), and satellites (extra drops of ink). Clearly, for digital printing of textiles to advance, significant improvements in print quality must be achieved.

2.2 Literature Reviews

The relationship between polymer structure and ink properties was studied using a multidisciplinary approach. Waterborne styrene acrylic polymers, varying in composition and structure, were used to prepare pigment dispersions and inks. The rheology profiles of the pigment dispersions were measured using an oscillatory viscometer. Polymer solubility parameters were calculated with a molecular modeling program and correlated with the pigment dispersion's rheology and quality characteristics. It was found that oxygen content and molecular weight were the most important factors in pigment dispersion quality and performance for the polymer studied.[16] The application of small particle sized polymer latex systems in inkjet printing on textile substrates. Pigments are incorporated in the latex to give colored inks. The routine of selecting microlatex and nanolatex polymer resin is set up. Particle sizes, surface tension, conductivity and viscosity of selected latices are measured and adjusted to meet the requirements of the printer. The printed substrates are evaluated in four aspects, colorfastness, hand stiffness, comfort and microstructure. The type of resin and ink formulation are optimized and used to develop a pigmented CMYK ink system.[17]

Development of jet inks for use in these processes is challenging for the ink formulator due to restrictions in viscosity, particle size and the need for highly reliable jetting. The jet-inks for textiles using dye-based often require post-treatment to achieve satisfactory levels of fastness to washing. As a further consequence, un-fixed dye may have to be removed by a post-washing process. Furthermore, dye selection may have to be altered from substrate to substrate to achieve sufficient levels of fixation. Resin-pigment printing represents a special challenge for inkjet printing due to the fact that neither resin nor pigment is soluble in water or organic solvents. These two phase systems are subject to problems with high viscosity, particle size instability, agglomeration, shear instability and phase separation. Despite these problems, resin-pigment systems can be formulated, which meet requirements for delivery by inkjet engines and give very acceptable properties on printed fabrics.

Pigmented polymer latices with sub-micron particle size appear to be a promising and cost effective approach to inkjet printing of a wide variety of textile substrates. Very fine particle latices prepared by microemulsion polymerization of acrylate monomers and containing very finely ground and well dispersed pigments are a promising system for use in inkjet printing of textiles. Silk fabric printing is expected to be an early production application of inkjet technology. A variety of silk fabrics have been printed with a continuous inkjet printer using a pigmented ink with sub-micron particle size polymer latex resins. Inks with pigment loading of 5-9% and resin content of 15-20% could be successfully jetted. Bending rigidity, air permeability and fastness properties were obtained on all printed samples. Acrylic resins with glass transition temperatures of -10 to - 20 degrees C gave good fabric hand and acceptable wet and dry crockfastness properties. Surprisingly high solids levels can be successfully inkjetted. Increase in viscosity appears to be the limiting factor in solids level for good drop formation. The use of a good hydrogen bonding, additive, in this case urea, reduces viscosity and decreases the clogging problem in the continuous inkjet recycle line. Good hand and crocking properties were obtained on silk fabrics in a wide range of fabric styles and weights. Inks containing up to 20% solids with resin to pigment ratios of 2.5 or greater gave acceptable printed fabric performance. Resins with Tg value near –15 degrees C would appear to be best for a good balance between hand and crockfastness for use in silk fabric printing. It is anticipated that latices with mixed particle sizes may be capable of giving lower viscosities at higher solid levels. The performance of the printing formulation might also be improved by availability of smaller particle size pigments or pigments with a different particle size distribution.[18]

Establishment of the relationship between the pretreatment and the digital printing quality can be achieved by the use of digital image analysis and optical microscopy. As in the traditional textile printing, miss color, out of fit patterns, mottle and color defects due to poor ink surface coverage can occur in digital printing. Woven and knitted cotton fabrics were treated with pretreatment agents including ingredients like alginate, silicone and silica. Printed patterns were analyzed to quantify the print qualities in terms of color-related issues and appearance-related issues. Results show that the digital textile print quality is strongly influenced by the fabric pretreatment. The print quality was not significant affected by fabric structure, and hydrophilicity of the fabric surfaces. The pretreatment can give cotton fabrics required characteristics of digital printing substrates. The print quality of digitally printed cotton fabrics with the optimum pretreatment was as good as that of the high quality photo paper. This indicates that quality digital printing onto textile fabrics is achievable.[19]

The application demonstrates the automated print quality analysis to research and development of digital printing of textile fabrics. Print quality (PQ) analyses were performed using an automated print quality analysis system to quantify quality attributes including line width, image noise, optical density, tone reproduction and CIELAB color. Wicking tests were also conducted to elucidate the correlation between the observed print quality and the wicking behavior of the fabric structure. As for the main observations, it can be summarized as follows:

1). The subjective, visual quality of inkjet printed cotton fabrics was as good as printed plain paper.

2). A technique using a transmission lighting arrangement was developed to observe the fabric structures more clearly. This technique was shown to allow the fabric structure to be distinguished from the printed image on the surface of the fabric.

3) Several important print quality attributes including line quality, image noise, optical density and color quality were measured using the automated print quality analysis system. The results clearly show the efficacy of using automated print quality analysis on textiles.

4) The effects of several key fabric properties on print quality were studied. These include fabric structure, yarn size, yarn type, and pre-treatment. The test results suggest that the most significant fabric variables be fabric structure, yarn size, and the hydrophilic/hydrophobic nature of the fabric.

5) An image processing technique to enhance the signal-to-noise ratio in textile print quality analysis has been demonstrated. The technique uses a simple averaging method and is found to be very effective for analyzing print quality in fabrics having a repetitive structure. [15]