CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Theoretical background

2.1.1 History of Inkjet Printing

The active history of inkjet printing began when Lord Rayleigh in 1879 began studying regularly disturbed jets of liquid.[1] Since then Richards in 1938, Winston in 1958, Sweet in 1964, and Hertz in 1971 are just a few of the many who have developed certain principles related to inkjet printing. These principles have been further incorporated into products that can place computer-generated data onto media to form an image in either alphanumeric or graphic output, and do it at an extraordinary speed. This process eliminates the need to first mechanically place the data on letterpress or roll. Unlike traditional printing processes inkjet is relatively young. It is also fast emerging as a high technology and a practical solution, well suited for many diverse printing applications within the industrial and office sections. Inkjet is a versatile, non-contact printing technique, which has grown dramatically in popularity over the last ten years. Broadly speaking inkjet technology divides into two distinctive techniques for generating droplets namely, continuous inkjet printing (CIJ) and drop-on-demand printing (DOD).

CIJ is the fastest form and is highly demanding of the properties of an ink for successful operation.

In contrast, DOD printing is characterized by the fact that droplets are only produced when required for printing and, in general, droplets are produced by an ejection mechanism rather than by destabilizing a jet. Several methods are currently in use to do this, including valve-jet, impulse, piezo, thermal and hot-melt printer.[2]

2.1.2 Overview of Inkjet Printing

Ink jet printing can be defined as a fluid control device with specific fluid control parameters. Microscopic ink drops are emitted under pressure from an orifice onto a substrate. The size of an orifice can vary from 10 to about 100 μm depending on the technology used. The color of the output also varies according to the type of printer used. Some printers output in monochrome (black); some have a three-color output, using the primary subtractive colors, magenta, yellow, and cyan; and some printers use the four-color technology, which includes inks in the primary subtractive colors plus a black ink.

Ink jet printer offers quiet operation, high speed, and compatibility with various substrates. The ink jet technology is one of the most fitting for use in the production of color fidelity and fine detail, ink jet technology is the best current candidate for use as a hard copy device.

Table 2-1: Comparison of non-impact printing

Printing technique	Image quality	Print speed	Plain paper	Running cost	Maintenance
Electrophotography	Δ	☆	☆	O	X
Silver halide	☆	X	X	X	Δ
Thermal transfer	X~Δ	X	Δ	Δ	☆
Dye sublimation	☆	X	X	X	☆
Ink jet	X~Δ	Δ	O	O	O
Electrostatic rec.	X~Δ	O	X	Δ	X

X = bad Δ = satisfactory O = good ☆ = best

2.1.3 Inkjet Technologies

Two basic forms of ink jet printers comprise the majority of ink jet printers in the marketplace today. The first is the continuous flow ink jet technology, and the second is the drop-on-demand or impulse ink jet technology. However, both these forms can be further divided into other categories according to the mechanism by which the drops are projected from the orifice onto the printing medium or to the novelty of the ink in its application to the ink jet technology.[1]

1. Continuous Inkjet

    1.1 Binary deflection

    1.2 Multiple deflection

1.3 Hert

1.4 Microdot

2. Drop-on-demand Inkjet

2.1 Thermal (bubble jet)

- Top shooter

- Side shooter

2.2 Piezoelectric

- Squees tube

- Bend mode

- Push mode

- Shear mode

2.3 Electrostatic

2.4 Acoustic

2.1.3.1 Continuous Inkjet Printing

Continuous flow ink jet printing has attracted attention because of its ability to produce color graphics at a relatively high resolution. The continuous flow technology is based on the principle of continuous emission of ink from a high pressure source through a capillary of between 10 and 15 μm. Drops are generated at frequency of 40-45 kHz. The drops travel at about 35 m/s. The ink stream undergoes a charge/no charge condition by binary switching. In certain Hertz technology ink jet printers, individual drops, which are formed when the main steam of ink separates, pass through a high voltage field of approximately 2000 V. Uncharged drops pass through the high voltage field and are deposited on to the substrate to form part of an image. Unwanted drops have a 200 V charge applied to them. When these charged drops pass through the high voltage, they are repelled by the 2000 V electrode and are deflected into a reservoir.

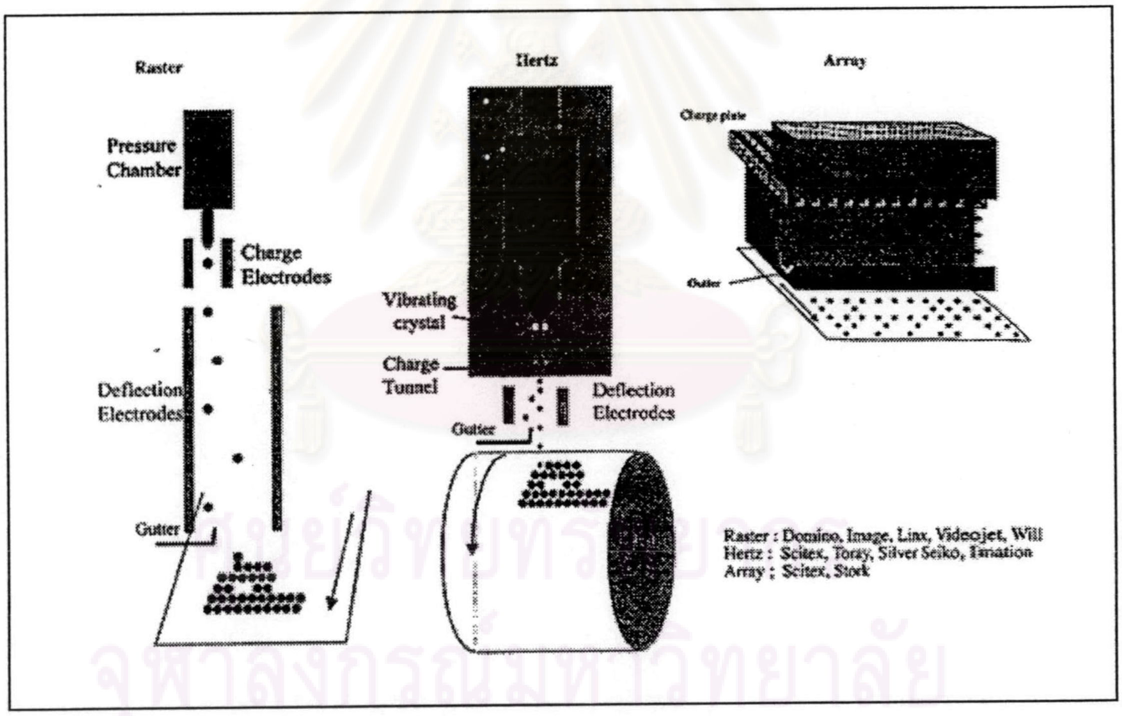

Figure 2-1 Continuous inkjet print head

A print medium is attached onto a rotation drum. The printhead containing the nozzles moves a distance of approximately 0.2 mm per step. The incremental step are regulated by a stepping motor. Depending on the speed of the drum, the number of drops to fill a picture element will vary. With the generation of multiple dots per pixel and the small orifice diameter (10 μm), some continuous flow ink jet printers can print up to 300 dpi. Continuous ink jet printers can be used for a variety of applications: seismic data, business graphics, medical scans, demographic data, and mapping charts.

2.1.3.2 Drop-on-demand Inkjet

The basic concept of drop-on-demand or impulse ink jet printing is to project a drop of ink from an orifice onto a substrate. The drop is emitted by means of binary pulse acting on a mechanism (a diaphragmin some models), which delivers the energy to produce such a drop. In use, a succession of such drops is ejected in respond to a succession of drive pulse. The drops are projected onto a substrate to form a predetermined dot matrix. The ink is contained in a chamber (either a reservoir or the nozzle assembly); at rest, the forces of hydrostatic pressure cause the ink to form a concave meniscus. One end of the chamber may be in the form of a diaphragm, 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. 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.

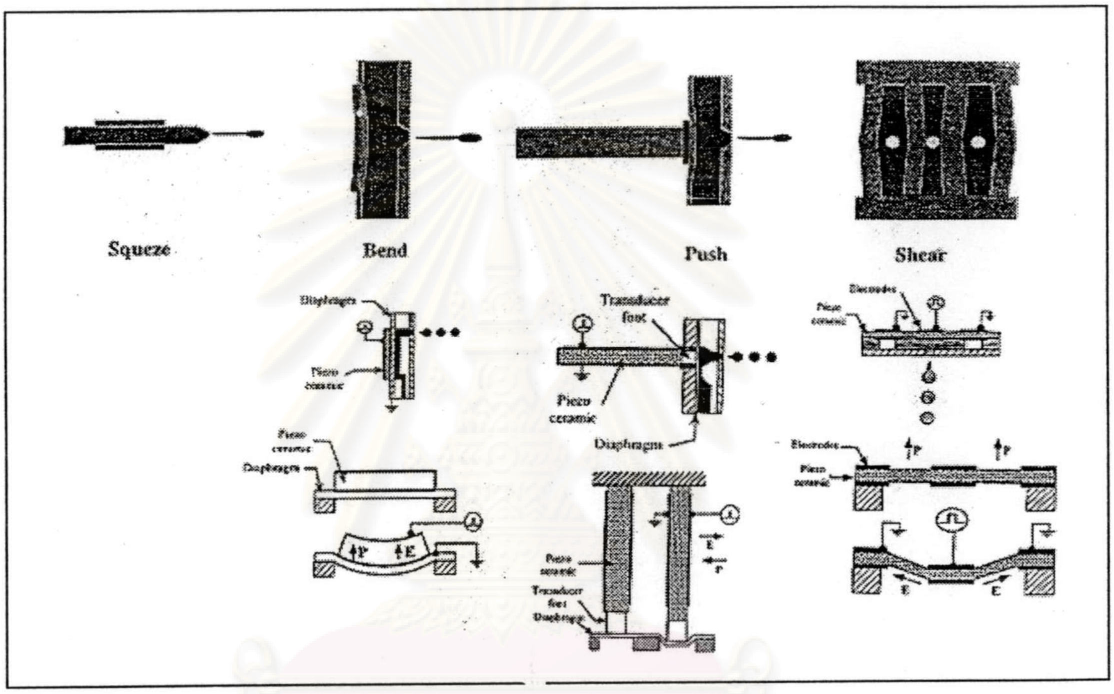

Figure 2-2 Piezo electric mode

Drop on demand printing designs mainly in the mechanism used in the printhead to produce droplets. The main techniques employed commercially include piezo impulse, thermal jet, valve jet and hot melt. The versatility of DOD printing is not as broad as CIJ printing. There are a number of reason including speed, throw distance and ink performance. Speed is many times slower than CIJ and is dependent on the technique used. Throw distance, a term used to describe the distance the drop can be propelled without deterioration to print quality, is much smaller, approximately a millimetre or so compared with over one centimetre with CIJ printing. Although print quality can be superb with some systems ink performance limits the use to printing mainly on absorbent materials

Piezo impulse inkjet is one of the simplest forms of DOD and consists of a printhead with open nozzles and channels. Droplets of ink within the capillary channels are ejected by the action of an oscillating piezo crystal. In the case of thermal inkjet or bubble jet as it is commonly known, the piezo crystal is replaced by a heater element located on the wall of the capillary channel. The heater is activated by an electrical signal, delivering energy to the liquid, creating a bubble which grows rapidly causing a droplet of ink to be displaced from the nozzle.

In valve jet DOD printing a valve is located at the nozzle which seals the ink in the capillary channels. The ink is held under pressure and when the valve is opened via an electrically operated solenoid a large droplet of ink is ejected.

Hot-melt systems, dubbed phase-change systems, have been applied to most systems and more recently introduced commercially in combination with a piezo crystal. Ink is heated within the printhead to a temperature above the melting point of the ink, typically between 100 and 150 ^{o}C and when an electrical pulse is applied to the piezo crystal the wall of the capillary channel deforms to displace a droplet from an open nozzle.

2.1.4 Ink System for Inkjet Printing

The inkjet printing system is becoming popular in the market. There are two varieties of ink in the conventional inkjet ink system. One is water-soluble dye-based ink and the other is pigmented ink.[3] Theses are summerised below as shown in Figure 2-3.

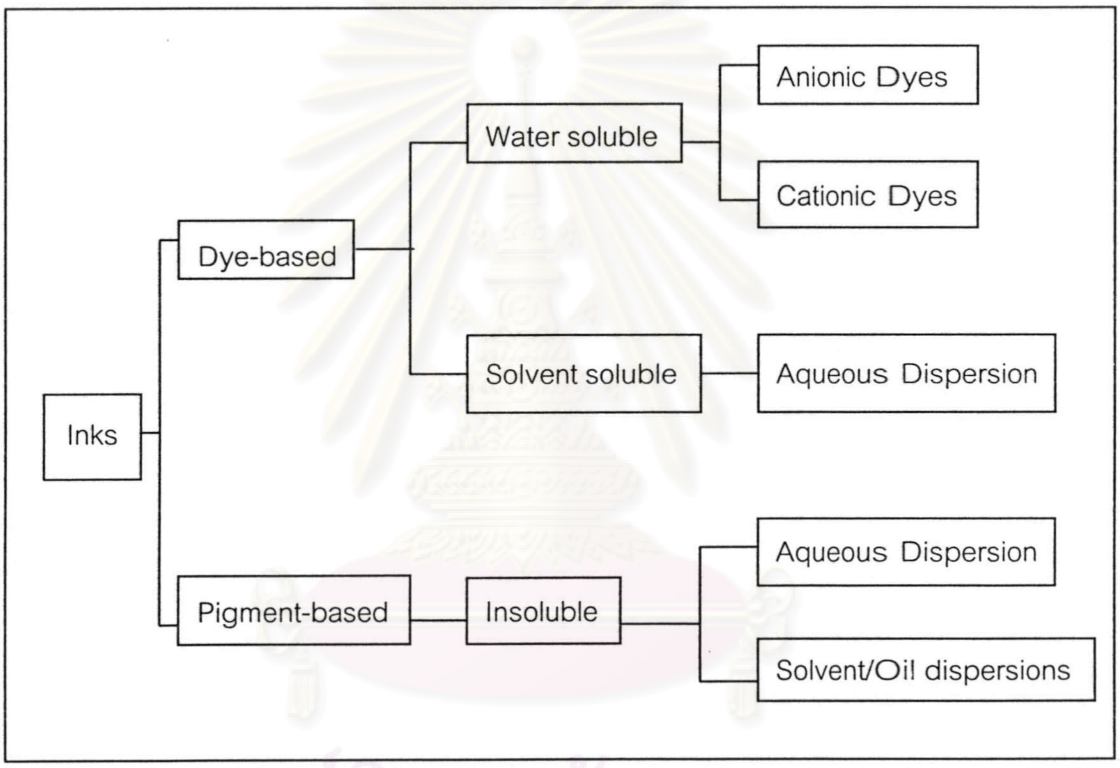

Figure 2-3 Ink system used for inkjet

The first generation of inkjet ink is composed of water-soluble dye. The most serious drawback of this ink is lack of waterfastness on plain paper. Another problem is the difficulties to improve lightfastness from ink composition. Of course water soluble or dispersable lightstabilizers can be used, but these additives slightly protect lightfastness of the dye because when it is printed the relative concentration of these additives changes on the paper. Most current printers contain dye-based systems and the majority of ink systems are aqueous. The dyes are mainly water soluble and anionically charged.

Color pigmented inks, once designed and implemented in a printing system, the inks must do their job. Pigment inks are becoming more popular due to their enhanced durability of such ink systems, then pigment-based inks could become more important for the production of digital images. Very fine particle size, stable dispersions, functional binders, wetting agents are tuned for the substrate intended to be printed upon with dot spread, bleed and film forming properties required in the specific application being addressed. The optimization of color gamut, transparency, UV resistance, hue must be made for the intended use through a careful selection of pigments and both the preparation of their dispersions and the final ink formulation. It provides little benefit to achieve a fine particle dispersion with a durable binder if the pigment particles flocculate on drying or the binder cracks as it dries. Unacceptably poor color gamut will result.

2.1.5 Pigmented Inkjet Inks

When inkjet printers were first introduced almost all the inks were dye-based. Today pigments have many inherent advantages over dyes as inkjet colorants. In printing applications that require permanence properties, such as waterfastness, lightfastness, and rub resistance, pigmented colorants are preferred.

Pigmented inks are normally prepared in a two–step process. In the first step, a mixture of pigment and water is milled or otherwise mechanically sheared in the presence of a dispersant or stabilizer. During this step, the clumps of as-received pigment particles are broken down into their primary particles. The primary particles become coated with the dispersant molecules and are thereby stabilized against re-aggregation and/or setting. The pigment concentrate thus produced is then diluted in a second step to a working strength ink by addition of co-solvents, called humectants, and other addenda, such as surfactants or biocides. Commercially available pigmented inks produced by this method generally result in average particle sizes in the range of 100-200 nm, with particle size distributions often extending to greater than 400 nm. The first requirement of a pigmented ink is that the pigment dispersion is stable over a reasonable range of temperatures and times.

The main objective of pigment dispersion is to separate clustered particles and keep them permanently isolated from each other.[4] 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 utilisation in industrial process.[5]

2.1.5.1 Fine Particle Dispersion of Pigment

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.

Pigment is dispersed by three main processes:

(1) Wetting by which air adsorbed on the surface of the pigment is displaced by vehicle materials,

(2) Fine granulation by which pigment particles aggregated is broken down nearly to their primary size by external friction force and grinding force within the dispersing apparatus,

(3) Stabilization of the pigment particles is achieved by an adsorption of the dispersing agent on their surface.

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.

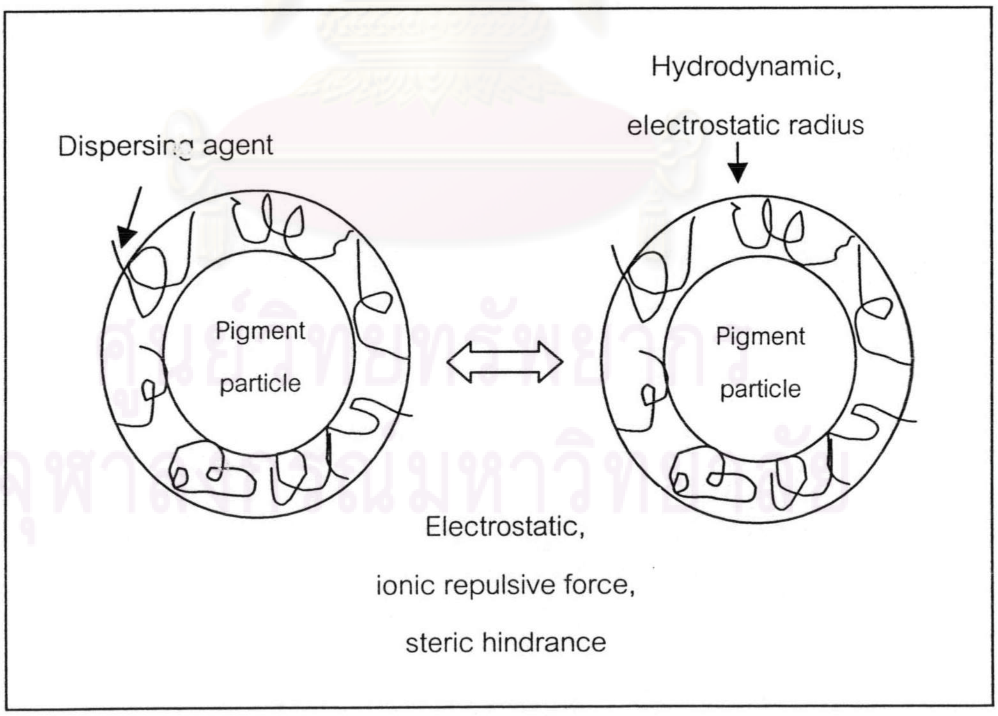

Figure 2-4 Stability of adsorption[6]

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.[7]

2.1.5.2 Dispersion Technologies in Pigmented Ink

The technology of inkjet printing system progressed very rapidly in these several years, but the colorants do not proceed that fast in this decade. There are many pigment dispersion technologies to overcome the coagulation problem of inkjet ink, such as, polymer dispersion, surfactant dispersion, micro-encapsulation and surface modification. These technologies have been developed for the next generation inkjet ink, which provides a significant improvement over the existing inks.

a. Polymer dispersion

The targeted inkjet ink must satisfy all of the following three performances; reliability, print performance, and print durability. Therefore, we have devised a water-based polymer emulsion containing a water insoluble dye or pigment to satisfy the above performances as shown in Figure 2-5.

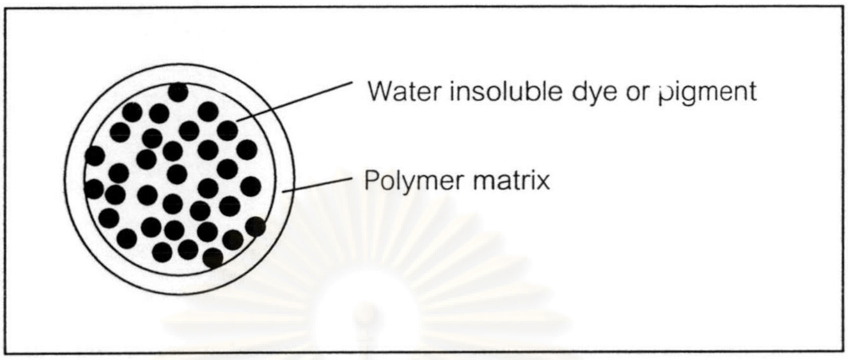

Figure 2-5 Schematic diagram of emulsion colorant

In a dispersion type colorant, dispersion stability is essential for print reliability. Since additives such as biocides, chelating agents, humectants and buffers are added to inkjet ink, the polymer emulsion must be stable to these additives. Generally, electrostatic mechanism and steric mechanism are known to stabilize polymer emulsions. The sterically stabilized emulsion is known to be relatively insensitive to inkjet additives. Therefore, emulsions for inkjet inks were preferably designed to be stabilized by a highly steric effect and a reasonably electrostatic effect. Moreover, dispersion stability relies on particle size and its distribution. Average particle diameter was controlled to be around 100-200 nm and largest particle diameter below 400 nm.[8]

The inkjet colorant made from polymer emulsion containting water soluble dye or pigment exhibits outstanding dispersion stability, excellent heat stability, fine particle size, high compatibility with ink components, low viscosity and controllable surface tension and satisfy all properties to use for inkjet colorant. Pigment-containing emulsion colorant shows good rub resistance compared with the conventional pigment dispersions, which can be applicable to highly durable purposes.

b. Surfactant dispersion

Surfactant molecules consist of structures providing both water-hating, "hydrophobic", and water-loving, "hydrophillic", characteristics built into the same molecule. These hydrophobes effectively displace the water molecules at the surface and give the water more hydrocarbon-like properties. Attached to the organic hydrophobe is the hydrophile- a water soluble segment, often a polyether or acid salt.

Recently, a number of studies have been reported on the stability of aqueous suspensions of pigments in the presence of surfactants, which described that a small amount of surfactant markedly affects the stability of suspension. On the other hand, the effect of surfactants on the flocculation and peptisation of sols and dispersions has been extensively investigated both experimentally and theoretically. The flocculation and redispersion were explained by the twofold layer adsorption mechanism of surfactants. Adsorption of a second layer of surfactant molecules due to Van der Waals attraction force between the hydrocarbon chains is then possible with the ionized groups of the second layer oriented towards solutions. Therefore, when particles have a twofold layer, they attain a highly negative charge which causes repulsion between the particles and consequently stabilization of the suspension results.[9]

Because of the relatively low dielectric constant of all the common organic solvents, the electrostatic stabilization mechanism is not effective. Instead, we must rely upon the so-called "steric stabilization" mechanism. This type of stabilization is generated via the absorption of a layer of surfactant, resin or polymer onto the surface of the pigment particles. When two particles approach each other, and the layers of adsorbed material start to overlap, they effectively repel each other. Steric stabilization can only occur when the polymer chains are very soluble in the continuous phase. In polymer solution theory, the saying "better solubility than Theta Solvent Conditions" is required.[10]

When the pigment dispersion with low molecular weight surfactant, the surfactant is wetting the pigment particles and lowering the interfacial tension, making particle deagglomeratation more favorable. The surfactant also displaces occluded air and allows more intimate pigment/resin contact for maximum efficiency.

c. Micro-encapsulation

Recent improvements of print qualities of inkjet printing are remarkable, and achieved the photo quality. Inkjet printing has been prominent in color printing of consumer use. For industrial application, inkjet printing is used for graphics, signs, labels, textile printing and so on. Because inkjet printing is non-contact printing, it can be thus applicable for various substances.

Dyes, mainly acidic dyes, are used as colorants for inkjet inks, but they are usually inferior in light-fastness and water-resistance. For industrial application, pigments began to be used, especially 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. In the process to develop the pigments which are suitable for water-borne systems, we have found that micro-encapsulation technique is excellent to modify the surfaces of pigments for water-borne systems. These dispersions were very excellent in dispersibility and dispersion stability. Moreover the dispersions showed excellent resistance to water-soluble organic solvents.[11]

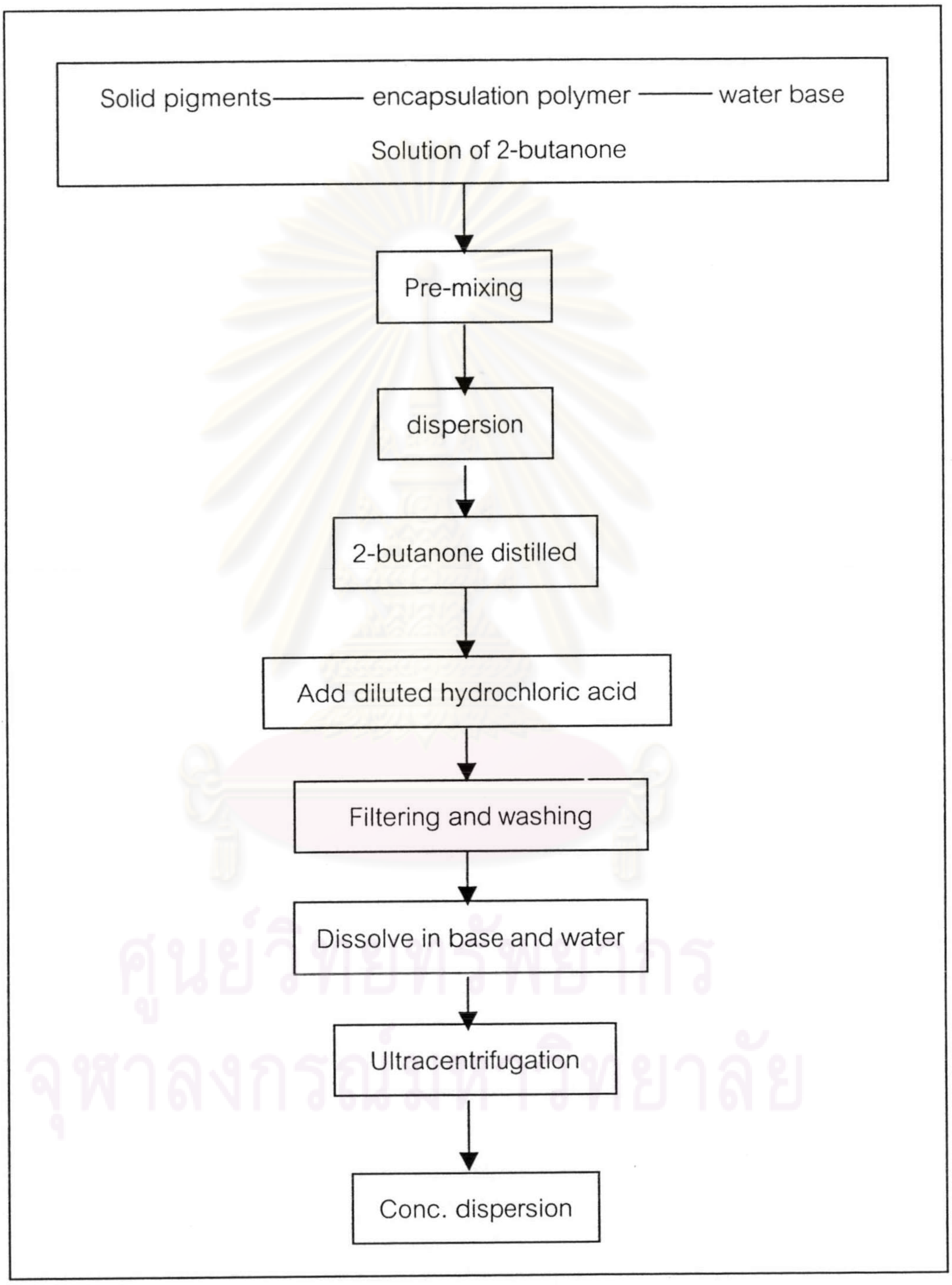

Figure 2-6 Preparation of micro-encapsulation

d. Surface modification

Surface-modified pigments have been developed for industrial inkjet use.[12] Requirements (printer compatibility, print performance, and ink stability) and major concerns will be presented with respect to colorants (dyes and pigments). Inks containing currently-used industrial inkjet dyes and conventional pigments, surface modified pigments are very different from conventional pigments and offer significant advantages over current-used dyes for industrial inkjet use.

Although dyes may be lacking or limited in some property respects, they are the most used colorant of choice because they perform better than "conventional pigments". Conventional pigments are defined as pigments that are stabilized by adsorption of dispersing aids (surfactant or polymer). The dispersant is in a dynamic equilibrium adsorbtion on the pigment surface while also desorbing off the pigment going onto the suspending liquid as shown in Figure 2-7.

Conventionally dispersed pigments containing surfactants or polymer dispersants generally have low surface tension and high viscosity. Ideally the pigment dispersion would have properties much like water, allowing the ink formulator the flexibility to adjust the surface tension and viscosity to the desired level.

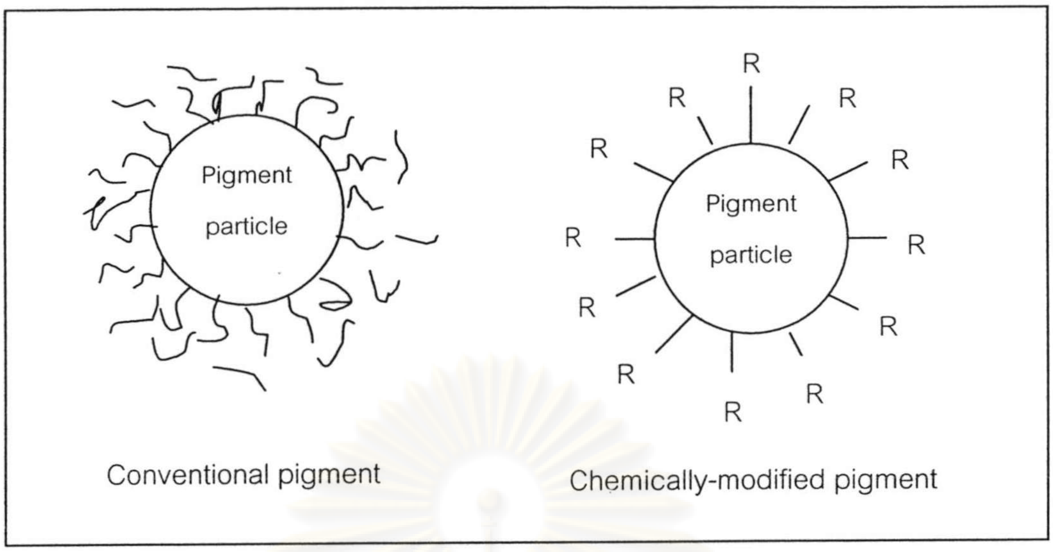

Figure 2-7 Schematic diagram of conventional and surface modified pigments

Conventional pigment dispersions used in traditional printing ink, is generally not used in industrial inkjet systems due to deficiencies which include ink stability, non-uniform jetting characteristic (variety in drop size, large changes in viscosity, foaming or nozzle clogging, etc.) or solidification at the nozzle or in the printer. Inks with conventional pigments can work in an industrial printer, but usually for a very limited time.

Cabot Corporation possesses proprietary surface treatment technology that enables to chemically attach a wide variety of functional groups to the surface of pigments.[13] A new technology that modifies the surface of pigments without adsorption, but with the attachment of chemical groups as shown in Figure 2-8. This technology involves the controlled chemical bonding to specific types and amounts of functional groups to pigment.

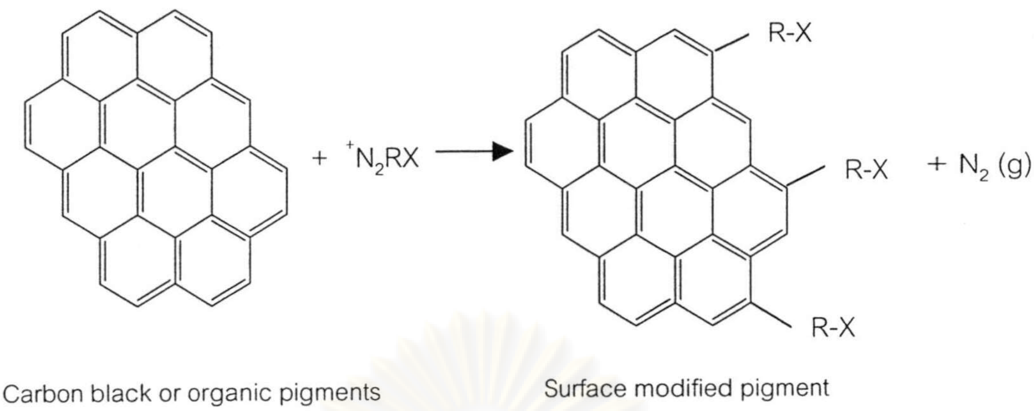

Figure 2-8 Surface modification reaction using carbon black by Cabot Co.

The technology allows functional moieties to be chemically bonded to the black pigment. The groups are not in an equilibrium with the suspension liquid, and they do not behave like conventional pigments. The technology involves the controlled chemical bonding of the specific type and the amounts of functional groups bonded on the surface of carbon black. This technology is extended recently to organic, color pigments by using this method.

Unlike conventional dispersions, these products rely on charged functional groups that have been chemically attached to the pigment surface to provide electrostatic stabilization. As a result this new pigment dispersion set does not contain any internal dispersant.

Surface modification chemistry, when color pigment surfaces are modified with ionic groups, stable pigment dispersions with favorable physical characteristic can be achieved for aqueous inkjet ink.

2.1.6 Textile Printing

The pigments used in textile printing are mainly synthetic organic materials, except for carbon black. When choosing these synthetic pigments, the price, the fastness properties, the brilliance and the coloring power of the many products are all taken into consideration. Especially important pigments are:[14]

Azo pigments	: for yellow, orange and red
Naphthalene, perylenetetracarboxylic acid, anthraquinone, dioxazine and quinacridone	: for very fast and brillant orange, red and violet colours
Copper phthalocyanine and Halogenated products	: for blues and greens

Textile inkjet printing for proofing systems and short run productions can shorten the total textile print production time scale, with consequently considerable savings. For the future this technique will gain much more interest for textile printing because of improved systems.[15]

In traditional screen printing the investment costs for the machinery are high whereas the running costs are low. In inkjet printing this is just the opposite: low investment and high running costs. The costs for one meter squared (m^2) textile printed traditionally are going down with longer run lengths. In inkjet costs are nearly the same for shorter and longer run lengths. There is a point where the costs for traditional and digital printing are the same.(16)

It is probable that inks based on both dyes and pigments should be required. The greatest divergence of opinion occurs in the extent of post print processing that will be acceptable. A number of systems are being developed based on standard dyeing processes currently used in textile coloration. These systems require different dye classes for different fiber types and typically require post steaming, washing and drying to achieve acceptable properties in the printed fabric. Other experts feel strongly that fabric printing must be like paper printing with no post processing requirement. A number of variations between these two extremes have been proposed. The different opinions arise primarily due to the varying concepts of where in the textile manufacturing chain inkjet printing will actually be performed. Those who believe that inkjet printing will replace current printing technologies in the textile industry feel that post processing will be readily acceptable. Those who feel that inkjet printing will be practiced by design studios, apparel manufacturers and retail establishments argue for little or no post processing.(17)

2.1.7 Textile Fiber and Their Properties

The substrate to be printed must be chemically and dimensionally stable at the printing temperature. Fabric structure is an important feature which determines not only the amount of shrinking induced at high temperatures.

Textile fibers have been used to make cloth for the last 4,000 or 5,000 years. The fibers most commonly used were wool, flax, cotton and silk. Many man-made fibers were produced in the first half of the twentieth century and from that time onward tremendous advances have been made in the man-made fiber industry, primarily modifications of the parent fibers to provide the best combination of properties for specific end uses.

Of the many natural fibers, those that are most widely used are wool, cotton, flax, and silk. There are 19 families of man-made fibers and many type modifications, variants, or second- and third-generation fibers.[18]

Natural Fibers	Man-Made Fibers	
Asbestos	Acetate and Triacetate	
Cotton	Acrylic	Nylon
Flax	Anidex	Nytril
Jute	Aramid	Olefin
Mohair	Azlon	Polyester
Silk	Glass	Rayon
Wool	Lastrile	Saran
	Metallic	Spandex
	Modacrylic	Vinal
	Novoloid	Vinyon

2.1.7.1 Natural Fibers

a. Silk

Silk, a protein fiber. The protein is extruded from two spinnerets, one on each side of the caterpillar, as a pair of continuous filaments between 3000 and 4000 m in length, joined together by a gum called sericin.[19]

Silk is the very fine strand of fiber and universally accepted as a luxury fiber. Silk has a unique combination of properties not possessed by any other fiber: dry tactile hand, natural luster, good moisture absorption, lively suppleness, draping qualities and high strength.[20-23]

Physical Structure

Silk is a natural continuous filament fiber. It is a solid fiber, smooth but irregular in diameter along its shaft. The filaments are triangular in cross section with rounded corner. Silk fibers are very fine (1.25 dynier/filament).

Chemical Composition and Molecular Structure

Silk fibroin contains CHON in polypeptide chain. Silk has reactive amino (NH_2) and carboxyl (COOH) groups. There are some amorphous areas between the crystalline areas.

Durability Properties

Silk is a strong fiber with a tenacity ranging from 3.5-5.0 g/d dry. It loses some strength when it is wet.

Comfort Properties

Silk has good absorbency with moisture regain of 11 percent and it is hygroscopic. This makes silk fabrics comfortable in summer in skin contact apparel. Silk is a poor conductor of heat so that silk scarves and raw silk suitings are comfortably warm. The weight of a fabric is important in heat conductivity sheer fabrics, possible with filament silk, will be cool whereas heavy suiting fabrics will be warm. Silk is smooth and soft and is thus not irritating to the skin.

Care Properties

Silk fibers do not shrink. They swell a bit when wet but the molecular chains are not easily distorted. Crepe fabrics will shrink if washed but this is the result of yarn structure not fiber content.

Silk fabrics do not soil readily because of the smoothness of the fiber. Silk is harmed less by strong alkalis. Dry cleaning is usually recommended for silk garments because of the yarn structure or non-fast colors.

Silk is resistant to dilute acids and to organic acids. Silk is sensitive to sunlight, which causes white silk to yellow silk and all silk lose strength.

b. Cotton

Cotton is the most widely used of the textile fibers. Cotton has a combination properties of durability, low cost, easy washability, and comfort. The cotton fiber is a single cell structure taken from the cotton plant as a seed hair. The parallel fibers from slipping past each other, thus contributing to the strength of the yarns when they are twisted together during spinning.[19, 23-25]

Physical Structure

Raw cotton is creamy white in color. The fiber is a single cell, which, during growth, pushes out of the seed as a hollow cylindrical tube over one thousand times as long as it is thick. The quality of cotton depends on the staple length, the number of the convolutions, and the brightness of the fiber.

Chemical Composition and Molecular Arrangement

Cotton, when picked, is about 94 percent cellulose; in finished fabrics it is 99 percent cellulose. Like all cellulose fibers cotton contains carbon, hydrogen, and oxygen with reactive hydroxyl (OH) groups. Cotton has 2,000-12,000 glucose residues per molecule. The molecular chain is a spiral form.

Durability Properties

Cotton is a medium strength fiber having a breaking tenacity of 3.5-4.0 g/d. It is stronger yarns because there are more points of contact between the fibers when they are twisted together. Cotton can stand rough handling during laundry. The elongation of cotton is low, 3 percent, and it has low elasticity, making it a rigid fiber.

Comfort Properties

Cotton makes very comfortable skin-contact fabrics because of its absorbency and its good heat and electrical conductivity. It is lacking in any surface characteristics which might be irritating to the skin. Cotton has a moisture regain of 7 percent. When cotton becomes wet, the fibers swell and become somewhat plastic-like (plasticized). This property makes it possible to give a smooth, flat finish to cotton fabrics when they are ironed.

Care Properties

Cotton fibers are stable. They do shorten a bit when wet but on drying their original length is restored. Shrinkage of cotton fabrics is not the result of any property of the fibers but rather is a result of the finishing process of the fabric.

Cotton is harmed by acids. It is not greatly harmed by alkalis. Cotton can be washed with strong detergents and under proper conditions it will withstand chlorine bleaches. Cotton is resistant to organic solvents so that it can be safely dry-cleaned. Cotton is attacked by fungi especially in starched fabrics. Cotton oxidizes in sunlight, which causes white and pastel cottons to yellow and all cotton to degrade.

2.1.7.2 Man-Made fibers

c. Polyester Fiber

By the time the polyesters were synthesized much had been learned about high polymers and about the structure of fibers. Many of the problem of production had been solved for example, controlled luster and strength, spinning methods, making of tow for staple fibers, and crimping of staple. Polyester is made by reacting an acid with an alcohol. The fibers are melt spun by a process that is very similar to that used to make nylon. The polyester fibers are hot drawn to orient the molecules and make significant improvement in strength and elongation, and especially in the stress-strain properties. As the polyester fibers have the ability to retain the shape of the spinneret hole, modifications in the cross-section shape are possible.[23, 26-28]

Physical Properties

Polyester fibers are produced in many types of filament yarns, staple fibers and tow. Filaments are high tenacity or regular, bright or delustered, white or solution dyed. Staple fibers are available in deniers from 1.5 to 10 and are delustered.

They may be regular or low-pilling or high tenacity. A variety of cross-section shapes are produced: round, trilobal, octalobal, oval, hollow, voided, hexalobal, and pentalobal (star shape).

Chemical Composition and Molecular Structure

Polyester fibers are manufactured fibers in which the fiber forming substance is any long chain polymer composed of at least 85 percent by weight of an ester of dihydric alcohol and terephthalic acid, (*p* HOOC-C_6H_4-COOH)-Federal Trade Commission.

Polyester fibers are made from two kinds of terephthalate polymers. The original fibers Terylene and Dacron were spun from polyethylene terephthalate (abbreviated as PET). The PET spinning solutions may be homopolymers or copolymers. The copolymers are pill resistant, lower strength staple fibers used primarily in knits and carpets. Polyester fibers have straight molecular chains that are packed closely together and are well oriented with very strong hydrogen bonds.

Durability Properties

The strength and abrasion resistance of polyesters are quite high, and the wet strength is comparable to the dry strength. The high strength is developed by hot drawing or stretching to develop crystallinity and also by increasing the molecular weight.

Comfort Properties

Absorbency is quiet low for the polyesters, ranging from 0.4 to 0.8 percent moisture regain. Fabrics are resistant to waterborne stains and are quick drying. Polyester upholstery fabrics have more stability in humid weather than nylon, which has a higher moisture regain. Polyesters are more electrostatic than the other fibers in the heat-sensitive group. Static is characteristic of fibers that have low absorbency. Static is a definite disadvantage because lint is attracted to the surface of fabrics and it is difficult to keep dark-colored fabrics looking neat.

Care Properties

Resiliency relates to tensile work recovery and refers to the extent and manner of recovery from deformation. Polyester fibers are generally resistant to acids and can be bleached with either chloride or oxygen bleaches. This is very important because the largest single use of the polyesters is in blends with cotton for durable press. They are resistant to biological attack and to sunlight damage.

d. Fiber Blend

A blend is an intimate mixture of fibers of different composition, length, diameter, or color spun together into a yarn. A mixture is a fabric that has yarn of one fiber content in the warp and yarn of different fiber contents in the filling. A combination yarn has two unlike fiber strands twisted together as a ply. Blends, mixtures, and combinations give properties to fabrics that are different from those obtained with one fiber only.[23]

Blending is done for several reasons:[29]

1. To obtain cross-dyed effects or create new color effects such as heather, when fibers with unlike dye affinity are blended together and then piece-dyed.
2. To improve spinning, weaving, and finishing efficiency for uniformity of product, as with self-blends of natural fibers to improve uniformity
3. To obtain better texture, hand, or fabric appearance.
4. For economic reasons. Expensive fibers can be extended by blending them with more plentiful fibers.
5. To produce fabrics with better performance. This is perhaps the most important reason for blending. In end uses where durability is very important, nylon or polyester blended with cotton or provide strength and resistance to abrasion, while the cotton look is maintained.

2.1.8 The Textile Testing

The two groups that have developed the most widely used textile testing methods are the American Association of Textile Chemists and Colorists (AATCC) and the American Society for Testing and Materials (ASTM).

The American Association of Textile Chemists and Colorists is composed of persons from the textile wet processing industry, textile chemists, others working in varying segments of the textile industry, and educators. The Association establishes testing methods, largely in the area of chemical testing, and maintains an active educational program implemented through national and regional meetings, and a monthly journal, the AATCC Review.

Tests established by the American Society for Testing and Materials are more specifically focused on physical testing and the testing of fabric construction.[30]

2.1.8.1 Color Measurement

There are several three-dimensional “color space” or “color order” systems that have been devised to classify colors. However, the Munsell, Ostwald and CIELAB systems are three most widely used color order systems. The CIE (Commission International l’E’clairage) tristimulus value system was formulated in 1931 and is not based on the perceived color of the object but on the principle that the stimulus of color is dependent on the interaction are proper combination of a light source, an object, and a standard observer. The CIE tristimulus values are the mathematical values X, Y and Z that represent the spectrum of the primary colors red, green and blue respectively.[31] From these XYZ values, the CIE constructed the xyY Chromaticity Diagram to define the visible spectrum as a three-dimensional color space.

2.1.8.2 Air permeability

Air permeability is the ability of air to pass through a fabric. Obviously, where openings between yarns or between fibers within yarns are large, a good deal of air will pass through the fabric. Contrary-wise, where compact yarns are packed tightly into fabrics with little air space between them, the flow of air through the fabric is diminished.[32]

Some finishes for fabrics such as curing of thermoplastic fabrics decrease air permeability by causing fibers and yarns to fuse slightly. Fabrics may be coated with another material that closes up interstices in the fabric. To make garments that are warm enough for sports such as skiing in which moving air may cool the athlete, a fabric with low air permeability (such as closely woven nylon) may be combined with materials of low thermal conductivity (such as polyester or acrylic fiberfill or with pile fabrics) that trap air close to the body.

The most commonly permeability of fabrics to gases measured is that to air or wind. The ability of a fabric to resist air (low air permeability) or have air freely flowing through it (high air permeability) is dependent primarily on its thickness, porosity, construction, geometry, type and amount of finish and coating and similar factors. Generally, the fabrics are ranked from lowest to highest permeability in amount of cubic feet of air that passes through a square meter of fabric. Air permeability prediction and measurement is more complex for very porous structures such as nonwoven fabrics than it is for less permeable structures. Air permeability has been related and correlated with numerous other fabric properties. These correlations have usually been made in an attempt to relate them to comfort factors of textiles that will be discussed in detail later in this chapter.

2.1.8.3 Stiffness

Yarn stiffness is related to fiber stiffness. It is not possible to make a flexible yarn from an inflexible fiber. Moreover, the way in which fibers are combined in the yarn will affect yarn flexibility. It is easy to see that more tightly twisted yarns, in which fibers have less freedom of movement, will be less flexible. The most flexible yarn of all should be the ones in which the filament fibers are combined with little or no twist. The least flexible yarns should be those in which the fibers are bonded together by an adhesive or fused by heat or chemical means. An excellent example of this principle can be seen after a heavily sized fabric with a water-soluble sizing has been laundered. The fabric after laundered will be much softer and more flexible when the sizing that has held the fibers together has been removed.

Stiffness is the ability of material to resist deformation. In the case of a yarn subjected to a tensile force or pull, stiffness is the ability to resist elongation. The units for stiffness are grams per denier per unit elongation.

Average stiffness is the stiffness of a material from its original state to breaking point. It is the ratio of unit breaking stress to unit breaking strain and thus indicates the average stress for the entire range of extensibility of the material per unit increase in strain. Average stiffness is an indicator of the general character of a material with regard to the stiffness quality.

The flexural rigidity or stiffness of fabrics relates to their overall mechanical integrity and comfort. Test methods and fundamental studies have focused on the mechanics of bending, stiffness and the measurement and prediction of fabric drape.[32]

2.1.8.4 Colorfastness

The colorfastness of fabrics to a variety of substances and conditions can be measured by the use of wide variety of specific testing methods and machinery.

Some fabrics lose color through crocking, or rubbing against another fabric. Some fabrics crock when dry, some when wet, and some when both dry and wet.[30]

A laboratory device called a crockmeter, that can be used for testing for crocking, works on the same principle as the home test, by rubbing a white fabric sample across the fabric to be tested.

Literature review

The color pigmented inkjet inks used in wide format applications have been applied to some of the most demanding applications with which inkjet has ever been challenged. Work presented since their introduction in 1996, the design is complex and the optimization is difficult to achieve but when it is achieved the result is dramatic. Color pigmented inks without any significant binder now available from several printer suppliers which give properties which meet many of the needs of the fine art and art reproduction markets.[33] The nanoparticulate ink technology offers the best of both dye-based and pigment-based inks.[34] Base on the nano technology, Bugner and Bermel studied these ultrafine pigmented inks having average particle sizes of an order of magnitude smaller than other commercially available pigmented inkjet inks. In verifying claims that very small particle size pigmented inks would exhibit poorer lightfastness, inkjet printing inks have been realized based on selected fine grade pigment preparations. The choice between pigmented and dyed inks depends on the desired print-out profile such as color gamut, transparency, color strength and fastness properties. Hauser and Buhler presented that aqueous, low viscosity, stable pigment concentrates were suitable for further formulating.[35]

The pigment/binder ratio, coating, and silica type of major formulation parameters on the properties of a model coating system was studied by Adair.[36] Three important image properties were measured regarding ink capacity, CMYK densities, and adhesion of the dry coating. Pigment particle size was found to be very important in determining the coating properties. Use of as largest size as possible pigments in consistent with coating roughness and resolution constrains is recommended. There is a tradeoff among the parameters of coatweight, pigment-oil absorbance, and pigment/binder ratio.

A new emulsion colorant can solve the problem about limitation of pigmented ink on clear color and rub stability or rub resistance. The colorant is a water-based polymer emulsion containing a water insoluble dye or pigment. Tsutsumi et al.[8] presented that when using a polymer emulsion containing a water insoluble dye, prints show clear color, waterfastness, and rub resistance properties. The emulsion-based ink would be a technological breakthrough to improve the durability of an aqueous inkjet system.

The advantages of the oil-based pigmentary inks in the Xaar printhead were studied by Schofield. When compared with conventional water-based inkjet inks, the inks provide better performance including high lightfastness, absence of cockle on paper substrates and a rapid dry time, which facilitated higher printing speeds. The color gamut accessible using a trichromatic ink system is, to some extent, dependent upon the lightfastness required.[10] The compromises involved were discussed, and reference is made available for certain high chroma pigments that are only suitable for use in non-aqueous ink systems. Enhancement of the color gamut, particularly in the secondary color regions, by application of a six ink set was then discussed. Finally, the capability of printhead, and the benefit of such inks in terms of durability on non-porous substrates such as film, metal, and glass were disclosed.

Tanaka et al.[11] presented the characteristics and application to inkjet inks of water-borne dispersions of micro-encapsulate pigments, as follows;

1. The dispersions were excellent in dispersibility with median diameter of around 100 nm.

2. The dispersions were stable over one year under ambient conditions.

3. The inks showed excellent resistance to water-soluble organic solvents.

4. The inks formulated from these dispersions showed good print qualities and had great potential of applications for inkjet inks.

Two commercial products used in industrial inkjet printers were developed by Johnson and Bok. The products are very compatible with common ink components and have a wide formulation latitude.[12] Yu and Gottberg in Cabot Corperation studied the surface modification technology, from which the pigment surface could be modified by attaching functional groups used to impart the desired physiochemical properties for the systems. The color pigment dispersion set has high surface tension (>70 dynes/cm), low viscosity (< 3 mPa s at 10 % solid), small particle size, and reliable long term stability, while providing an unprecedented formulation latitude and retaining the inherent permanance properties of the color pigments.[13]

The physical properties of some pigment-based inks were studied wherein the commercially available specially treated and modified surface as well as unmodified dry pigments were used in the formulations. Basak and Dante found that the pigment particles adsorbed a layer of resin or polymer chains on their surface. As pigment particles approach each other, these adsorbed layers intermingle, they lose a degree of freedom.[37] Kwan presented the nature of resin/binder employed, which was shown to affect the lightfastness of the colorants both in dye and in pigment. Polymers bearing UV light absorbers as the pendant group, as well as styrene containing polymers, are shown to destabilize the colorants even further. As the inkjet printing market is approaching a receptor-less phase, color protection provided by the resin alone may prove to be vital in realization of such receptor-less applications.[38]

The ink formulations are rapidly evolving to fulfill the multichallenges of the emerging markets such as packaging, textile and large format. Keller[39] described that printing textiles requires much larger quantities of ink or more concentrated inks to yield the desired colorant levels or color depth throughout a fabric. A larger color gamut is required to equalize the traditional screen printing with multiple color inks. Work reported a digital inkjet pigment textile printing, which offers both opportunities and challenges when compared to the traditional screen-printing. The application of colorant to textiles by inkjet printing is very different from screen-printing, and the ink-fabric interactions produce different results. Inkjet pigment printing provides a very different set of printing and end use characteristics in the printed textile compared with traditional pigment printing techniques.[40] Tian and Tincher explored the application of small particle size 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 resins 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.[41] Tincher and Yang presented very fine particle latices prepared by micro-emulsion polymerization of acrylate monomer and containing very finely ground and well dispersed pigments, which are a promising system for use in inkjet printing of textiles. The use of a good hydrogen bonding additive, in this case urea, reduces viscosity and decreases the clogging problem.[42]