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A study of the effect of water-pick up of UV curable offset ink on its curing time and its end use properties

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A STUDY OF THE EFFECT OF WATER-PICK UP OF UV CURABLE OFFSET INK ON ITS CURING TIME AND ITS END USE PROPERTIES

by

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A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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Certificate of Approval

Master's Thesis

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With a major in Printing Technology
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ABSTRACT

The curing time and the end use properties are as important as printing quality for the printer. Shorter curing time equals more jobs and higher productivity each week. The latest available technology for decreasing curing time is Ultraviolet curing technology. This technology uses ultraviolet radiation as the energy source to excite the active site of the monomer in the ink to start the polymerization process. The desired result is a hard polymerized ink film. Another advantage of Ultraviolet curing technology is that the ink is solventless. The screen printing process has the advantage of being a single-fluid printing process. Ink is the only chemical compound to be considered in this printing process.

Lithography requires compatibility between ink and fountain solution. Extensive research has been done to better understand the relationship between fountain solution and ink, primarily with conventional ink. The water pickup characteristics of conventional ink is mainly studied for the effect of water on the printing quality. Due to the nature of Ultraviolet ink, the water-ink relation is more complicated. The water pickup by the ink is thought to have an effect on the curing process. This thesis studies the effect of water pickup of ultraviolet ink on curing time and end use properties. The water pickup of the ink was varied by using three levels of acidity for the fountain solution. To simulate the actual printing condition, the fountain solutions used were those commonly used on press. Three resistance properties including film hardness,

abrasion resistance and adhesion resistance were measured in this study for responses relating to end use. The effect of the substrate absorptivity on the curing time was also reviewed.

This study indicates that the higher water pickup of the Ultraviolet ink needed longer curing time. There is a significant effect of acidity of fountain solution on water pickup of the ink. Curing time is considerably affected by the color of the ink or by the transmission properties of the pigment. Cyan acts like a neutral density filter on the printed film. Increased absorptivity of the substrate helps shorten the curing time.

Water pickup of the UV inks affects its film hardness. High water pickup decreased film hardness. On the other hand, the effect of water pickup of the ink with regard to abrasion resistance and adhesion resistance is insignificant.

Tack as a rheological property of the ink and the curing stages are also reviewed in this study.

Chapter 1

Introduction

Quality of a printed product consists of its physical quality (meeting customer's specification), price and delivery time. The method required to achieve a product of high quality will vary according to printing process. For the Lithographic process, one important required factor to produce a good result is the so-called "water-ink balance". Water or fountain solution in this process is responsible to keep the non-image area clean. Braun [1] reported that the behavior of Lithographic ink is primarily governed by the amount of water pickup by the ink, the position of the ink/water equilibrium, the nature of the emulsion and the drop size distribution. Fountain solution is not purely water, it also consists of several additives to meet the requirements of the process. The chemicals in fountain solution influence the water-ink relationship of the process.

Drying time is also a quality attribute. Shorter drying time reduces turnaround time and drying related problems such as set-off. The Environmental Protection Agency regulations in usage of volatile solvents make radiation curing techniques seem to be the better choice over conventional drying mechanisms. Radiation curing techniques involve polymerization of monomers and low molecular weight polymers initiated by radiation energy. This technique eliminates the need for spray powder. Radiation curing inks are solvent-free. They dry faster than conventional inks but their price is a major drawback

in their implementation. Radiation curing processes are classified according to the type of energy source applied. Three processes currently available are Electron Beam(EB), Infrared(IR) and Ultraviolet(UV). UV curing has the largest volume of the specialized radiation curable ink and varnish market. It offers faster drying rate with more simple equipment than other radiation curing techniques. The final ink film properties of the printing is superior to that of conventional ink.[2]

The ink contains a photoinitiator that acts as a catalyst to initiate the reaction. As with other chemical processes, polymerization will be influenced by such factors such as the concentration of the reactive sites and the irradiation energy. The reaction could be inhibited by the presence of other chemicals and the impurities from a variety of sources.

The purpose of this study was to investigate the effect of the water pickup characteristic of UV curable offset inks on its curing rate and end use properties. Considering the price and the complexity of UV curing equipment, the investigation was conducted by comparing different UV offset inks in laboratory/process simulation. Therefore the behavior of UV curable ink on the press is beyond the scope of this study. This study was further limited by the fact that most ink formulations are proprietary, therefore the study of formulation was not specifically addressed but will probably be inferred on the Basis of Material Safety data sheets and whatever the manufacturer may was willing to share. The information on the curing unit was also limited to that which is available in the manufacturer's data sheet.

The result of the testing will be useful for the printer that intends to use UV curing technology since implementing a new technology requires a thorough understanding about the technology itself and it's related factors. One of the important factors will be the ink itself. An understanding of the behavior of this ink will help the

lithographic printers to decide the best technology to be used for them. On the other hand, the ink industry may find the result of this study useful for the improvement of UV curable ink.

Definitions :

Radiation is the term to describe a passage of energy from a transmitting source to an absorbing body without interaction with any intervening matter. [3]

UV offset inks are solvent-free lithographic inks which dry by polymerization of monomers and molecular weight polymers initiated by the absorption of ultraviolet light. [3]

Ultraviolet curing is a conversion of a coating from its application state to its final state by means of a mechanism initiated by ultraviolet radiation generated by equipment designed for that purpose .[4]

Conventional inks are solvent based lithographic inks and dry by absorption, oxidation or evaporation. Sometime it is also called oleoresinous ink.

Water Pick up characteristic is the degree of the water picked up by the ink. Since water pickup of the ink is measured over cumulative period of time, the water pickup characteristic in this experiment is stated in terms of water pickup rate.

Tack is a rheological parameter indicative of internal cohesion of the fluid and is defined as a function of the force required to split a thin fluid film of a printing ink or vehicle between two rapidly separating surfaces .[4]

Resistance Properties are the ink characteristics to resist certain forms of chemical and physical attack during their life span. In this study three resistance properties will be measured. These include the following :

- Film Hardness : the ability of a film to resist deformation. [4] In this experiment, film hardness is stated in term of scratch resistance or the force required to scratch the film.

Two end points defined are the force required to slightly mark the film and the force required to scratch the film into the substrate.

- Abrasion resistance: the ability of a film to resist being worn away and to maintain its original appearance and structure when subjected to rubbing, scraping or wear. [4]

- Adhesion : the property denoting the ability of a material to resist delamination or separation into two or more layers. Delamination is separation of one coat or layer from another coat or layer or from the substrate.[5]

Curing rate is how fast the ink could be dried by the curing process. In this experiment, cure state is defined as the dryness of the ink to the touch (it does not set-off).

Endnotes for Chapter 1

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2. Chatterjee, P.C. and Ramaswamy, R., "Ultra Violet Radiation Drying of inks", *The British Ink Maker*, February 1977, p. 76
3. R. H. Leach (ed.), *The Printing Ink Manual*, 4th ed., Van Nostrand Reinhold (International), London, 1989, p. 516
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5. *Compilation of ASTM Standard Definitions*, ASTM, 6th edition, 1986

Chapter 2

Theoretical Bases of the Study

Ultraviolet curable inks in general have the following composition [1]:

Pigment	15 - 20 %
Prepolymers	35 - 25 %
Monomers (including oligomers)	10 - 25 %
Photoinitiator package	5 - 10 %
Additives	1 5 %
	100 %

The low viscosity monomer, usually referred as diluent, acts like the solvent in oleoresinous ink. It wets the pigment and determines the rheology of the UV ink. Being a monomer, diluent in UV inks are chosen from difunctionality species which will also chemically react with each other and the rest of the ink to form polymer. Prepolymer acts as a hard resin portion of the ink and contributes to its hardness, gloss, adhesion, strength and flexibility of the ink. The radiation sensitive material in the ink is called photoinitiator. It catalyzes the polymerization reaction. A small part of it will be used up in the reaction but the rest will be left unbound in the cured polymer. [2] This residual initiator affects the printed performance and resistance properties.

Curing process will involve three stages:

(1) Initiation

(2) Polymer chain propagation

(3) Termination

Initiation is the first stage of the reaction where the free radicals needed in the reaction are generated. Photoinitiators are effective sources of photochemically generated radicals to start the polymerization. The photoinitiators are broken-down to free radicals by exposure to UV radiation in the 200-400 nm waveband. The concentration and the reactivity of the photoinitiator influence the average molecular weight and the technical properties of the polymer. The most common chemicals used as photoinitiators in UV inks are the carbonyl function. The Initiation reactions usually follows the following form [3] :

1. $AB^{\circ} \xrightarrow{h\nu} AB^{*}$

Energy absorption by a photoinitiator and excitation

2. $AB^{*} \longrightarrow AB^{\circ}$

Fluorescence and phosphorescence

3. $AB^{*} + AB^{\circ} \longrightarrow AB^{0} + AB^{*}$

Energy transfer

4. $AB^{*} \longrightarrow A^{\circ} + B^{\circ}$

Formation of free radicals

The free radicals react with double bonds in UV curable resin to form propagating chain species. The free radicals begin to open the double bond in the monomer and oligomer and the parts begin to hook onto each other forming a cross-linking chain. The further reactions of propagating chain species form polymer chains are similar to those for a vinyl solution polymer. Termination starts when the free radicals become inactive

and stop to react. Ultimate termination occurs as the rate of polymerization decrease to zero by a decrease in free radicals or molecular mobility as the viscosity of the system increases .[4] Certain materials can interfere in the propagation step causing the reaction terminate before it is completed.

The overall reactions are more complicated since some of the pigments in the ink compete with the photoinitiator to absorb UV radiation. The absorbancy property of the pigment to UV irradiation determines the efficiency of the curing process. The pigment that absorbed a high portion of UV light will retard the curing rate of the inks. Otsubo [5] reported that for the same film thickness, magenta ink shows the fastest curing rate and followed by yellow, cyan and black. The research conducted by Bassemir et al [6] also led to the same conclusion as shown in figure 1.

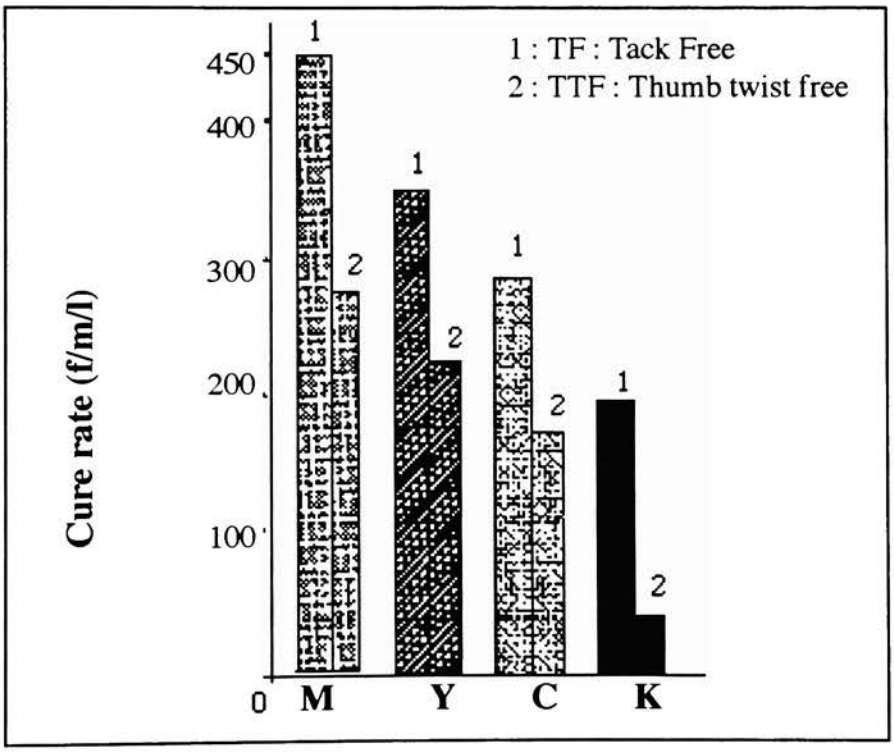

Figure 1

Cure rate for different ink color [6]

They defined the cure state by two different methods, as thumb twist free (TTF) and tack free (TF). The thumb twist free method involved the application of 5 kgs pressure while a rotary twisting motion is applied to the film with the thumb. Tack free method is defined as the absence of stickiness or ink transfer when the film is touched or come into contact with another surface. Since TTF method is more severe than TF method, the cure rate of TTF is slower than TF. Magenta appears to have the fastest cure rate among the four color process. The unit of cure is expressed in f/m/l (ft/min/lamp) to provide the information for scaling purposes from laboratory test to actual press condition at given speed. Further, they measured the UV transmission of a set of process colorants dispersed in a non-absorbant oil. The result is shown in Figure 2 .

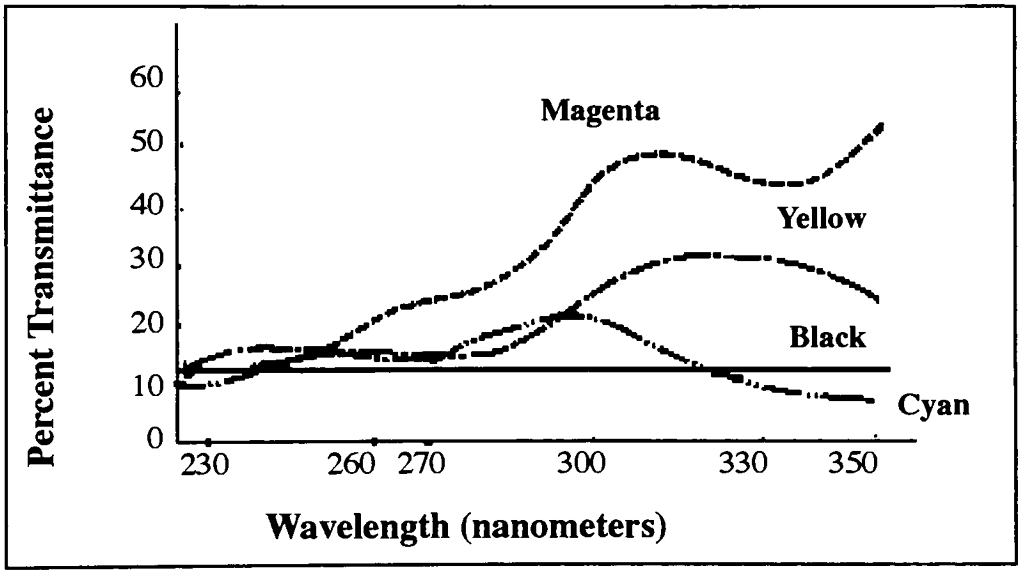

Figure 2

UV Transmission of Ink Pigments. [6]

The colorant characteristics maybe explained by the difference of the cure rate by Figure 1. Magenta transmit the most energy and is expected to have the fastest cure rate

which is the case in Figure 1. Metallic pigments reflect most of the UV irradiation and should reduce the amount of UV energy absorbed by the film to form polymer. [7] This characteristic will influence the curing rate of the inks. The choice of pigments should be suitable for the photoinitiator. As an example, an epoxy system photoinitiator has acidic active species which should not be mixed with basic pigments. They will neutralize the activity of the photoinitiator. This photoinitiator with acidic pigments will also shorten its shelf-life and lead to gellation during storage. [8,9] Some pigments commonly used in conventional ink are not suitable for UV ink formulation since some resin available for UV ink has poor pigment-wetting characteristics.

In the lithographic process the image and non image area is separated by applying fountain solution onto printing plate. The ink-water balance is crucial in this type of process. Water-miscible resins which are more popular in UV screen printing ink should be avoided for UV litho ink. A study by Mac Phee and others[10] indicates that the fountain solution on press is mostly carried by the ink. Some of the fountain solution is transferred to the substrate and is absorbed and the rest evaporates from the inking system. In both cases the fountain solution deposits impurities in the ink. The water soluble impurities can react with the free radicals thereby preventing particle generation and inhibiting polymerization processes. There is always a risk that the photoinitiator will leach into the fountain solution with a subsequent reduction in cure efficiency. Acidity of the fountain solution will also be very critical regarding the active site of photoinitiators. It also defines the amount of the water picked-up by the ink.[11] The NPIRI Task force on Water Pick-up reported that the fountain solutions provide lower water pick-up than distilled water.[12] Lower pickup characteristic of the ink performs better on the press and reduce the effect of water in drying time. Surland [13] concluded that "..the emulsification capacity of an ink/dampening solution pair is proportional to

the pH and conductivity of the dampening solution, and to particular ink and dampening solution constants".

The ultraviolet system of ink drying utilizes radiant UV-light energy as the driving force to convert a fluid ink into a dry abrasion-resistant ink in a fraction of a second. The energy required in the process is generated by mercury vapor quartz lamps. To cure the ink completely, UV irradiation must reach the bottom of the film and must generate sufficient free radicals throughout the film. Therefore for the same level of energy used, the thickness of the film will determine the curing time. The polymerization process can be retarded or terminated in the presence of oxygen. An incomplete polymerization process will influence the resistance properties of the dry film. The rub resistance of the film and the overall adhesion might also be affected. The rub resistance test is used to test the dryness or completeness of the polymerization process.

Endnotes for Chapter 2

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2. Ibid, p. 526
3. Dr. R. Holman B.Sc. Ph.D. & Dr. P. Oldring Ph. D. BA (ed.), *UV & EB Curing Formulation for Printing Inks Coatings & Paints,* SITA-Technology, London, 1988, p. 10
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12. NPIRI Task Force on water pick-up, "Effect of ink water pick-up on printability in a high speed lithographic press", *TAGA Proceedings*, 1990, p. 226

13. Surland, Aage, "Factors determining the efficiency of lithographic inks", *TAGA Proceedings*, 1983, p. 191

Chapter 3

Review of Literature

Ink formulation has a great influence on its properties. The combination of pigments, varnish, solvent and additives are formulated to meet certain properties for each printing process. Solvent in conventional ink acts as viscosity reducer to help flow. It physically interacts with the vehicle components. On the other hand, viscosity reducer in UV ink is a diluent (low viscosity monomer) and "... will ultimately form a part of the cured polymer matrix. Thus the choice of material used, not only influences the rheology of the ink or varnish, but can have a profound effect on the characteristics of the cured product." [1] The complexity of the interaction of diluent in UV ink formulation makes the choice of material more difficult. Increased functionality of the diluent leads to a faster cure, but this is often at the expense of adhesion and scuff resistance.[2] The resistance of UV-cured coatings to water vapor and chemicals depend on the type of prepolymer and reactive diluent selected. [3]

K. Nate and T. Kobayashi [4] investigated the adhesive characteristics of Ultraviolet Radiation Curable resins. The UV curable resin was applied to aluminium oxide substrate/plate using screen printing technique. They mentioned that photoinitiator and UV radiation condition (time and distance) would not affect the adhesive strength. They also mentioned that : " Tensile strengths of the UV resins decreased by water

absorption in all cases". There is a significant effect of the additive on the tensile adhesive strength of the resin especially due to the presence of boiling water. Golovoy [5] reported that water absorption by the polymer reduces its mechanical properties.

Most water pickup characteristics of the lithographic inks were studied in relation to ink rheology and press perfomance. Surland[6] reported that the emulsification curve of the ink/dampening solution can be used to predict press perfomance as shown by Figure 3.

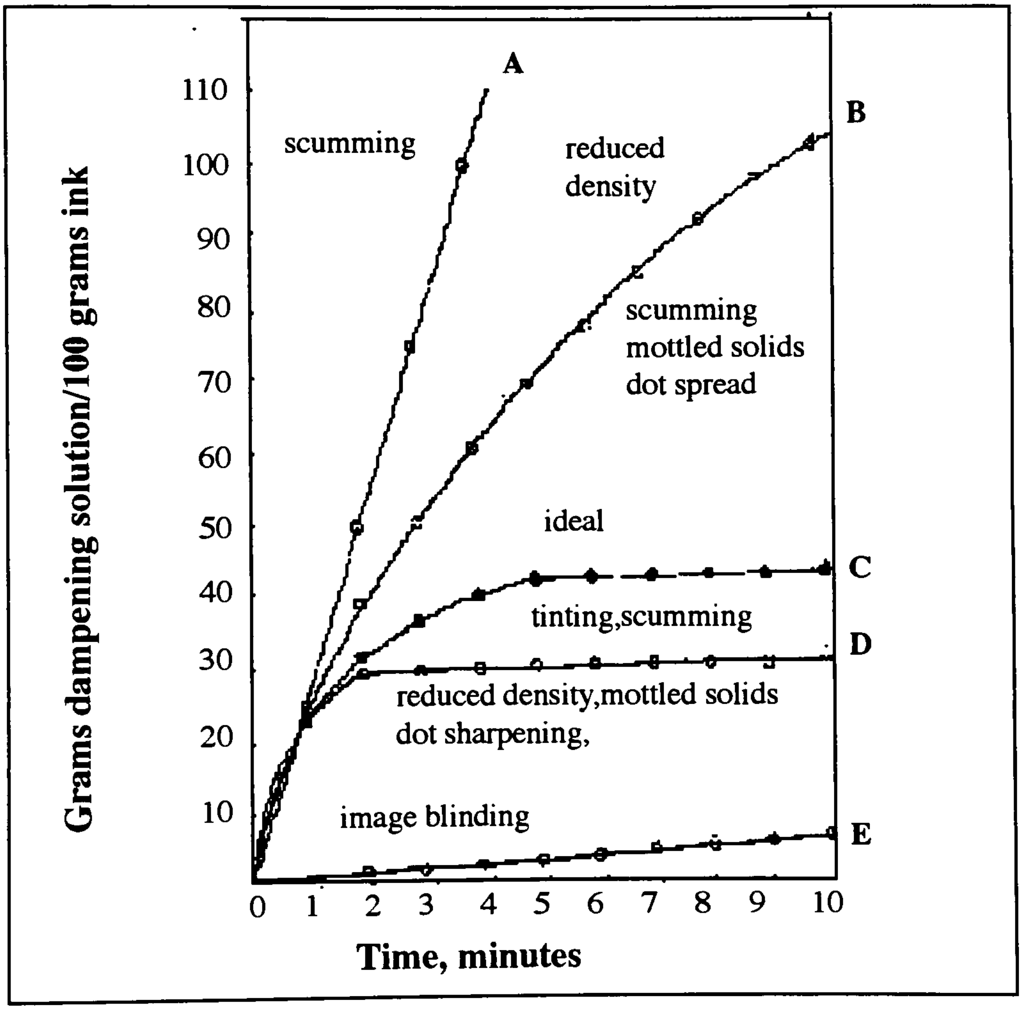

Figure 3

Typical emulsification curves.[6]

He also mentioned that the addition of isopropil alcohol to the dampening solution improves emulsification characteristics. In the case of UV curable lithographic ink, Tasker[7] pointed out that two of the three UV inks used were difficult to run. Most of the constituents of these UV inks were soluble in isopropanol. These are extracted by isopropanol in the fountain solution. This study also indicated that inks emulsify water by first-order reaction and have a limit on the amount of water they can emulsify. Water-ink balance is also a problem with UV ink. Some lithographic processes use propanol solution in place of propanol substitute and problems have been experienced with UV ink formulations being either too resistant or too sensitive to this alcohol replacement.[8]

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Chapter 4

Hypotheses

The water pick-up characteristic of UV curable inks and its effect on curing rate and end use properties is the subject of this study. The questions answered are :

1. Related to water pickup and curing time

1.1 Do different color of UV inks differ in water pickup rate ?

1.2 Does the water pickup of the UV curable ink affect its curing rate ?

1.3 Does the acidity of fountain solution affect the water pickup rate of the ink ?

1.4 Do different substrates influence the curing rate ?

2. Related to the end use properties

Does the water pick up affect film hardness, abrasion resistance and adhesion resistance of the end product ?

Hypotheses

There were seven hypotheses formulated from these research questions :

1. Related to water pickup and curing time

1.1 Different color of UV inks have similar water pickup rate

1.2 Water picked up by the ink does not affect the curing rate of the ink

1.3 The acidity of fountain solution does not affect the water pick-up characteristic of the ink.

1.4 The curing rate will be similar for different substrates.

2. Related to the end use properties :

2.1 Water pick-up of the UV curable ink does not affect film hardness.

2.2 Water pick-up of the UV curable ink does not affect abrasion resistance.

2.3 Water pickup of the UV curable ink does not affect adhesion resistance

If the null hypotheses are rejected at the 95% confidence level the alternate hypothesis is then inferred. To test the above hypotheses the regression analysis and analysis of variance were applied. The regression analysis was used to find the relationship between variables. The oneway analysis of variance and crossed design analysis of variance were used to study situations between more than one population.

Chapter 5

Methodology

The study to test the hypotheses was conducted as follows :

1. The water pick-up characteristics.

Water pickup characteristic of several UV inks were determined using the Duke Ink-Water Emulsification Tester. The test procedure followed the method specified in ASTM D4942-89 test method B. One set of measurements in a ten minute period required 50 grams of the ink and 100 ml of fountain solution. The clean bowl, mixer and spatula were weighed before and after the addition of 50 grams of ink. 20 ml Water/Fountain solution was added to the ink and were mixed for one minute at 90 rpm. After each mixing period, the free water was returned to the beaker glass containing the unused water. The ink with the spatula and the mixer were weighed. For the next mixing interval, the returned and unused water was mixed before it was added to the ink. These steps were repeated until the cumulative mixing time total was 10 minutes. The water picked up by the ink after each mixing period was determined gravimetrically using the following equation :

$$P = (W-S) \times 100/S,$$

where :

P : water pickup, % or ml water/100g ink.

W : weight of the specimen plus water picked up after each mixing interval, g, and

S : weight of initial specimen, g.

Condition of the instrument, water and ink sample was kept constant in room temperature. Distilled water and two kind of Rosos fountain solution were used in this experiment. Each measurement was repeated 3 times (ASTM specified two measurements). The design of the experiment is shown in Table 1.

Table 1

Water pickup tests.

Inks	Fountain Solution		
	Distilled water	Rosos RV 1000	Rosos G-C #1
	pH = 6.6	pH = 3.4	pH = 7.1
Yellow (Y)	Y-6.6	Y-3.4	Y-7.1
Magenta (M)	M-6.6	M-3.4	M-7.1
Cyan (C)	C-6.6	C-3.4	C-7.1
Black (K)	K-6.6	K-3.4	K-7.1

2. Tack

The tack of the ink was measured using the LTF Inkometer from Thwing Albert Instrument Company. The Inkometer is connected with an electronic readout. The measurement procedure followed the ASTM Standard Method D4361-89. The cooling water was set at 90 ^{O}F. The volume of the ink was 1.32 mL (thickness 12.3 um). 800 rpm and 1200 rpm operating speed was used. The ink was applied and distributed by the three

rollers of the Inkometer. The Inkometer and a stopwatch were started simultaneously. The first reading was taken at 20 seconds after Inkometer operated and then every minute for a total period of ten minutes. The measurement was repeated three times for each ink at each speed.

3. Curing rate

The UV Trix curing unit for screen printing was used to cure the ink in this study. This apparatus is Manufactured by Argon Industrie Meccaniche Italy. The radiation source and the speed of the belt in this curing unit can be varied. In this experiment, the intensity of the radiation source was kept constant for all inks and the time required for the curing process was measured by varying the speed of the belt. The speed displayed by the machine was calibrated by passing paper through the unit and determined the time required for the paper to pass through the curing unit. A stopwatch was used. The safety feature of the machine will shut down the whole unit if the heat build up exceed a specified temperature (75-85 ^{O} C). The heat build up is determined by the intensity of the lamp and speed of the belt. The full intensity at the slow speed can shut down the machine. For this study, the speed of the machine was maintained above 25 ft/min. If the ink was not cured at the slowest speed, it was passed through the curing unit several times. Since the length of curing unit is known, the curing time will be :

$$t = l/s * 60 * f,$$

where : t : curing time in second

l : length of the curing unit = 2250 mm

s : belt speed in m/minute

f : frequency of the ink passing the curing unit at specified speed

The degree of the dryness of the ink film was tested using a rubbing test or set off test as standardized in ASTM D3732-82 (Reapproved 1989). One sample was put in contact with a sheet of paper immediately after curing. The other method used was dry to the touch. The degree of set off will define the dryness of the ink. All the UV inks were printed on coated paper. To find the effect of different substrates on the curing rate, a clear overcoat varnish was used to prepare the sample and was applied to :

1. Conventional ink printed on mylar/plastic
2. Conventional ink printed on coated paper
3. Conventional ink printed on uncoated paper

For this experiment, the overcoat varnish was applied using wire-wound rod #3 and the ink was printed using the Little Joe Proof Press. The ink used was metered using a metal adjustable clearance applicator. The volume of the ink for each clearance stripe was approximately 0.1 mL. The volume of the ink used in this study was 0.1 mL.

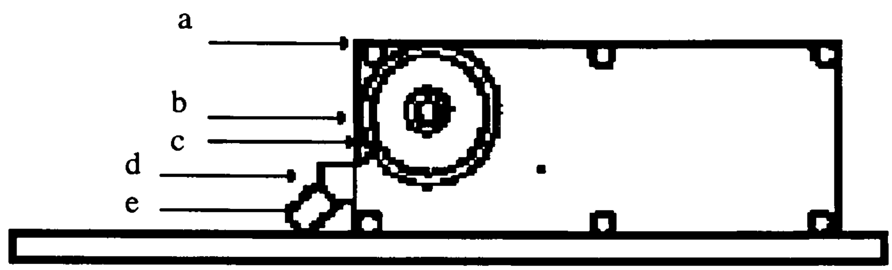
4. End Use Properties

The end use properties tested were film hardness, abrasion resistance and delamination.

4.1 Film Hardness

The film hardness was tested using the Gardco/ Hoffman S.A.M. Tester. As specified in ASTM STP 500, 5.1.2.5, to determine scratch resistance, the low range of the tester should be used. The low range include a force from 20 grams to 250 grams. The tested film was placed on a firm horizontal surface. The force of the tester was set to the lowest level (20 grams). The scratch tester was held firmly against the film at a 90° angle (point

away from operator) and pushed away. If the film was not marked at the lowest force, the force was increased until the film was marked. The force required to slightly mark the film was defined as the lower end. The force was continuously increased until the ink film was scratch through to the substrate. This force was defined as the upper end of scratch resistance. These procedures were repeated for five different prints.



a : Locking nut on reverse side
b : Fulcrum selection on reverse side
c : Load Control dial
d : Pull Direction
e : Hoffman cutter

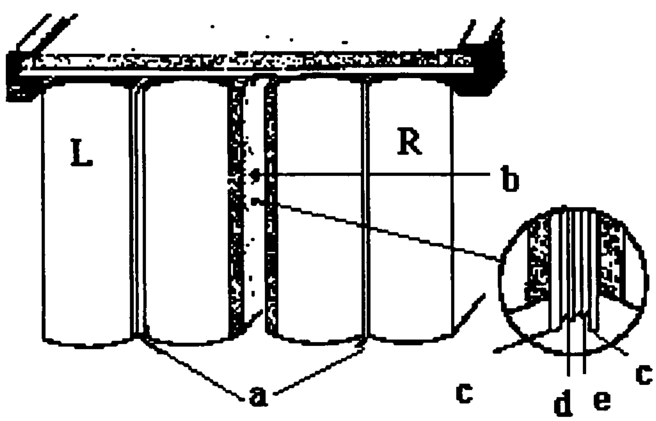
Figure 4

The Gardco/ Hoffman tester.

4.2 Abrasion Resistance

To simulate actual resistance to handling more accurately, the abrasion resistance of the film was tested using the Graphic Arts Comprehensive Abrasion Tester (GA CAT) as

specified in ASTM standard method no. D5181-91. The tested printed sheet and a receptor paper were put together face to face. Two pieces of foam sheeting were used as a backing for the specimen and the receptor to provide uniform pressure over the test surface and prevent the particles from imbedding into the sensitive surface of panel holder. This sandwich was clamped in the panel holder of the GA CAT with a known force and were made to slide over each other at a known frequency and at a determined time period (this arrangement is shown in Fig 5).



a : Spacer panels | b : Test panels
c : Protective foam sheets | d : Receptor
e : Test Print
L : Left | R : Right

Figure 5

Panel Holders.

For this measurement, the following conditions were applied :

Side pressure : 20 psi

Top pressure : 40 psi

Span : 1.0 inch

Frequency : 2.0 Hz.

Time : 120 sec.

Three types of receptors available are :

C1 , Glossy coated paper suitable for lowest quality graphics (least abrasive).

- A-0 to A-5 for intermediate abrasiveness and A-6, trimite 600 (most abrasive).

- B2-2 to B3-3, for evaluating the abrasiveness of another printed panel.

This experiment used the A-0 to A-5 type receptors which are imperial lapping film with aluminium oxide abrasive particles of different sizes (3, 9, 12, 30 and 40 um, respectively).

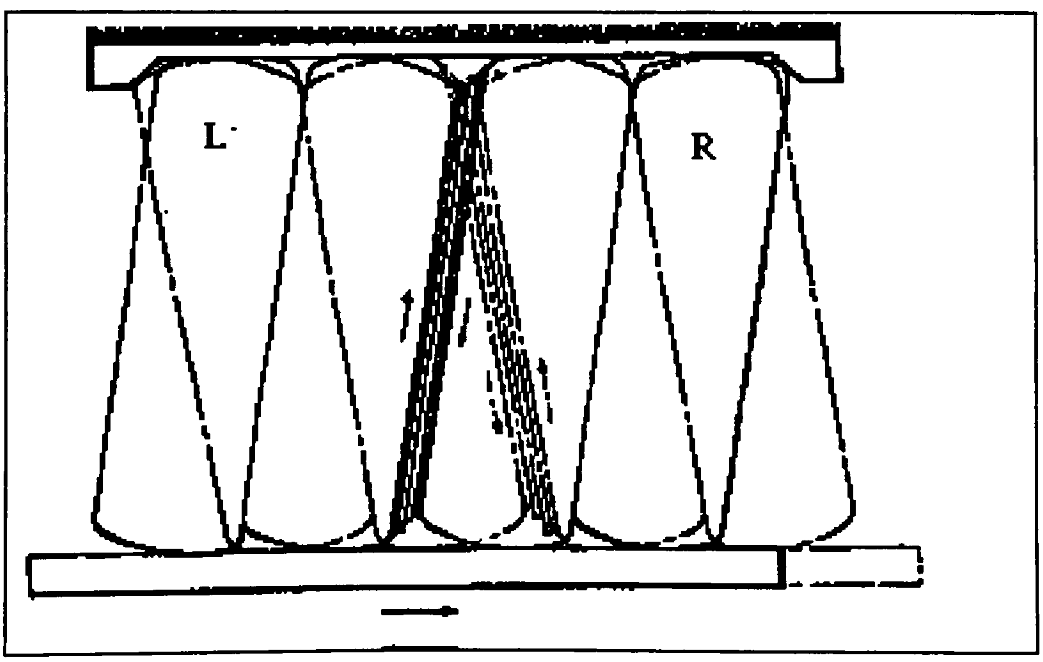


Figure 6

The movement of GACAT Comprehensive Abrasion Tester.

4.3 Adhesion Resistance

The delamination of the film was tested using the peel off test or Scotch tape test as specified in Standard Method ASTM D3359-90 method B. Figure 7 shows the cut pattern applied to the ink film. The cut should be through the ink film into the substrate. There are 6 cuts 2 mm apart as illustrated in Figure 7. After cutting, the film surface and cutting edge was smoothened by a soft brush to remove flakes.

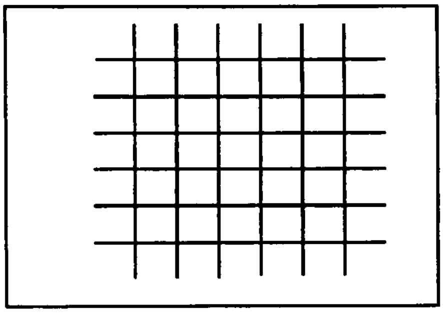


Figure 7

The cutting pattern for adhesion test.

A three inches (75 mm) long size of tape was placed smoothly and firmly over the cut ink film. Within 90 +/- 30 seconds application, the tape was removed rapidly by pulling it off at as close to an angle of 180 ^{O} as possible. The tape used was 0.75 inch (19 mm) wide semitransparent pressure-sensitive Scotch tape no. 519 and transparent pressure-sensitive Scotch tape no. 600 from 3M. ASTM recommend to use tape from the same batch to eliminate the variability of adhesion strength of the tape from batch to batch.

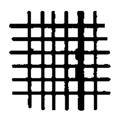
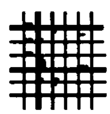
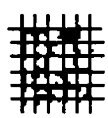
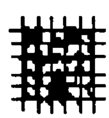
Classifications	Surface of Cross-cut area from which the flaking has occurred
5B	None
4B	
3B	
2B	
1B	
0B	Greater than 65 %

Figure 8

Classification of Adhesion Test Result.

(ASTM D3359-90)

The film surface after tape test will be classified to the following scale :

5B The edges of the cuts are completely smooth; none of the squares of the lattice is detached.

4B Small flakes of the coating are detached at intersections, less than 5% of the area is affected.

3B Small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15% of the lattice.

2B The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35% of the lattice.

1B The coating has flaked along the edges of cuts in large ribbons and whole squares have detached. The area affected is 35 to 65% of the lattice.

0B Flaking and detachment worse than grade 1.

Chapter 6

The Results

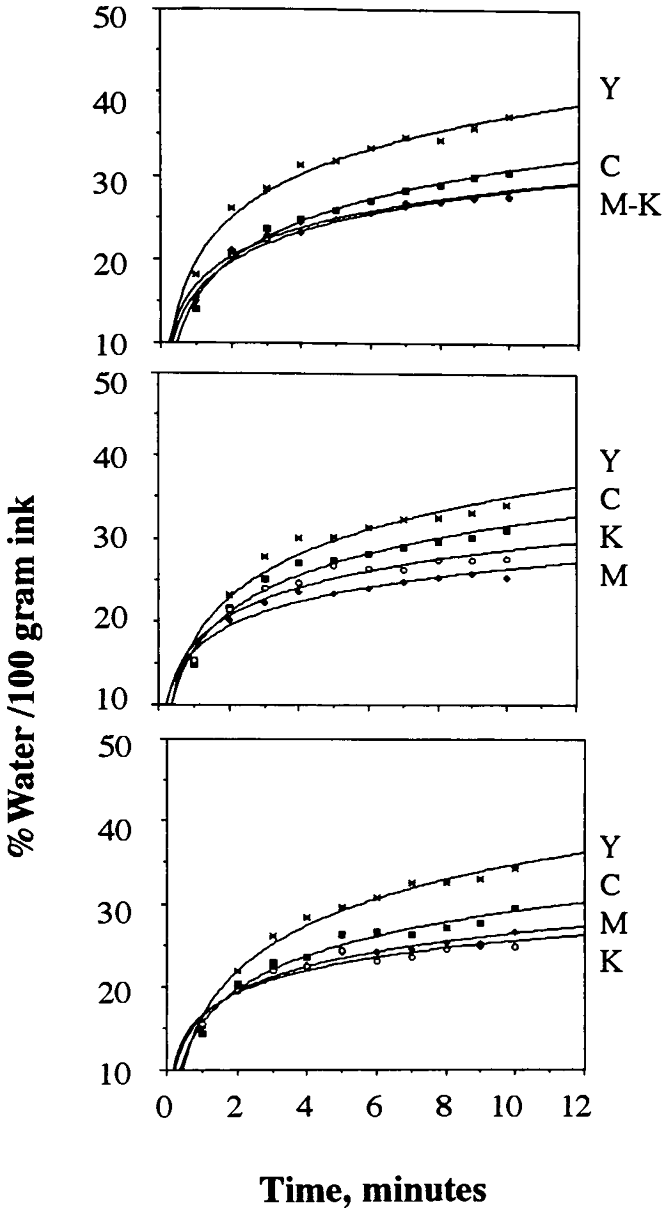
1. Water pick-up characteristics.

The ink used for this project was Ultraviolet Ink manufactured by Tjemani Toka Indonesia under licensed by Toka Shikisho, Japan. The set consisted of four color process inks, i.e. yellow, magenta, cyan and black. Two Rosos fountain solutions and commercial distilled water were used to test the water pickup rate of the inks. The fountain solution was used to simulate the actual condition on the press. Distilled water is considered a standard solution for many laboratory procedures was used in laboratory measurements of water pickup. The acidity of fountain solutions were chosen between acid and neutral as the pH range and that which is normally found in the press room. The complete data of these inks and fountain solutions are shown in Appendix A. The results of the water pickup rate test is shown on Table 2. Each number is the average of three measurements as displayed in Appendix C. % Water pickup tends to increase over time for all these inks in three fountain solutions. However, these rates are lower than the water pickup of conventional offset ink. The data were also plotted against time and classified according to the pH and to the ink color. The water pickup rate of the inks using each fountain solution are shown in Figure 9.

Table 2

Water pickup rate of four colors process UV inks

Time	Percent water pickup of four colors process UV inks											
	pH=3.4				pH=6.6				pH=7.1			
	Yellow	Magenta	Cyan	Black	Yellow	Magenta	Cyan	Black	Yellow	Magenta	Cyan	Black
1	18.15	15.39	14.04	14.96	14.90	15.39	14.79	15.27	15.27	15.15	14.40	15.40
2	26.07	21.13	20.70	20.52	20.19	21.13	21.59	21.47	21.83	19.88	20.27	19.50
3	28.54	22.93	23.67	22.38	22.23	22.93	25.09	23.91	26.00	22.28	22.93	21.93
4	31.40	24.52	24.81	23.25	23.49	24.52	27.02	24.67	28.33	22.58	23.57	22.33
5	31.80	25.96	25.93	24.75	23.33	25.96	27.42	26.74	29.53	24.21	26.20	24.27
6	33.40	25.52	26.99	25.52	23.99	25.52	28.16	26.34	30.77	24.18	26.60	23.07
7	34.77	26.89	28.32	26.42	24.73	26.89	28.99	26.24	32.43	24.48	26.20	23.43
8	34.43	26.92	29.02	26.92	25.29	26.92	29.62	27.31	32.47	25.21	27.07	24.40
9	35.86	27.39	29.97	27.55	25.76	27.39	30.06	27.38	32.97	24.84	27.63	25.07
10	37.26	27.52	30.57	27.71	25.29	27.52	31.02	27.51	34.20	26.57	29.47	24.80



pH = 3.4

Yy=19.6 + 17.64Log(x)
R^2=0.977 R=0.988
Cy=15.14 + 15.64Log(x)
R^2=0.985 R=0.992
My=16.8 + 11.61 Log(x)
R^2=0.953 R=0.976
Ky=15.92 +12.31Log(x)
R^2=0.983 R=0.991

pH = 6.6

Yy=17.55 +17.45Log(x)
R^2=0.944 R=0.971
Cy=16.49 + 15.07Log(x)
R^2=0.960 R=0.979
Ky= 17.16 + 11.47Log(x)
R^2=0.916 R=0.957
My=16.4 + 9.93Log(x)
R^2=0.933 R=0.966

pH = 7.1

Yy=16.27 +18.47Log(x)
R^2=0.986 R=0.992
Cy=15.53 + 13.58Log(x)
R^2=0.964 R=0.981
My=16.32 +10.09Log(x)
R^2=0.948 R=0.974
Ky=16.54 +8.97Log(x)
R^2=0.923 R=0.961

Figure 9

Water pickup with different fountain solution as a function of the ink.

The yellow ink appeared to have the highest water pickup rate of the tested inks in each fountain solution while black and magenta inks have a similar rate for each fountain

solution. The data point fitted the logarithmic equation and yielded high coefficient correlation (R) for each ink and fountain solution.

To more clearly show the effect of pH to each ink, the above curves were classified according to the color as shown by Figure 10.

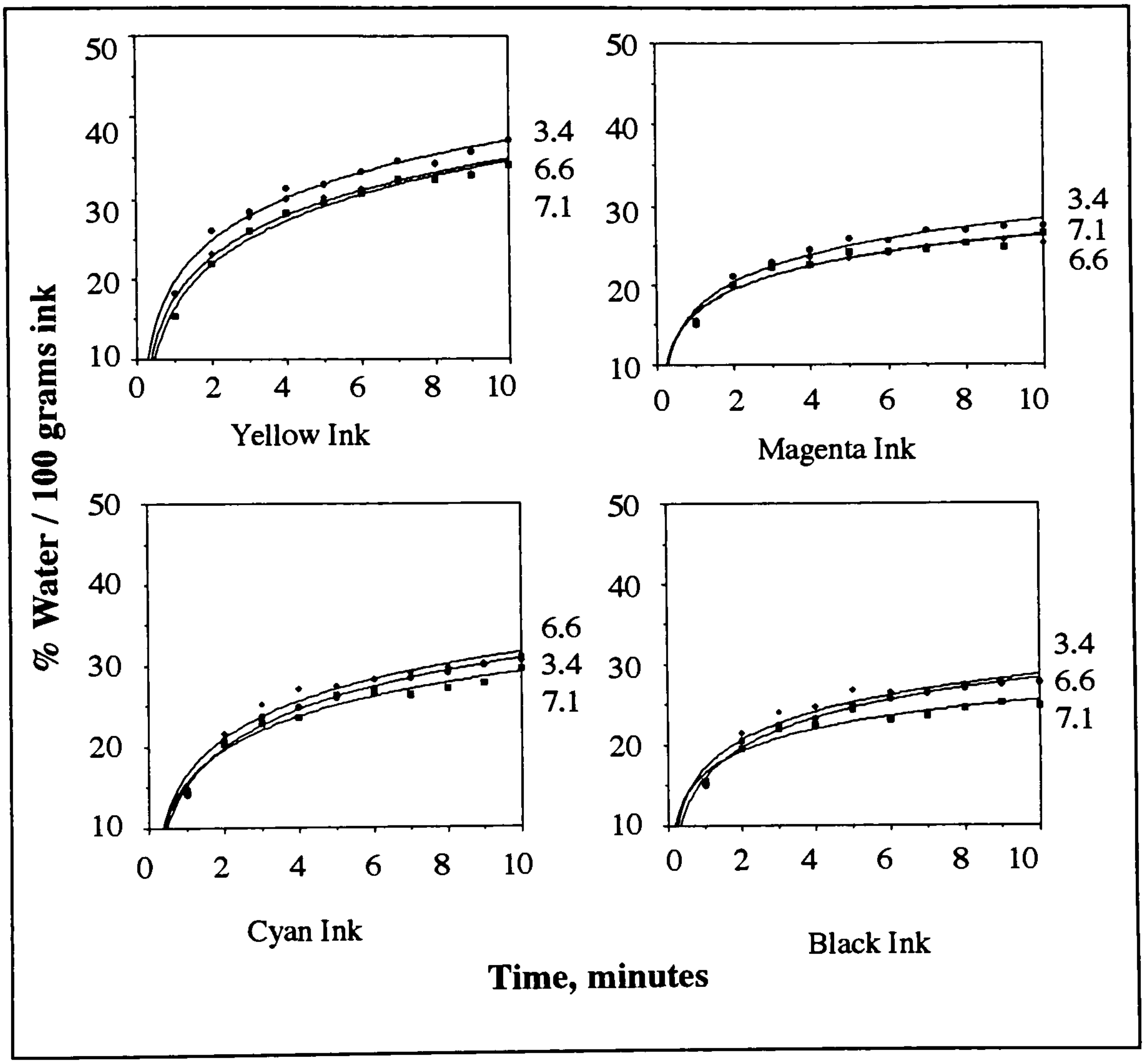


Figure 10

Water pickup rate as a function of fountain solution for each ink.

Yellow, magenta and black inks showed the same tendency. The rate is higher at the lower pH. The rates of pH=6.6 and pH=7.1 for yellow and magenta are close to each other. The solution with the acidity of 6.6 was distilled water. Although distilled water and fountain solution with the acidity of 7.1 are chemically very different and have different formulation and conductivity, the effect of acidity appears to be important for these inks. The narrow pH range between these two solution did not have a significant difference in the water pickup for yellow and magenta inks. On the other hand, the cyan ink behaved differently. The highest water pickup rate for the inks tested was reached when the inks were emulsified with distilled water. Distilled water had the lowest conductivity among all the solutions used in this experiment. Even though lower pH yielded a higher water pickup rate, the conductivity appears to have a larger effect on the water pickup rate for cyan ink.

The overall effect of acidity and different inks to the water pickup rate were tested using ANOVA for crossed design. The purpose of this significance test was to draw verbal conclusions about this study by using a numerical test. The calculated F value is compared to the F critical value from the table. The rejection of the null hypothesis implies a difference between the subjects of the test. The critical F value from the table is denoted by $F(\alpha,\upsilon_1,\upsilon_2)$ where α represent the risk, υ_1 is the degree of freedom of the numerator (the subject of the test) and υ_2 is the degree of freedom of the denominator (residual or error). ANOVA calculation for this study was performed using Minitab, the statistical package in the RIT-VAX system. The result of this calculation is shown in the following table :

Table 3

ANOVA Table of water pickup rate.

Source	DF	SS	MS	F	P
pH	2	184.710	92.086	56.51	0.000
Time	9	6188.135	687.571	421.92	0.000
Ink	3	2131.396	710.465	435.97	0.000
pH*Time	18	37.217	2.068	1.27	0.209
pH*Ink	6	126.509	21.085	12.94	0.000
Time*Ink	27	313.821	11.623	7.13	0.000
pH*Time*Ink	54	37.241	0.690	0.42	1.000
Error	240	391.112	1.630		
Total	359	9409.603			

The critical F value for the ink at 95 % confidence level is $F(0.05,3,240) = 2.60$. From Table 3, the calculated F for ink is higher than 2.6 . Therefore hypothesis 1.1 which stated that different inks have similar water pickup is rejected at 95 % confidence level. Different UV inks performed different water pickup characteristics. Since the calculated F of pH is also higher than $F(0.05,2,240) = 3.00$, hypothesis 1.3 which stated that the acidity of fountain solution does not affect the water pick-up characteristic of the ink, is also rejected at 95 % confidence level. The acidity of fountain solution affected the water pickup characteristic of the UV inks.

2. Curing time

The curing time of the ink were measured through several steps. The Argon Curing unit has never been used on a regular basis. Some important information in regard to this

curing unit remains unknown because of the lack of calibration equipment namely a radiometer. The technical sheet of the manual did not state any information regarding the intensity of the lamp, the unit of absorbed dose and the unit of the belt speed. The belt speed of the curing unit was calibrated using a stopwatch. The length of the curing unit was stated in the manual. There are four UV lamps, two of them are 300 W/inch and the other are 200 W/inch. Two meters measured the absorption dose, one for each side. The full capacity of the lamps will turn both absorption meters to 35 (70 in total). Half capacity of each side will turn the absorption meter halfway (15-18). In total, there were four lamp capacity settings available. The first experiment used full capacity for both side. In the middle of the experiment, the left lamp control burnt down. All measurements were repeated using one setting, i.e. one fourth of the overall capacity. The printed sheet was positioned in same spot in the curing unit to ensure a similar curing pattern for all the samples.

The curing system was used at the slowest speed. If the sample is completely dry, the speed is increased for the next fresh sample until the speed with a slightly wet sample was found. Several samples were passed through the curing unit using the fastest dry speed and the slightly wet speed. If the ink was still wet using the slowest speed, the sample was passed through the unit several times with the similar speed until it dried. The procedure was repeated for other samples of each color. Magenta ink appeared to dry with the fastest speed. There were different rates due to the different pH for the same ink. Cyan appeared to be the most difficult ink to dry. The curing speed was slower at low pH for yellow, magenta and black. This result led to the conclusion that higher water pickup (lower pH) for yellow, magenta and black reduced the curing speed. This conclusion was also valid for cyan ink since the slowest curing rate for cyan occurred at pH=6.6 which was the highest water pickup rate for the ink.

The difference in time needed to dry the ink between cyan and the other color was considerable. The summary of the result of this experiment is shown in the following table.

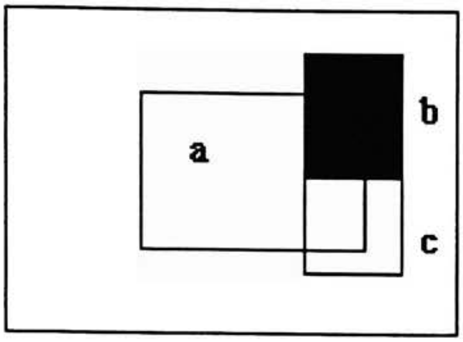
Table 4

Curing time of the UV inks at different fountain solution.

Inks	Curing time,seconds		
	pH=3.4	pH=6.6	pH=7.1
UV-Yellow	10.21	5.52	5.15
UV-Magenta	4.27	4.04	3.81
UV-Cyan	114.77	122.29	106.03
UV-Black	27.81	25.52	24.54

The cyan pigment appeared to act like a neutral density filter for the UV radiation. Referred to fig. 2, there is a possibility that the cyan pigment in this ink had lower UV radiation transmittance than the black colorant or the wavelength of the UV energy from the Argon Curing Unit was longer than 300 nm. Therefore the drying process of the cyan ink was inhibited.

To prove the first assumption, the magenta, yellow and black prints were covered by the blue laminated film and clear film. The clear film prolonged the drying process of the magenta, yellow and black inks. The blue laminated film inhibited the drying process to some large extent. The quantitative effect of this neutral density itself is different for different colored inks. The result of this process is shown in Table 5.



a : printed area
b : blue laminated film
c : clear film

Figure 11

The print with blue laminated film.

Table 5

Curing time of UV inks with neutral density.

Inks	Curing time,seconds		
	pH=6.6	Clear film	Blue film
UV-Yellow	5.52	18.20	54.60
UV-Magenta	4.04	18.20	36.40
UV-Black	25.52	35.61	71.22

The hypothesis 1.2 stated that water picked up by the ink does not change the curing rate of the inks. This hypothesis was tested using crossed design ANOVA in Minitab for the complete data as shown in Appendix B. The calculated F in Table 6 is higher than F(0.05,2,48)=3.23. Therefore hypothesis 1.2 is rejected at 95 % confidence level. Water pickup of the UV inks changed the curing rate of the inks. Table 6 also shows that the calculated F value for the ink is considerably higher than F(0.05,3,48)=2.84 which support the experiment conducted by Bassemir and others.

Table 6

ANOVA of curing time.

Source	DF	SS	MS	F	P
pH	2	261	130	24.94	0.000
Inks	3	121394	40465	7739.82	0.000
pH*Inks	6	510	85	16.27	0.000
Error	48	251	5		
Total	59	122416			

The effect of the substrates were studied by applying conventional ink to three different substrates and overcoating the ink film by the UV varnish. Due to the UV inks' tack, it was impossible to print the UV ink on the uncoated paper. Three different substrates were chosen including coated paper, uncoated paper and mylar film. Thickness, porosity, roughness and oil absorptivity of these substrates were measured as shown in Table 7.

Table 7

Substrates properties.

Substrates	Thickness	Porosity	Roughness	% K&N Oil
	per 1000th inch	mL/min	um	absorptivity
Domtar 50# offset	3.68	424	6.65	68.00
(Uncoated)				
M Offset Austria 80#	7.13	1	1.33	25.96
(Coated)				
Mylar plastic	2.75	0	1.90	9.46

The samples generated were cured and tested for resistance properties. The results were as follows :

Table 8

Curing time for overcoat varnish on different substrates.

Substrates	Curing time, seconds
Uncoated paper	12.17
Coated paper	22.6
Mylar plastic	26.84

Table 8 reveals the curing time for the overcoat varnish on different substrates. Uncoated paper is the most absorbent substrate used in this experiment and produced the fastest curing rate. Some of the varnish applied to the printed uncoated paper was absorbed by the paper which helped the curing process.

The mylar plastic used is classified as a non absorbent substrate. It is the most difficult to cure. Eventhough the sample passed the rubbing test, the varnish on the mylar plastic was still slightly wet to the touch. To find out if this result is significantly different one to another, a Oneway ANOVA was used to test the data and produced the following table :

Table 9

Oneway ANOVA for different substrates.

Source	DF	SS	MS	F	P
Substrates	2	342.2	171.1	15.13	0.005
Error	6	67.8	11.3		
Total	8	410.0			

The calculated F value is higher than F(0.05,2,6)=5.14 which means substrates have significant effect on the curing time. Hypothesis 1.4 states that the curing rate will be similar for different substrates is rejected at 95 % confidence level.

3. Resistance Properties

3.1 Film Hardness

Film hardness was measured at two different levels of scratch severity. Table 10 shows the force required to scratch the ink film. For each color, the required force to slightly mark the film is nearly alike. The required force to scratch the film down to the substrate are different for different pH with each ink. For yellow, magenta and black, the highest scratch resistance properties were produced at pH=6.6 (Distilled water). At pH=6.6 these inks generated the lowest water pick-up rate. The highest resistance properties for cyan was reached at pH=7.1 which had the lowest water pick-up rate for cyan. This phenomenon led to the conclusion that the lowest water pickup will give the highest scratch resistance.

Table 10

Film hardness of four color process UV inks.

Apparatus : Gardco/Hoffman Tester

Position : Low range, 20 - 250 grams

	Required force to scratch the film, in grams					
Inks	pH=3.4		pH=6.6		pH=7.1	
	lower	upper	lower	upper	lower	upper
Yellow	35	208	30	246	35	210
Magenta	30	170	36	192	30	190
Cyan	33	182	32	188	34	198
Black	35	200	44	250	40	244

Hypothesis 2.1 was tested using the MINITAB program as summarized in table 11. The calculated F value for pH was higher than F(0.05,2,96)=3.10 which means that hypothesis 2.1 was rejected at 95 % confidence level. Water pickup of the UV inks affected the film hardness of the cured film. The calculated F value for ink is also higher than F(0.05,3,96)=2.7 which shows the significant effect of different ink to the film hardness.

Table 11

Anova for scratch resistance/film hardness.

Source	DF	SS	MS	F	P
pH	2	5075	2538	25.83	0.000
Setting	1	890963	890963	9070.25	0.000
Ink	3	14862	4954	50.43	0.000
pH*Setting	2	3870	1935	19.7	0.000
pH*Ink	6	2810	468	4.77	0.000
Setting*Ink	3	10065	3355	34.15	0.000
pH*Set*Ink	6	2861	477	4.85	0.000
Error	96	9430	98		
Total	119	939937			

3.2. Abrasion Resistance

Abrasion resistance was measured using the GA CAT Comprehensive Abrasion Tester. Although each color was tested using several receptors (C-1, A-0 to A-5), the result

displayed here were using receptor A-5 to ensure comparability. The result was compared to the Rank Book from GAVARTI. The higher the number, the poorer the abrasion resistance of the samples. Table 12 shows the rank of the abrasion resistance for each color and each pH. There were no significant difference among pHs of each color.

Table 13 is the ANOVA summary table of abrasion resistance to test hypothesis 2.2. The calculated F value for pH was less than F(0.05,2,24)=3.40 . Therefore hypothesis 2.2 which stated that water pickup of UV inks does not affect abrasion resistance of the cured film is accepted at 95 % confidence level. On the other hand, the calculated F value for ink was higher than F(0.05,3,24)=3.01 which indicated that there was significant effect of different inks to abrasion properties of the cured film.

Table 12

Abrasion resistance of UV inks.

Apparatus : GA CAT Comprehensive Abrasion Tester

Receptor : A-5

pH	Abrassion ranks		
	3.4	6.6	7.1
Inks			
UV-Yellow	4	5	4
UV Magenta	5	5	6
UV-Cyan	5	5	5
UV-Black	6	8	5

Table 13

Anova for Abrasion resistance.

Source	DF	SS	MS	F	P
pH	2	5.0556	2.5278	3.37	0.051
Inks	3	18.0833	6.0278	8.04	0.001
pH*Inks	6	11.1667	1.8611	2.48	0.052
Error	24	18.0000	0.7500		
Total	35	52.3056			

3.3. Adhesion Resistance

Adhesion test for the samples was done using two different Scotch tapes from 3M. The pressure sensitive transparent tape code no. 600 is more white than the pressure sensitive tape code no. 519. For all color inks and pHs, these tapes yielded a similar result. The rank of the adhesion properties of the samples was judged by counting the flaked area and compared them to Figure 8 (ASTM Standard D3359). The result is shown in table 14. The higher number, the better adhesion resistance of the samples.

The adhesion resistance was similar for each pH and ink's color. There was difference among colors at similar pH. The result indicated that water pickup had no significant effect on the adhesion properties of the cured film. The ANOVA calculation to test hypothesis 2.3 is shown in table 15.

The calculated F value for the pH was only 0.50 which was considerably lower than $F(0.05,2,12)=3.89$. Therefore hypothesis 2.3 which stated that water pickup of the

UV inks does not affect the adhesion resistance of the cured film is accepted at 95% confidence level. The calculated F value for the ink was significantly higher than F(0.05,3,12)=3.49. The null hypothesis is rejected indicating that the different inks significantly have different adhesion properties of the cured film.

Table 14

Adhesion resistance of four colors UV ink.

	Adhesion rank of the ink film					
Inks	pH=3.4		pH=6.6		pH=7.1	
	600	519	600	519	600	519
Yellow	0B	0B	4B	0B	4B	0B
Magenta	0B	0B	0B	0B	0B	0B
Cyan	4B	4B	4B	4B	4B	4B
Black	4B	4B	4B	4B	4B	4B

Table 15

Anova for adhesion resistance.

Source	DF	SS	MS	F	P
pH	2	1.333	0.667	0.50	0.619
Inks	3	72.000	24.000	18.00	0.000
pH*Inks	6	4.000	0.667	0.50	0.797
Error	12	16.000	1.333		
Total	23	93.333			

3.4 Resistance properties of different substrates

The testing methods to measure resistance properties of these samples were similar to those for UV inks' samples. Table 16 shows the result of these measurements.

Table 16

Resistance properties of UV varnish on different substrates.

	Resistance properties of the varnish + ink film			
Substrates	Abrasion	Adhesion	Scratch resistance	
			lower	upper
Uncoated	5	0B	30	166
Coated	7	4B	60	176
Mylar	3	5B	30	65

Different substrates gave different resistance properties. Coated paper had the lowest resistance to abrasion but resisted delamination and scratch. Mylar had good resistance to abrasion and delamination, but easily scratched. Uncoated paper poorly resisted delamination. The flaked formed was between the first layer to the substrate (between ink and substrate). For all the samples, there was no apparent flaking between first layer (ink) and second layer (Varnish).

Table 17 shows the oneway ANOVA table for these measurements. ANOVA had to be done one by one since the sample size for these three properties were different.

Table 17

Oneway ANOVA for the resistance properties.

Analysis of Variance on abrasion

Source	DF	SS	MS	F	P
Substrates	2	24.89	12.44	4.67	0.060
Error	6	16.00	2.67		
Total	8	40.89			

Analysis of Variance on Scratchtest

Source	DF	SS	MS	F	P
Substrates	2	28302	14151	4.64	0.019
Error	27	82383	3051		
Total	29	110684			

Analysis of Variance on adhesion resistance

Source	DF	SS	MS	F	P
Substrates	2	45.17	22.58	17.30	0.001
Error	9	11.75	1.31		
Total	11	56.92			

For abrasion resistance, the calculated F value is lower than F(0.05,2,6)=5.14 which means substrates have insignificant effect on abrasion resistance of the cured film. F(0.05,2,27)=5.45 is higher than calculated F value for scratch resistance which also indicates that substrates have insignificant effect on scratch resistance. The calculated F value for adhesion resistance is higher than F(0.05,2,9)=8.02. Among these three resistance properties, only adhesion resistance was significantly affected by the differences in substrates.

4. Other Findings.

4.1 Tack

In conducting the water pickup measurements, it was found that the UV inks were more difficult to work than the conventional ink, therefore tack measurement was performed. The tack was measured at two different rotating speeds such as 800 rpm and 1200 rpm. The result is shown in table 18. The tack of the inks are significantly higher than the conventional ink which is usually less than 25. Figure 12 shows the tack curves derived from table compared to the conventional ink. The conventional ink used was process black ink RS-0110-445 . Magenta ink had a flying(misting) problem at the higher speed. Tacks of the UV inks were high at the beginning of the process, after three minutes, the curves tend to flatten out. The shape of the curves might be interpreted to indicate that the inks were thixotropic.

At high speed, the magenta and yellow curves converged at some points. This phenomenon needs careful attention at the press since it might predict a trapping problem in multicolor printing. The ranks of the tack were difficult to judge since the inks performed differently at different speeds.

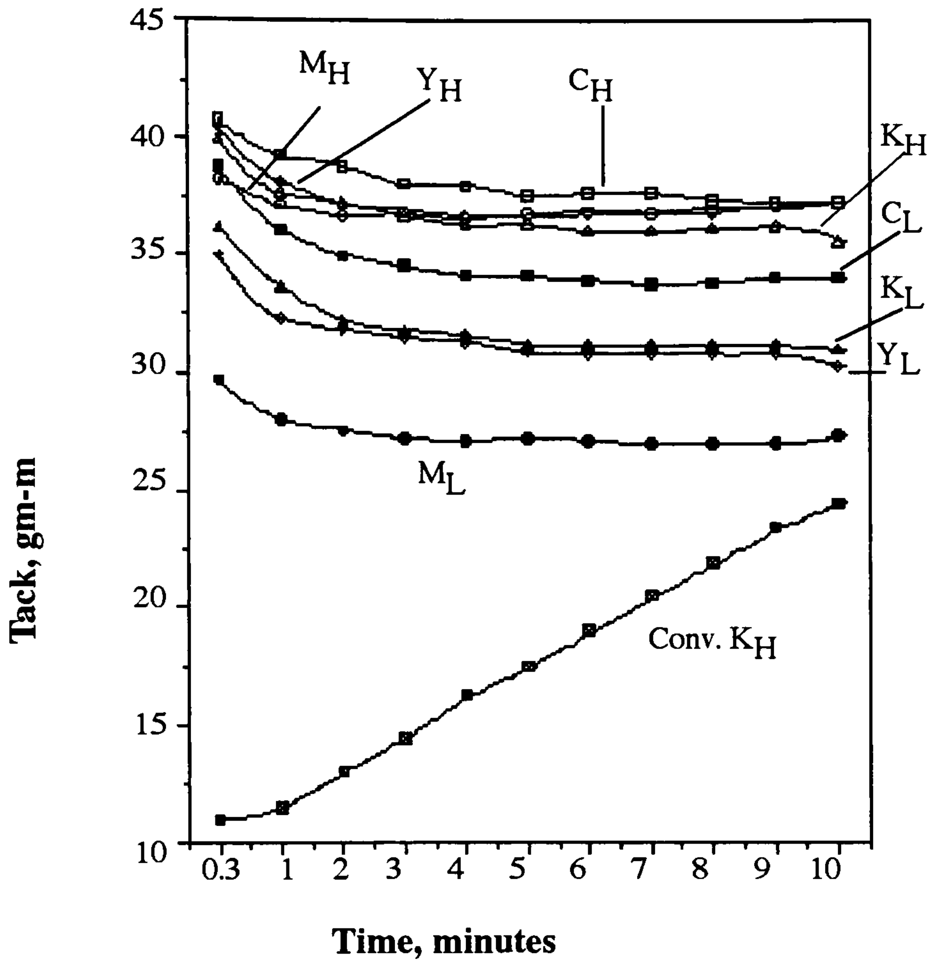
Table 18

Tack value of the four colors process UV inks.

Apparatus : LTF Inkometer, Thwing Albert Instrument company

Temperature : 90 ^{O}F

	Tack value of four colors process UV inks, in gm -m							
Time	Yellow-102994		Magenta-82255		Cyan-102975		Black-1021009	
	800	1200	800	1200	800	1200	800	1200
20 sec.	35.00	40.50	29.67	38.33	38.83	40.83	36.17	40.00
1	32.33	38.17	28.08	37.17	36.08	39.33	33.67	37.67
2	31.83	37.25	27.58	36.67	35.00	38.83	32.25	37.25
3	31.50	36.92	27.25	36.75	34.50	38.08	31.83	36.67
4	31.33	36.67	27.17	36.58	34.17	38.00	31.58	36.33
5	30.92	36.67	27.25	36.75	34.17	37.58	31.25	36.33
6	30.83	36.75	27.17	36.92	33.92	37.67	31.25	36.08
7	30.83	36.75	27.00	36.83	33.75	37.67	31.25	36.08
8	30.75	36.83	27.00	37.00	33.83	37.42	31.17	36.17
9	30.75	37.17	27.33	37.08	34.00	37.25	31.17	36.25
10	30.25	37.25	27.33	37.33	34.00	37.33	31.00	35.58



Y : Yellow, M : Magenta, C : Cyan, K : Black

Subscript : H : High speed = 1200 rpm

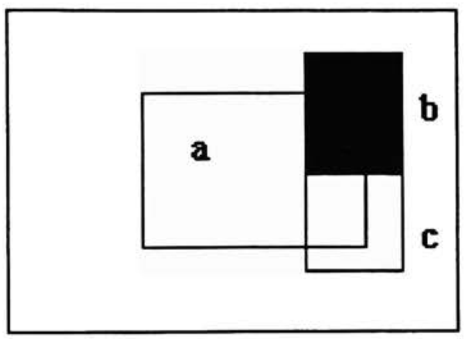
L : Lower speed = 800 rpm

Figure 12

Tack of UV inks compared to conventional ink.

4.2 Different curing stages

All the above samples could be considered cured at the optimum level. As stated earlier, the sample covered with the clear and blue film had longer curing time. Therefore, those samples cured using blue and clear film had three different curing stages. When the UV ink under clear film was fully cured, the part under blue film would be undercured and the rest of the ink without any film would be overcured as described in Figure 13.



a : printed area without film : overcured stage

b : printed area with blue film : undercured stage

c : printed area with clear film : cured stage

Figure 13

Three different curing stages.

The samples cured with this method was subjected to the abrasion test using the GA CAT Comprehension Abrasion Tester. The result is shown in the following table. The result shows that zone b which was undercured had the poorest abrasion resistance. The overcured zone (zone a) performed better than the undercured zone and slightly worse than zone c.

Table 19

Abrasion ranks for different curing stages.

Inks	Abrasion ranks		
	zone a	zone b	zone c
Yellow	4	9	4
Magenta	6	9	4
Black	4	7	3

Chapter 7

Summary and Conclusions

This thesis tried to answer some questions regarding one of the important characteristics of UV curable offset inks. This includes water pickup rate. Several hypotheses were tested and are summarized in table 20. Water pickup rate of this particular set of UV inks were influenced by the acidity of the fountain solution. Since different inks produced a different water pickup rate, the effects of acidity on the water pickup rate will vary for each ink. The result also showed that different inks of this set performed differently in terms of the water pickup rate.

Curing time of the printed sheets were altered by the color of the ink, the amount of water picked up by the ink and also the absorbancy of the substrates. Due to its colorant transmittance characteristic, cyan appeared to be the most difficult color to cure for this particular set of UV inks. This result is different from previous experiments by Otsubo and Bassemir. There is a high possibility that this difference is due to the difference in UV wavelength radiation used. Magenta showed the fastest curing rate among these inks. Increasing the amount of water picked up by the ink inhibited the curing process. Absorbent substrates are likely to have a faster curing rate than a less absorbent substrate. The substrate absorbed some of the liquid state of the ink and accelerated the curing process.

Water pickup rate of the ink only affected the film hardness of the cured film among the three resistance properties studied in this experiment. There is a significant effect on the ink to film hardness, abrasion resistance and adhesion resistance. On the other hand, only adhesion resistance was significantly affected by different absorptivity of the substances. The curing stages also influenced the resistance properties of the cured film. The overcured film is likely to have better abrasion resistance than the undercured film. Since only abrasion resistance of this sample was measured, generalization for the other resistance properties could not be done.

Table 20

Summary of hypotheses testing.

Null Hypotheses	Calculated F	F value	Conclusions
1.1 Different UV inks have similar water pickup	435.97	2.60	Ho is rejected
1.2 Water pickup of the UV inks does not change the curing rate	24.94	3.23	Ho is rejected
1.3 The acidity of fountain solution does not affect the water pickup characteristics of the ink	56.51	3.00	Ho is rejected
1.4 The curing rate will be similar for different substrates	15.13	5.14	Ho is rejected
2.1 Water pickup of the UV ink does not affect film hardness	25.83	3.10	Ho is rejected
2.2 Water pickup of the UV ink does not affect abrasion resistance	3.37	3.40	Ho is accepted
2.1 Water pickup of the UV ink does not affect adhesion resistance	0.50	3.89	Ho is accepted

Tack of this particular set of UV inks were considerably higher than that of conventional ink. The shape of the curves indicates that the inks are probably thixotropics. After the inks were worked for a short period, the tack of the inks become stabile. As expected, the tack increased as the speed increased. High tack is expected to become a problem in substrate selection.

The study of the relation between curing stages and the end use properties of the film is recommended for further study.

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APPENDIX A

MATERIAL DATA

APPENDIX A

MATERIAL DATA

A.1 UV Inks data

- Manufacturer : PT Tjemani Toka, under licensed from TOKA, JAPAN
  Jalan Pasar Minggu Km 16 Jakarta - INDONESIA
- Descriptions:
  UVL Carton Black batch no. 1021009
  UVL Carton Yellow batch no. 102974
  UVL Carton Cyan batch no. 102975
  UVL Carton Magenta batch no. 82255

A.2 Heatset Ink data

- Manufacturer : Morrison Ink Company
  4801 W, 160th St, Cleveland, OHIO
- Description : 400445
  O/S SF Process Black
  MSDS #14
  H=1 F=1 R=0
  5 Lbs, Batch no. L3743

A.3 Fountain solutions data

Fountain solution 1 : Rosos G7A "V"comb RV 1000

Isopropil Alcohol , 10 %

pH : 3.4

Conductivity : 1600 uS

Fountain solution 2 : Rosos G-C #1 J Phosphate Free

Allied Photocff-1-3 oz/gal

Ethylene Glycol, ACC 1H - 50 ppm- Dgnafouw Neutral

pH : 7.1

Conductivity : 1900 uS

Distilled Water : 'Aqua Pure', sodium free

bottled by Meyer Bros, Apple Products

West Seneca, NY 14224

pH = 6.6

Conductivity : 100 uS

A.4 Substrates data

- Uncoated Paper : Domtar 50#

Windsor Offset

- Coated Paper : Seneca paper 80#

M Offset, Austria

Mylar Plastic : Cronar Clear Film C-72

DUPONT Graphic Arts Film

Imaging Systems Department, Wilmington, DE 19898

A.5 Varnish data

UV Varnish overcoat

Product J9328D B 9107130

Bookcover Hart Graphic

Pierce & Stevens Corp. PO Box 218 Kimberton, PA 19442

A.6 Receptor Paper data (for Abrasion Resistance)

C-1 : Glossy coated paper is used for testinglow to average quality print (magazine covers, inserts,etc).

C-5 : Uncoated paper is used for testing abrasion or smudging of newspapers or all non-contact printing or electronic printing copies.

A-0 : Imperial Lapping film with aluminium oxide abrasive particles of 3u diameter (light purple film)

A-1 : Imperial Lapping film with aluminium oxide abrasive particles of 9u diameter (light blue film)

A-3 : Imperial Lapping film with aluminium oxide abrasive particles of 12u diameter (yellow film)

A-4 : Imperial Lapping film with aluminium oxide abrasive particles of 30u diameter (green film)

A-5 : Imperial Lapping film with aluminium oxide abrasive particles of 40u diameter (dark blue film)

All the receptors "A" can be used wet and dry.

B2-2, B2-3 : Glossy coated paper printed with a colored ink for evaluating the abrasiveness of another printed panel or corrugated-over-coated or not (tan)

B3-2,B3-3 : Glossy coated paper printed with a colored ink for evaluating the abrasiveness of another printed panel or corrugated-over-coated or not (blue)

B2-2 is the most sensitive of the four. Higher number indicates a higher density.

A-7 K and N data

K and N Testing Ink

Lot No. D92

K and N Laboratory

6502 Joliet Road #104, Countryside, IL 60525

A-8 Tapes data (for Adhesion Tape)

Manufacturer : 3M Commercial Office Supply Division

St Paul, MN 55144

Description :

-Scotch Transparent tape, catalog no. 600

1 Roll 3/4 in x 1296 in

Scotch semi transparent tape, catalog no. 519

1 Roll 3/4 in x 1296 in

APPENDIX B

EQUIPMENT DATA

APPENDIX B

EQUIPMENT DATA

B.1 Water Pickup Equipments

- Mixer : Duke Ink -Water Emulsification Tester

  Patent No. 4403867

  Duke Custom Systems, Inc.

  8371 Hwy 49, Pleasant View, TN 37146

  Model :D-10 Serial No. 779

Balance : OHaus, Newark, NJ

  Max. capacity : 610 grams

  Accuracy : 0.05 grams

B.2 Printing Equipment

Little Joe Offset Color Swatching Press

Model no. S76, Serial no. 539

Little Joe Color Swatcher Inc.

Clark, NJ

B.3 Curing unit

- Apparatus : UV Trix Curing Unit, ARGON Industrie Meccaniche Milano Italia
- Bulb intensity : 300 W/inch and 200 W/inch

Number of bulbs : 4

Length of the curing unit : 2250 mms

B.4 Abrasion Resistance equipment

- GA CAT Comprehensive Abrasion Tester

  Model no. B, Serial no. 043-R

  Frequency : 60 Hz. Voltage : 120 V

  Gavarti Associates LTD

  9240 N. Sleepy Hollow Lane, Milwauke, WI 53217

B.5 Scratch tester

- Gardco/Hoffman SAM Tester

  Paul N. Gardner Company, Inc.

  Gardner Building, 316 N.E. First Street, Pompano Beach, FL 33060

B.6 Roughness/Porosity

Parker Print-Surf

World Patents applied for serial no. 8919

H.E. Messmer LTD.

London- England

B.7 Thickness

- tmi Model 549 Micrometer

  Testing Machines, Inc.

  Ammityville, L.I, NY

B.8 Tack

Lithographic Technical Foundation, Inc (LTF) Inkometer

under licensed of Thwing-Albert Instrument Company

Philadelphia, USA

Order no. 57L-1470, serial no. 11868

APPENDIX C

MEASUREMENT RESULT

APPENDIX C

MEASUREMENT RESULT

C.1 Water pickup

Table 21

Water pickup of UV inks with Fountain solution 1.

Fountain solution 1 :Rosos G7A "V"comb RV 1000

pH : 3.4, Conductivity : 1600 μS

Inks	% Water pickup / 100 gram ink							
	Yellow / 102974				Magenta / 82255			
Time	1	2	3	Average	1	2	3	Average
Initial	50.05	50.10	50.00		50.10	49.95	50.00	
1	15.28	23.55	15.60	18.15	15.97	14.91	15.30	15.39
2	24.68	28.14	25.40	26.07	20.96	21.52	20.90	21.13
3	27.27	29.34	29.00	28.54	23.15	23.12	22.50	22.93
4	31.07	30.14	33.00	31.40	24.95	24.52	24.10	24.52
5	31.27	31.34	32.80	31.80	26.15	25.93	25.80	25.96
6	33.27	33.73	33.20	33.40	26.15	25.13	25.30	25.52
7	34.17	34.93	35.20	34.77	27.25	26.93	26.50	26.89
8	34.27	34.93	34.10	34.43	26.75	25.93	28.10	26.92
9	34.27	35.73	37.60	35.86	27.35	26.53	28.30	27.39
10	36.26	38.32	37.20	37.26	26.75	26.93	28.90	27.52

Table 21 (Continued)

Water pickup of UV inks with Fountain solution 1.

Fountain solution 1 : Rosos G7A "V"comb RV 1000

pH : 3.4, Conductivity : 1600 μS

Inks	% Water pickup / 100 gram ink							
	Cyan / 102975				Black / 1021009			
Time	1	2	3	Average	1	2	3	Average
Initial	49.90	50.95	49.95		50.00	50.10	50.00	
1	17.33	11.68	13.11	14.04	14.60	16.87	13.40	14.96
2	20.94	18.74	22.42	20.70	19.00	22.16	20.40	20.52
3	24.25	23.55	23.22	23.67	22.20	22.85	22.10	22.38
4	25.85	24.24	24.32	24.81	23.40	23.85	22.50	23.25
5	27.86	26.01	23.92	25.93	23.90	25.95	24.40	24.75
6	28.86	26.30	25.83	26.99	25.40	26.45	24.70	25.52
7	30.46	27.58	26.93	28.32	26.10	27.25	25.90	26.42
8	30.46	28.16	28.43	29.02	27.80	27.05	25.90	26.92
9	31.26	30.13	28.53	29.97	28.10	27.84	26.70	27.55
10	32.26	30.13	29.33	30.57	28.20	28.24	26.70	27.71

Table 22

Water pickup of UV inks with Fountain solution 2.

Fountain solution 2 : Rosos G-C #1 J Phosphate Free

Allied Photocff-1-3 oz/gal

Ethylene Glycol, ACC 1H - 50 ppm- Dgnafouw Neutral

pH : 7.1 , Conductivity : 1900 μS

Inks	% Water pickup / 100 gram ink							
	Yellow / 102974				Magenta / 82255			
Time	1	2	3	Average	1	2	3	Average
Initial	50.00	50.00	50.00		50.10	50.00	50.05	
1	14.30	16.40	15.10	15.27	15.57	14.40	15.48	15.15
2	20.90	22.20	22.40	21.83	19.56	19.90	20.18	19.88
3	25.70	26.60	25.70	26.00	23.95	20.60	22.28	22.28
4	27.90	29.20	27.90	28.33	22.55	21.70	23.48	22.58
5	29.10	29.80	29.70	29.53	23.95	22.60	26.07	24.21
6	29.30	32.20	30.80	30.77	24.55	23.00	24.98	24.18
7	32.10	33.80	31.40	32.43	23.95	23.30	26.17	24.48
8	31.80	33.50	32.10	32.47	24.15	24.50	26.97	25.21
9	32.90	33.50	32.50	32.97	24.35	24.20	25.97	24.84
10	33.90	36.20	32.50	34.20	26.75	28.00	24.98	26.57

Table 22 (Continued)

Water pickup of UV inks with Fountain solution 2

Fountain solution 2 : Rosos G-C #1 J Phosphate Free

Allied Photocff-1-3 oz/gal

Ethylene Glycol, ACC 1H - 50 ppm- Dgnafouw Neutral

pH : 7.1 , Conductivity : 1900 μS

Inks	% Water pickup / 100 gram ink							
	Cyan / 102975				Black / 1021009			
Time	1	2	3	Average	1	2	3	Average
Initial	50.00	50.00	50.00		50.00	50.00	50.00	
1	14.20	13.80	15.20	14.40	15.20	14.80	16.20	15.40
2	19.80	21.00	20.00	20.27	18.10	20.00	20.40	19.50
3	22.60	24.00	22.20	22.93	22.20	20.80	22.80	21.93
4	22.80	25.20	22.70	23.57	22.40	23.00	21.60	22.33
5	27.20	27.20	24.20	26.20	25.20	24.20	23.40	24.27
6	26.80	26.40	26.60	26.60	24.20	23.80	21.20	23.07
7	27.20	26.00	25.40	26.20	22.90	24.00	23.40	23.43
8	27.60	27.40	26.20	27.07	24.20	25.80	23.20	24.40
9	27.50	28.00	27.40	27.63	24.20	26.00	25.00	25.07
10	29.00	30.20	29.20	29.47	25.40	26.20	22.80	24.80

Table 23

Water pickup of UV inks with Distilled water

Distilled Water : 'Aqua Pure', sodium free

pH = 6.6

Conductivity : 100 uS

Inks	% Water pickup / 100 gram ink							
	Yellow / 102974				Magenta / 82255			
Time	1	2	3	Average	1	2	3	Average
Initial	50.10	49.95	49.85		49.90	50.05	50.10	
1	16.07	13.41	16.55	15.34	15.43	13.79	15.47	14.90
2	23.45	21.52	24.77	23.25	20.04	19.88	20.66	20.19
3	27.25	26.53	29.89	27.89	22.04	22.58	22.06	22.23
4	29.84	29.13	31.19	30.05	22.24	24.18	24.05	23.49
5	30.84	27.93	32.00	30.25	23.75	21.78	24.45	23.33
6	31.64	29.53	32.80	31.32	24.25	23.48	24.25	23.99
7	33.83	30.73	32.40	32.32	24.75	24.38	25.05	24.73
8	33.93	29.33	34.00	32.42	25.65	24.58	25.65	25.29
9	34.03	30.13	35.01	33.06	25.75	25.77	25.75	25.76
10	34.33	31.33	36.61	34.09	26.45	24.18	25.25	25.29

Table 23 (Continued)

Water pickup of UV inks with Distilled water

Distilled Water : 'Aqua Pure', sodium free

pH = 6.6 Conductivity : 100 µS

Inks	% Water pickup / 100 gram ink							
	Cyan / 102975				Black / 1021009			
Time	1	2	3	Average	1	2	3	Average
Initial	50.00	50.00	50.05		49.90	50.05	50.00	
1	13.00	15.50	15.88	14.79	14.53	15.68	15.60	15.27
2	20.30	22.60	21.88	21.59	19.94	21.78	22.70	21.47
3	25.20	24.60	25.47	25.09	23.35	24.38	24.00	23.91
4	26.80	26.60	27.67	27.02	23.95	24.38	25.70	24.67
5	26.40	27.20	28.67	27.42	26.05	27.97	26.20	26.74
6	27.20	27.60	29.67	28.16	25.55	26.27	27.20	26.34
7	27.90	29.40	29.67	28.99	26.05	26.37	26.30	26.24
8	27.60	29.80	31.47	29.62	27.25	27.27	27.40	27.31
9	28.50	30.20	31.47	30.06	27.66	26.97	27.50	27.38
10	30.20	30.20	32.67	31.02	27.66	27.37	27.50	27.51

C.2 Tack

Table 24

Tack of the UV inks at lower speed

Speed : 800 rpm, temperature : 90 ^{O}F

Inks	Tack , gm-m							
	Yellow / 102974				Magenta / 82255			
Time	1	2	3	Average	1	2	3	Average
20 sec.	31.50	37.00	36.50	35.00	30.50	30.00	28.50	29.67
1	29.50	33.50	34.00	32.33	28.50	28.50	27.25	28.08
2	29.00	34.50	32.00	31.83	28.00	27.50	27.25	27.58
3	28.50	34.50	31.50	31.50	28.00	26.50	27.25	27.25
4	28.50	34.50	31.00	31.33	28.25	26.00	27.25	27.17
5	28.00	34.50	30.25	30.92	28.25	25.75	27.75	27.25
6	28.25	34.50	29.75	30.83	28.50	25.25	27.75	27.17
7	28.50	34.50	29.50	30.83	28.75	24.50	27.75	27.00
8	28.50	35.00	28.75	30.75	28.75	24.50	27.75	27.00
9	29.00	35.00	28.25	30.75	29.25	24.25	28.50	27.33
10	28.00	35.00	27.75	30.25	29.25	24.00	28.75	27.33

Table 24 (continued)

Tack of the UV inks at lower speed

Speed : 800 rpm, temperature : 90 ^{O}F

Inks	Tack , gm-m							
	Cyan / 102975				Black / 1021009			
Time	1	2	3	Average	1	2	3	Average
20 sec.	42.50	37.00	37.00	38.83	37.50	35.50	35.50	36.17
1	38.50	34.75	35.00	36.08	34.50	33.50	33.00	33.67
2	36.50	34.25	34.25	35.00	33.50	32.00	31.25	32.25
3	35.00	34.25	34.25	34.50	33.50	31.50	30.50	31.83
4	34.25	34.00	34.25	34.17	33.25	31.50	30.00	31.58
5	34.00	34.25	34.25	34.17	33.25	31.00	29.50	31.25
6	33.00	34.25	34.50	33.92	33.25	31.50	29.00	31.25
7	32.50	34.25	34.50	33.75	33.50	31.75	28.50	31.25
8	32.25	34.50	34.75	33.83	33.50	32.00	28.00	31.17
9	32.25	34.75	35.00	34.00	33.75	32.25	27.50	31.17
10	32.25	34.75	35.00	34.00	33.75	31.75	27.50	31.00

Table 25

Tack of the UV inks at higher speed

Speed : 1200 rpm, temperature : 90 °F

Inks	Tack , gm-m							
	Yellow / 102974				Magenta / 82255			
Time	1	2	3	Average	1	2	3	Average
20 sec.	38.50	40.50	42.50	40.50	37.50	38.50	39.00	38.33
1	36.50	37.50	40.50	38.17	36.50	37.50	37.50	37.17
2	35.75	37.00	39.00	37.25	35.75	37.00	37.25	36.67
3	35.75	37.00	38.00	36.92	36.00	37.25	37.00	36.75
4	35.75	36.75	37.50	36.67	36.00	37.00	36.75	36.58
5	35.75	36.75	37.50	36.67	36.00	37.25	37.00	36.75
6	36.00	36.75	37.50	36.75	36.00	37.25	37.50	36.92
7	36.00	36.75	37.50	36.75	36.00	37.50	37.00	36.83
8	36.00	37.00	37.50	36.83	36.00	37.50	37.50	37.00
9	36.00	37.50	38.00	37.17	36.25	37.50	37.50	37.08
10	36.50	37.00	38.25	37.25	36.50	38.00	37.50	37.33

Table 25 (Continued)

Tack of the UV inks at higher speed

Speed : 1200 rpm, temperature : 90 ^{O}F

Inks	Tack , gm-m							
	Cyan / 102975				Black / 1021009			
Time	1	2	3	Average	1	2	3	Average
20 sec.	39.00	38.50	45.00	40.83	39.00	40.00	41.00	40.00
1	38.00	36.50	43.50	39.33	37.00	37.50	38.50	37.67
2	37.00	36.50	43.00	38.83	37.00	37.00	37.75	37.25
3	37.00	35.75	41.50	38.08	36.50	36.50	37.00	36.67
4	37.00	36.00	41.00	38.00	37.00	36.50	35.50	36.33
5	37.00	35.75	40.00	37.58	36.50	37.00	35.50	36.33
6	37.00	36.50	39.50	37.67	36.75	36.50	35.00	36.08
7	37.50	36.50	39.00	37.67	37.00	36.75	34.50	36.08
8	37.50	36.50	38.25	37.42	37.00	37.50	34.00	36.17
9	37.75	36.25	37.75	37.25	37.50	37.50	33.75	36.25
10	38.00	36.50	37.50	37.33	37.25	37.00	32.50	35.58

Table 26

Curing Time data

Apparatus : UV Trix Curing Unit, ARGON Industrie Meccaniche Milano Italia

Bulb intensity : 300 W/inch and 200 W/inch

Number of bulbs : 4

Length of the curing unit : 2250 mms

Age of printed sample : 5 - 20 minutes

Cure test used : Rubbing test/ dry to the touch

Power used : 1/4 of full capacity

Inks	Substrate	pH	Curing time , seconds				
UV-Yellow	Coated	3.4	10.52	11.02	9.85	9.85	9.85
	paper	6.6	5.64	5.32	6.01	5.32	5.32
		7.1	5.03	5.32	5.32	5.03	5.03
UV-Magenta	Coated	3.4	4.17	4.24	4.32	4.32	4.32
	paper	6.6	4.17	4.02	3.95	4.02	4.02
		7.1	4.02	3.7	3.95	3.7	3.7
UV-Cyan	Coated	3.4	113.09	115.68	115.68	113.73	115.68
	paper	6.6	115.68	115.68	126.7	126.7	126.7
		7.1	101.22	107.23	107.23	107.23	107.23
UV-Black	Coated	3.4	33.69	25.48	28.92	25.48	25.48
	paper	6.6	28.92	24.31	25.02	25.02	24.31
		7.1	25.48	24.31	24.31	24.31	24.31
Ink +Varnish	Uncoated		11.02	11.02	14.46		
	paper						
Ink + Varnish	Coated		22.04	23.73	22.04		
	paper						
Ink + Varnish	Mylar		33.06	23.73	23.73		

C.3.2 Curing unit speed calibration

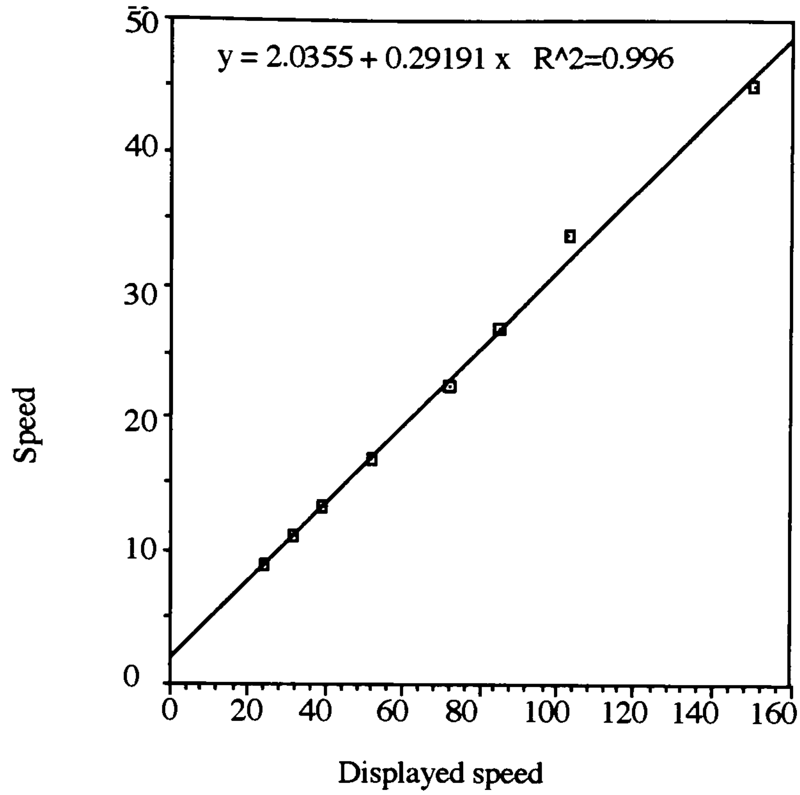

Figure 14

Calibration curve for curing unit speed

The above curve was derived from the following data :

Table 27

Belt speed data

Time	display	speed
sec		m/min
15	24	9.00
12	32	11.25
10	39	13.50
8	52	16.88
6	72	22.50
5	85	27.00
4	103	33.75
3	150	45.00

The third column was calculated as follows :

speed = length of the curing unit/time

where :

length of the curing unit = 2250 mm

The calibration equation was then used to calculate the time needed to pass the curing unit at displayed speed (curing time at displayed speed).

Table 28

Curing time calibration table

Display	Speed	Time
	m/min	second
20	7.87	17.15
25	9.33	14.46
30	10.79	12.51
35	12.25	11.02
37	12.84	10.52
40	13.71	9.85
50	16.63	8.12
60	19.55	6.91
70	22.47	6.01
78	24.80	5.44
80	25.39	5.32
85	26.85	5.03
90	28.31	4.77
94	29.48	4.58
99	30.93	4.36
104	32.39	4.17
110	34.15	3.95
137	42.03	3.21
150	45.82	2.95

C.4 Scratch resistance

Table 29

Scratch resistance data

Apparatus : Gardco S.A.M. Tester

Position : Low range, 20 - 250 grams

End points : - slightly marked : the lower point

- scratched through the paper : the upper point

Inks	% Water	Required force to scratch the film				
	pH	1	2	3	4	5
	3.4	30	40	45	30	30
		200	200	220	200	220
UV-Yellow	6.6	30	30	30	30	30
Coated		240	240	250	250	250
	7.1	30	30	30	40	45
		200	200	200	250	200
	3.4	30	30	30	30	30
		170	220	150	150	160
UV-Magenta	6.6	35	35	35	35	40
Coated		220	180	190	190	180
	7.1	30	30	30	30	30
		190	190	190	190	190
	3.4	30	40	30	30	35
		190	170	180	180	190
UV-Cyan	6.6	35	30	35	30	30
Coated		190	180	190	190	190
	7.1	30	40	30	35	35
		190	200	200	200	200
	3.4	30	30	30	40	45
		200	200	200	200	200
UV-Black	6.6	40	40	40	50	50
Coated		250	250	250	250	250
	7.1	30	30	45	45	50
		220	250	250	250	250
Varnish		50	60	70	50	70
Coated		190	180	170	170	170
Varnish		30	30	30	30	30
Uncoated		180	160	160	170	160
Varnish		30	30	30	30	30
Mylar		60	65	60	60	80

C.5 Abrasion Resistance

Table 30

Abrasion resistance data

Inks/	pH	Abrassion ranks		
Substrates		1	2	3
	3.4	4	4	4
UV-Yellow	6.6	5	5	5
Coated				
	7.1	4	3	4
	3.4	5	5	5
UV-Magenta	6.6	5	5	6
Coated				
	7.1	6	6	6
	3.4	5	4	6
UV-Cyan	6.6	2	6	6
Coated				
	7.1	5	4	5
	3.4	6	6	5
UV-Black	6.6	9	7	7
Coated				
	7.1	5	5	5
Varnish		8	7	5
Coated				
Varnish		6	4	6
Uncoated				
Varnish		5	1	2
Mylar				

C.6 Adhesion resistance

Table 31

Adhesion resistance data

Inks	pH	Adhesion ranks			
		1	2	3	4
	3.4	0B	0B	0B	0B
		0B	0B	0B	0B
UV-Yellow	6.6	4B	4B	4B	4B
Coated		0B	0B	0B	0B
	7.1	4B	4B	4B	4B
		0B	0B	0B	0B
	3.4	0B	0B	1B	0B
		0B	0B	0B	1B
UV-Magenta	6.6	0B	0B	0B	0B
Coated		0B	0B	0B	0B
	7.1	0B	0B	0B	0B
		0B	0B	0B	0B
	3.4	4B	4B	4B	4B
		4B	4B	4B	4B
UV-Cyan	6.6	4B	4B	4B	4B
Coated		4B	4B	4B	4B
	7.1	4B	4B	4B	4B
		4B	4B	4B	4B
	3.4	4B	4B	4B	4B
		4B	4B	4B	4B
UV-Black	6.6	4B	4B	4B	4B
Coated		4B	4B	4B	4B
	7.1	4B	4B	4B	4B
		4B	4B	4B	4B
Heatset					
Coated		0B	2B	4B	4B
Heatset					
Uncoated		0B	0B	1B	0B
Heatset					
Mylar		5B	5B	5B	5B

APPENDIX D

STATISTIC PROGRAMS

APPENDIX D

STATISTIC PROGRAMS

C.1 Minitab for Water pickup

```
MTB> Outfile'wpu'
MTB> Set c1 # pH
DATA> (1:3)120
DATA>end
MTB>set c2 #Time
DATA>3(1:10)12
DATA>end
MTB>set c3 #Inks
DATA>30(1:4)3
DATA>end
MTB>set c4 #wpu
DATA> 34.27 35.73 37.6 27.35 26.53 28.3 31.26 30.13 28.53 28.1 27.84 26.7
DATA> 36.26 38.32 37.2 26.75 26.93 28.9 32.26 30.13 29.33 28.2 28.24 26.7
DATA> 16.07 13.41 16.55 15.43 13.79 15.47 13 15.5 15.88 14.53 15.68 15.6
DATA> 23.45 21.52 24.77 20.04 19.88 20.66 20.3 22.6 21.88 19.94 21.78 22.7
DATA> 27.25 26.53 29.89 22.04 22.58 22.06 25.2 24.6 25.47 23.35 24.38 24
DATA> 29.84 29.13 31.19 22.24 24.18 24.05 26.8 26.6 27.67 23.95 24.38 25.7
DATA> 30.84 27.93 32 23.75 21.78 24.45 26.4 27.2 28.67 26.05 27.97 26.2
DATA> 31.64 29.53 32.8 24.25 23.48 24.25 27.2 27.6 29.67 25.55 26.27 27.2
DATA> 33.83 30.73 32.4 24.75 24.38 25.05 27.9 29.4 29.67 26.05 26.37 26.3
DATA> 33.93 29.33 34 25.65 24.58 25.65 27.6 29.8 31.47 27.25 27.27 27.4
DATA> 34.03 30.13 35.01 25.75 25.77 25.75 28.5 30.2 31.47 27.66 26.97 27.5
DATA> 34.33 31.33 36.61 26.45 24.18 25.25 30.2 30.2 32.67 27.66 27.37 27.5
DATA> 14.3 16.4 15.1 15.57 14.4 15.48 14.2 13.8 15.2 15.2 14.8 16.2
DATA> 20.9 22.2 22.4 19.56 19.9 20.18 19.8 21 20 18.1 20 20.4
DATA> 25.7 26.6 25.7 23.95 20.6 22.28 22.6 24 22.2 22.2 20.8 22.8
DATA> 27.9 29.2 27.9 22.55 21.7 23.48 22.8 25.2 22.7 22.4 23 21.6
DATA> 29.1 29.8 29.7 23.95 22.6 26.07 27.2 27.2 24.2 25.2 24.2 23.4
DATA> 29.3 32.2 30.8 24.55 23 24.98 26.8 26.4 26.6 24.2 23.8 21.2
DATA> 32.1 33.8 31.4 23.95 23.3 26.17 27.2 26 25.4 22.9 24 23.4
```

```
DATA> 31.8 33.5 32.1 24.15 24.5 26.97 27.6 27.4 26.2 24.2 25.8 23.2
DATA> 32.9 33.5 32.5 24.35 24.2 25.97 27.5 28 27.4 24.2 26 25
DATA> 33.9 36.2 32.5 26.75 28 24.98 29 30.2 29.2 25.4 26.2 22.8
DATA> end
MTB > anova c4=c1|c2|c3

Factor   Type Levels Values
C1       fixed   3    1  2  3
C2       fixed  10    1  2  3  4  5  6  7  8  9  10
C3       fixed   4    1  2  3  4

Analysis of Variance for C4
Source       DF        SS        MS        F      P
C1            2   184.171    92.086    56.51  0.000
C2            9  6188.135   687.571   421.92  0.000
C3            3  2131.396   710.465   435.97  0.000
C1*C2        18    37.217     2.068     1.27  0.209
C1*C3         6   126.509    21.085    12.94  0.000
C2*C3        27   313.821    11.623     7.13  0.000
C1*C2*C3     54    37.241     0.690     0.42  1.000
Error       240   391.112     1.630
Total       359  9409.603

MTB > stop
*** Minitab Release 7.2
*** Minitab, Inc.
*** Storage available 2759597 [EOB]
*exit

USER15:[ISF8721]WPU2.LIS;3 687 lines
```

C.2 Minitab for Curing time

```
MTB>outfile 'Curing'
MTB>set c1 #pH
DATA>(1:3)20
DATA>end
MTB > set c2 #Inks
DATA> 3(1:4)5
DATA> end
```

```
MTB>set c3 #Cure
DATA> 10.52  11.02  9.85  9.85  9.85  4.17  4.24  4.32  4.32  4.32  113.09
115.68  115.68  113.73  115.68  33.69  25.48  28.92  25.48  25.48
DATA> 5.64  5.32  6.01  5.32  5.32  4.17  4.02  3.95  4.02  4.02  115.68   115.68
126.70  126.70  126.70  28.92  24.31  25.02  25.02  24.31  41
DATA> 5.03  5.32  5.32  5.03  5.03  4.02  3.70  3.95  3.70  3.70  101.22   107.23
107.23  107.23  107.23  25.48  24.31  24.31  24.31  24.31
DATA>end

MTB > anova c3=c1|c2
Factor    Type  Levels  Values
C1        fixed   3     1   2   3
C2        fixed   4     1   2   3   4

Analysis of Variance for C3
Source    DF      SS       MS       F        P
C1         2     261      130    24.94    0.000
C2         3  121394    40465  7739.82    0.000
C1*C2      6     510       85    16.27    0.000
Error     48     251        5
Total     59  122416

MTB >Stop
 *** Minitab Release 7.2
*** Minitab, Inc.
 *** Storage available 2759597 [EOB]
*exit
```

C.3 Minitab for Curing time of different substrates

```
MTB> outfile 'Curesub'
MTB> set c1 #Substrate
DATA>(1:3)3
DATA>end
MTB>set c2 # Cure
DATA> 11.02 11.02 14.46
DATA> 22.04 23.73 22.04
DATA> 33.06 23.73 23.73
DATA>end

MTB > oneway c2 c1
```

```
ANALYSIS OF VARIANCE ON C2
SOURCE    DF      SS      MS       F      p
C1         2   342.2   171.1   15.13  0.005
ERROR      6    67.8    11.3
TOTAL      8   410.0
                                  INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
LEVEL   N    MEAN    STDEV    ----------+---------+---------+-----
  1     3  12.167    1.986     (-----*-----)
  2     3  22.603    0.976                (-----*-----)
  3     3  26.840    5.387                     (-----*-----)
                              ----------+---------+---------+-----
POOLED STDEV =   3.362                14.0      21.0      28.0

MTB > stop
 *** Minitab Release 7.2 *** Minitab, Inc.
 *** Storage available 2759597 [EOB]
```

C.4 Minitab for Scratch resistance

```
MTB>outfile 'Scratchtest'
MTB>set c1 #pH
DATA>(1:3)40
DATA>end
MTB > set c2 #Setting
DATA>3 (1:2)20
DATA> end
MTB>set c3 #Inks
DATA> 6(1:4)5
DATA>end
MTB>set c4 #Scratch
DATA>30 40 45 30 30 30 30 30 30 30 30 40 30 30 35 30 30 30
40 45
DATA>200 200 220 200 220 170 220 150 150 160 190 170 180 180
190 200 200 200 200 200
DATA>30 30 30 30 30 35 35 35 35 40 35 30 35 30 30 40 40 40
50 50
DATA>240 240 250 250 250 221 180 190 190 180 190 180 190 190 190
250 250 250 250 250
```

DATA>30 30 30 40 45 30 30 30 30 30 30 40 30 35 35 35 30 35 35 50
DATA>200 200 200 250 200 190 190 190 190 190 190 200 200 200 200 220 250 250 250 250
DATA>end
MTB > anova c4=c1|c2|c3

Factor	Type	Levels	Values			
C1	fixed	3	1	2	3	
C2	fixed	2	1	2		
C3	fixed	4	1	2	3	4

Analysis of Variance for C4

Source	DF	SS	MS	F	P
C1	2	5075	2538	25.83	0.000
C2	1	890963	890963	9070.25	0.000
C3	3	14862	4954	50.43	0.000
C1*C2	2	3870	1935	19.70	0.000
C1*C3	6	2810	468	4.77	0.000
C2*C3	3	10065	3355	34.15	0.000
C1*C2*C3	6	2861	477	4.85	0.000
Error	96	9430	98		
Total	119	939937			

MTB > Stop
*** Minitab Release 7.2
*** Minitab, Inc.
*** Storage available 2759597 [EOB]
*exit

C.5 Minitab for Abrasion Resistance

MTB>outfile 'abrasion'
MTB> set c1 #pH
DATA>(1:3)12
DATA>end
MTB>set c2 #Inks
DATA>3(1:4)3
DATA>end

```
MTB > set c3 #Ranks
DATA> 4 4 4 5 5 5 5 4 6 6 6 5
DATA> 5 5 5 5 5 6 2 6 6 9 7 7
DATA> 4 3 4 6 6 6 5 4 5 5 5 5
DATA> end

MTB > anova c3=c1|c2

 Factor    Type Levels Values
 C1       fixed    3    1    2    3
 C2       fixed    4    1    2    3    4

 Analysis of Variance for C3

 Source      DF       SS        MS       F      P
 C1           2    5.0556    2.5278   3.37  0.051
 C2           3   18.0833    6.0278   8.04  0.001
 C1*C2        6   11.1667    1.8611   2.48  0.052
 Error       24   18.0000    0.7500
 Total       35   52.3056

 <FF>
 MTB > stop
 *** Minitab Release 7.2 *** Minitab, Inc. ***
 Storage available 2759597
```

C.6 Minitab for Adhesion Resistance.

```
MTB > set c1 #pH
DATA> (1:3)8
DATA> end
MTB > set c2 #Inks
DATA> 3(1:4)2
DATA> end
MTB > set c3 #Adhesion
DATA> 0   0   0  0   4   4   4   4
DATA> 4   0   0  0   4   4   4   4
DATA> 4   0   0  0   4   4   4   4
DATA>end
MTB > anova c3=c1|c2
```

Factor	Type	Levels	Values			
C1	fixed	3	1	2	3	
C2	fixed	4	1	2	3	4

Analysis of Variance for C3

Source	DF	SS	MS	F	P
C1	2	1.333	0.667	0.50	0.619
C2	3	72.000	24.000	18.00	0.000
C1*C2	6	4.000	0.667	0.50	0.797
Error	12	16.000	1.333		
Total	23	93.333			

```
MTB >Stop
****Minitab
USER15:[ISF8721]ADHESION.LIS;2 193 lines
```

C.7 Minitab for Scratch resistance of different substrates

```
MTB> outfile 'Scratchsub'
MTB> set c1 #Substrate
DATA>(1:3)10
DATA>end
MTB > set c2 #Setting
DATA> (1:2)15
DATA> end
MTB> set c3 #Scratch
DATA> 50  60  70  50  70  30  30  30  30  30  30  30  30  30  30
DATA>190  180  170  170  170  180  160  160  170  160  60  65  60  60  80
DATA>end

MTB > oneway c3 c1
```

ANALYSIS OF VARIANCE ON C3

SOURCE	DF	SS	MS	F	p
C1	2	28302	14151	4.64	0.019
ERROR	27	82383	3051		
TOTAL	29	110684			

```
                                 INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
LEVEL    N     MEAN    STDEV   ---------+---------+---------+------
    1   10    45.00    17.16    (-------*-------)
    2   10   103.00    77.18              (-------*-------)
    3   10   115.50    53.87                (-------*-------)
                               ---------+---------+---------+------
POOLED STDEV =   55.24                 40        80       120
```

MTB > Stop
****Minitab

C.8 Minitab for Abrasion resistance of different substrates

```
MTB> outfile 'Abrasionsub'
MTB> set c1 #Substrate
DATA>(1:3)3
DATA>end
MTB>set c2 #Ranks
DATA> 8 7 5
DATA> 6 4 6
DATA> 5 1 2
DATA>end

MTB > oneway c2 c1
```

ANALYSIS OF VARIANCE ON C2

SOURCE	DF	SS	MS	F	p
C1	2	24.89	12.44	4.67	0.060
ERROR	6	16.00	2.67		
TOTAL	8	40.89			

```
                                 INDIVIDUAL 95 PCT CI'S FOR MEAN
                                 BASED ON POOLED STDEV
LEVEL    N     MEAN    STDEV   ---------+---------+---------+------
    1    3    6.667    1.528              (-------*-------)
    2    3    5.333    1.155             (-------*-------)
    3    3    2.667    2.082    (-------*-------)
                               ---------+---------+---------+------
POOLED STDEV =   1.633                2.5       5.0       7.5
```

```
MTB > stop
 *** Minitab Release 7.2 *** Minitab, Inc.
 *** Storage available 2759597
**exit

USER15:[ISF8721]ABRASIONSUB1.LIS;2 43 lines
```

C.9 Minitab for Adhesion resistance of different substrates

```
 MTB > set c1 #Substrate
 DATA> (1:3)4
 DATA> end
 MTB > set c2 #Ranks
 DATA> 0 2 4 4
 DATA> 0 0 1 0
 DATA> 5 5 5 5
 DATA> end
 MTB > oneway c2 c1

 ANALYSIS OF VARIANCE ON C2
 SOURCE    DF      SS      MS      F      p
 C1         2   45.17   22.58  17.30  0.001
 ERROR      9   11.75    1.31
 TOTAL     11   56.92
                                INDIVIDUAL 95 PCT CI'S FOR MEAN
                                  BASED ON POOLED STDEV
 LEVEL     N    MEAN    STDEV  -------+---------+---------+---------+
   1       4   2.500    1.915               (-----*-----)
   2       4   0.250    0.500    (-----*-----)
   3       4   5.000    0.000                          (-----*-----)

 POOLED STDEV =  1.143         ---+-----+-----+-----+

                                   0.0       2.0       4.0       6.0
MTB > stop
 *** Minitab Release 7.2 *** Minitab, Inc.
```