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Effects of Temperature Control on Gravure Packaging Inks

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EFFECTS OF TEMPERATURE CONTROL ON GRAVURE PACKAGING INKS

by

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EFFECTS OF TEMPERATURE CONTROL ON GRAVURE PACKAGING INKS

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It is well known that variations in ink temperature cause a variation in color density and viscosity. The viscosity of almost all liquids decreases with increasing temperature. In this research project, three different ink temperatures were selected to measure the effects of temperature control on solvent and ink consumption and on printability. Two colors were selected (magenta and cyan) and two heat exchangers were constructed to cool and/or heat the ink.

It was found that variations in ink temperature cause variation in solvent and ink consumption. As the temperature of the ink increases, solvent consumption and ink consumption increase, but print quality decreases. At higher ink temperatures, the pigment to solvent ratio is higher, thus printing with more ink particles and less solvent. A decreasing solvent to pigment ratio decreases drying time, thus wettability was the major printing problem. This research project proves that packaging printers may not only decrease ink and solvent consumption by reducing ink temperature, but may also increase print quality.

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INTRODUCTION

It is well known that variations in ink temperature cause a variation in color density and viscosity (Celio, 1998). The viscosity of almost all liquids decreases with increasing temperature. The viscosity of inks changes about 3 to 4% per degree Fahrenheit change (GATF, 1995). For example, if the temperature of an offset ink increases by 15°F, the viscosity of the inks decreases by approximately 45-60%; if the temperature of a gravure ink increases by 1.5°C, the viscosity of the ink decreases by 3% (Celio, 1998). In most printing companies, where there is no ambient temperature control, the ink temperature increases as it absorbs heat from the surroundings and/or from the operating equipment. Thus, the temperature of the ink increases because there is a temperature difference between the surroundings and the ink system. Changes in ink temperature cause variations in print quality and evaporation rate of the solvent being used. Vapor emissions resulting from evaporation are known as volatile organic compounds (VOC); packaging and publication gravure inks contain about 60 to 75% organic solvents such as toluene or ethyl acetate. The are two main sources of VOC emissions: (1) Drying operations and (2) fugitive emissions (Serafano, 1999). Fugitive emissions are emitted from cleanup and drying operations; however, little information is available which quantifies these emissions. Usually, VOC emissions are calculated based on raw material consumption (Blaszczak, 1998). On the other hand, changes in print quality can be quantified by measuring visual parameters, such as density, mottle, gloss, rub resistance, and tone step curve.

In the U.S., there are approximately 200 companies operating 500 ink facilities. More than 900 gravure plants produce a variety of flexible packaging products in the U.S.; the number of plants will continue to grow (GAA, 1991). In 1988, the gravure flexible packaging industry had a 5 percent growth rate and the value of the shipments was estimated at $7.3 billion (GAA, 1991). The versatility of the gravure printing process has an advantage over other processes because it can print more consistently, faster, and at lower cost per unit of package. The majority of these products are categorized as flexible packaging because they are used in the food industry. Examples are, candy wrappers, potato bags, cigarette boxes, and labels.

The gravure industry consumes about 1.9 million tons/year of publication and packaging substrate and about 400 million pounds/year of ink (Neal, 1989). Thus, the industry uses about 280 million pounds/year (400 million lbs. x 70% organic solvent content) of potential VOC's. Due to the amount of emissions produced by gravure companies from VOC's, the Environmental Protection Agency (EPA) regulates their emissions because they are thought to be precursors of organic compounds which may destroy the ozone layer (Neal, 1989).

INDUSTRY NEEDS

To understand the importance of VOC emission control, the history of the EPA since 1978 must be understood. In 1978, the Control Technology Guide Office (CTG) offered support to state and local juridistrictions for regulating VOC emissions from gravure plants (Abt Associates, 1997). In the same year, the CTG recommended using add-on control devices, water-based ink, and high solids ink to control the emissions. The CTG stated that these three options could capture at least 75% of the VOC's. In 1982, the CTG published a survey presenting the current situation in the gravure industry. This survey was used by the CTG to impose more restrictions on the emission of VOC's, increasing capture by another 84%. Throughout the years, the EPA has increased the control of air emissions and waste materials from the gravure, flexographic, and lithographic industries. In 1996, the EPA promulgated a National Emission Standard for Hazardous Air Pollutant (NESHAP) under section 112 of the Clean Air Act Amendments (CAAA) for the printing and publishing industries. The NESHAP requires new and existing major sources to control emissions of hazardous air pollutants (HAP) using Maximum Achievable Control Technology (MACT). Major sources are defined as those that emit or have the potential to emit 10 tons per year of any single HAP or 25 tons per year of any combination of HAP (Abt Associates, 1996). The NESHAP covers publication, packaging, and other gravure products. All U.S. publication gravure facilities and some packaging and gravure products are major sources of HAP's, including toluene, methyl ethyl ketone, xylene, ethyl acetate, and methyl isobutyl ketone.

The final rules state that publication gravure facilities must limit the emissions of organic HAP's to no more than 8% of the total volatile emissions each month. This can be achieved by capturing and controlling at least 92% of the organic HAP's used. To control emissions, the printing industry has installed complex systems for recovery and incineration. These systems are very expensive, but they do not eliminate 100% of the emissions. For this reason, the industry needs to control emissions to prevent damage to the environment.

As mentioned before, the evaporation rate is proportional to the temperature of the ink. The industry needs a temperature control system to reduce the amount of emissions from VOC's to potentially decrease the cost of the recovery process. The purpose of this study is to determine the effects of temperature control on the emissions from solvent-based inks and on the percent solids in the ink system. The amount of solids in the ink is important because most of the liquids undergo volume expansion when heated. Solids are what are left after the inks are completely dry. Solids content is very important in determining coat weight and specifications for cylinder engraving. For example, the solids content determines the engraved cell volume of the cylinder (GAA, 1991).

Ink cooling can be achieved by the use of a heat exchanger in the ink sump or ink circulating system where cooling occurs due to the difference in temperature between two fluids. Contamination from condensation with as little as 1% water can cause the ink to gel (GAA, 1991). On the other hand, if the ink is too cool, the viscosity of the ink will be too high which then requires more solvent to reduce the viscosity. In the end, the solids content will be so low that print quality will be lost. For these two reasons, it is important to determine the precise temperature to avoid condensation and/or excessive cooling.

OBJECTIVE

This study will provide experimental data to evaluate the effect of ink temperature control on print quality and on solvent and ink consumption. Knowledge of potential volatilization and solvent consumption is useful for estimating consistency in print quality and for controlling the hazards associated with the use of solvents. The EPA will use the information in this project to develop pollution prevention methods.

The primary objective of this study is to determine the effect of ink temperature control on print quality. A second objective is to determine the variation in solvent consumption due to temperature differences.

The experimental design consisted of applying a cooling/heating method to gravure packaging ink to determine the effect of different temperatures on ink viscosity, print density, mottle, gloss, rub resistance, and solvent consumption to that at room temperature.

LITERATURE REVIEW

The Gravure Unit

Figure 1 shows a standard layout for a gravure-printing unit. As can be seen, it is composed of a drying unit, an ink system, guiding rollers, and a frame that holds the unit together.

Inside the unit there are different components needed to print the substrate. Figure 2 shows these different components: an engraved cylinder, an impression roll, a reservoir, a circulating system, and a pump.

Where,

A is the impression roll (to push the substrate against the engraved cylinder).

B is the doctor blade (to wipe excess ink from the engraved cylinder).

C is the engraved cylinder (that provides the image).

D is the ink pan (where the engraved cylinder rotates in an ink bath).

E is the ink pump (to circulate the ink).

F is the main ink reservoir.

G is the recirculating ink system.

Gravure Packaging Inks

Ink is the critical component in this project. Throughout these experiments, ink is the only variable affected by temperature. Any variation in temperature, relative humidity, and viscosity will result in changes in ink behavior.

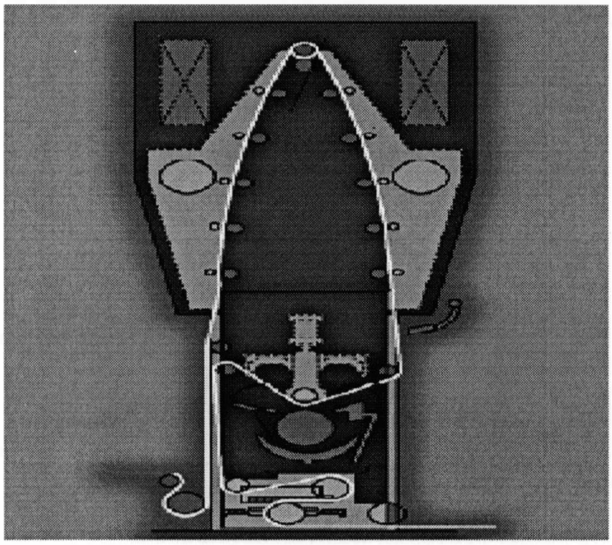

Figure 1. Layout of a Gravure Printing Unit (Daetwyler, 1998).

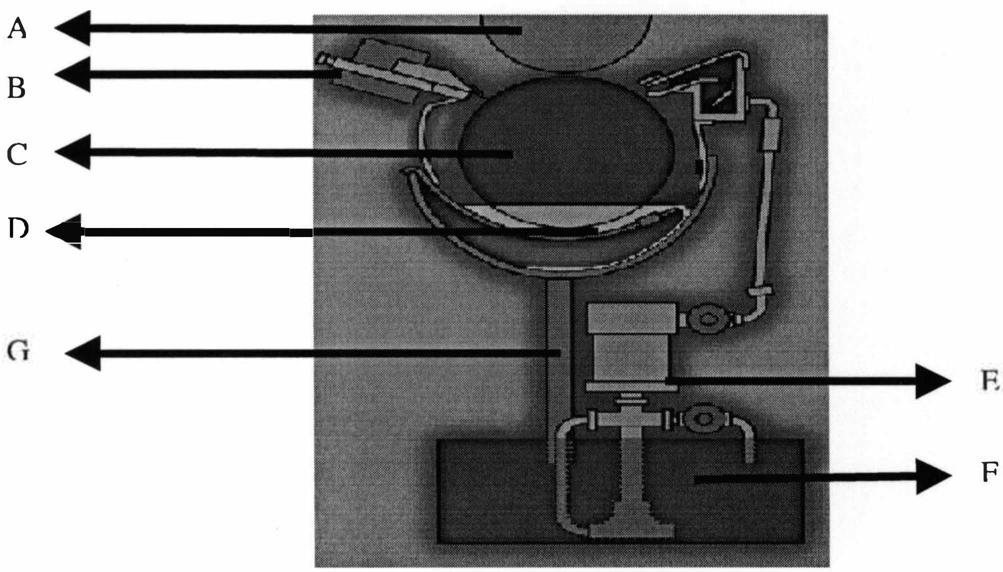

Figure 2. A Gravure Printing Unit (Daetwyler, 1998).

Gravure inks are considered fluid or liquid inks because they have low viscosity; they are not shear dependent like offset inks, and they dry through solvent evaporation (GAA, 1991). Gravure inks are designed to perform a specific task. For example, they are used to provide extremely good adhesion with U.S. currency and stamps and provide a balance between the colors so the human eye can read the message. There are many different types of inks, but for this project the focus will be on packaging inks. Packaging inks are also known as C-type or D-type of inks (GAA, 1991). In the C-type, the basic ingredient is nitrocellulose, which acts as the binder. Many other plasticizers may be added to the ink to achieve special properties (GAA, 1995). In the D-type, the basic ingredients are based on vehicles containing polyamide resins, and the usual solvent for these inks is a mixture of alcohol and aromatic hydrocarbons (GAA, 1991). Commonly used mixtures are either 50/50 blends of alcohol and aliphatic hydrocarbons (by volume) or 30/70 alcohol to aromatic hydrocarbons (GAA, 1991). The combination of the nitrocellulose with the solvents provides good heat and scuff resistance, as well as a soft and flexible ink film thickness to prevent cracking.

A typical packaging ink formulation will contain the following ingredients:

1. Pigments: Pigments are small ground materials that impart color to the ink. There are two common types of pigments. The organic pigments are usually more transparent, brighter, purer, and richer in color, although developments in chemistry have led to better inorganic pigments such as titanium oxide, TiO_2 (GATF, 1995).

2. Solvents: All solvents are classified as active, latent, or diluent. These classifications are based on the solvent's ability to dissolve polymers or resins. For example, a latent solvent does not dissolve resins, but active solvents do. Typical solvents used in the gravure industry are toluene, alcohol, acetates, and ketones (GATF, 1995).

3. Resins: A resin is a complex organic substance which, in solvent solution, forms gravure varnish (GAA, 1991). Resins are thermosetting, i.e., they react to form a rigid product that will not melt, or thermoplastic, i.e., they soften or melt when heated (GATF, 1995).

4. Additives: The suspension of pigments on a varnish carried by a vehicle does not provide all the necessary properties to print over specific substrates. Other additives are added to the system to provide good printability and performance. For example, typical additives are wetting agents, waxes, plasticizers, and reducers. Table 1 is a typical gravure ink formulation.

Table 1

Typical Formulation of Gravure Packaging Inks (GATF, 1995)

Description	**Amount**
Titanium dioxide	33%
Nitrocellulose varnish	22%
Rosin ester varnish	37%
Plasticizer	3%
Wax compound	5%
Total	**100%**

Usually 40 percent of an ink shipped from the manufacture and 60 percent of the solvent blend is mixed together to form viscosity-ready ink. It should be noted that solvents represent the highest proportion of substances contained in an ink system.

Solvent Consumption

Inside the printing unit (Figure 2), ink circulates from the main ink reservoir (F) through the ink pump (E) into the ink pan (D) and back to the main ink reservoir (F) through the recirculating system (G). During this process, the ink is contacted with materials and ambient air. To reach equilibrium, the hotter substance (air) must transfer energy to the colder substance (ink) thus increasing the temperature of the ink. One method of transforming energy is phase change or evaporation. Evaporation occurs when the partial pressure of the solvent vapor is less than the partial pressure of air and solvent vapor mixture at an equilibrium stage. A new balance is reached as soon as the temperatures of the liquid and air are equal and as soon as the air and solvent vapor mixture is saturated. It is important to note that the volume of air is infinite compared to the volume of liquid since the gravure printing units are not enclosed. The partial pressure of the solvent in the air and solvent vapor mixture will be less than that at equilibrium, thus evaporation will always occur.

Since the equilibrium partial pressure increases with temperature, decreasing the temperature of the ink reduces the evaporation rate. Figure 3 illustrates the relation between the liquid and air interface at time (t=0) when heat is applied to the ink system. The equilibrium between the air and the liquid solvent depends on the pressure of its saturated vapors.

Figure 3 is a representation of an ink-air interface, where (h) represents the original height of the control volume. After a period of time (t= t), the amount of energy released is proportional to the weight loss in the system, which is proportional to the height (h) of the control volume.

As seen in Figure 4, (h') represents the new volume of ink in the control volume. The evaporation rate of the solvent is proportional to the temperature difference between the ink and the surroundings, to the weight loss, to the volume of ink contained in a system, and to the exposed area between the ink system and the ambient.

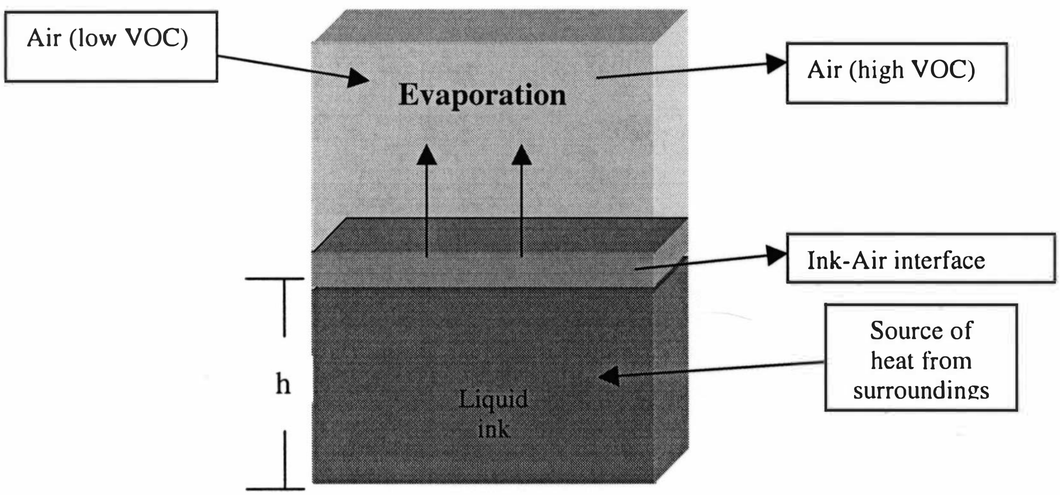

Figure 3. Representation of Ink-air Interface at t =0.

To prevent an increase in the evaporation rate of the ink system, ink cooling can be achieved through the use of chillers or heat exchangers located in the ink sump (GAA, 1991). By maintaining the temperature of the ink at a desired temperature value, the viscosity of the ink will not change as solvents are lost by evaporation. It is important to remember that any change in ink temperature not only increases the consumption of solvent, but also affects print quality. In most of the operating gravure presses, it is very difficult to control the exposed area of the ink system, and it is too expensive to reduce the temperature of the ambient with air conditioning systems. For these reasons, one of the best solutions relies on the use of ink cooling systems.

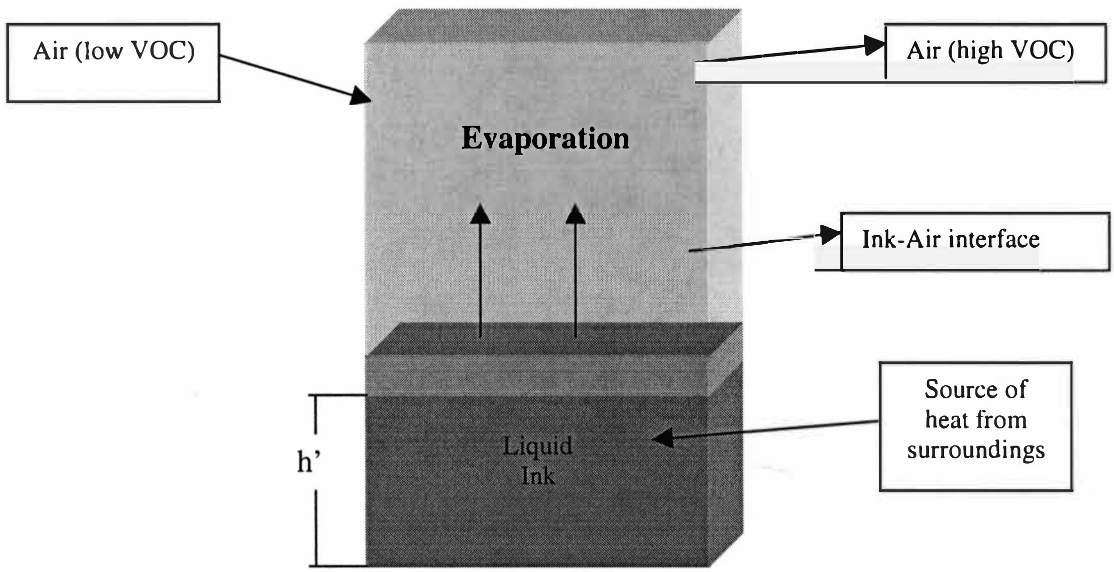

Figure 4. Representation of Ink-air Interface at t= t sec.

Print Quality

Technology has improved the way printers measure print quality or evaluate printability. The use of sophisticated instruments improves the accuracy of the measurements and reduces human error. Throughout this project, several instruments were used to predict print quality at a particular printing ink temperature. Reflection density, specular gloss, rub resistance, and tone step curves were all measured after the trial runs. Image Analysis was done on all samples.

Reflection Density

Reflection density is one of the most common color measurements in the printing industry. To measure reflection density, a densitometer is used to measure the optical density of the printed image. Optical density is a measure of a material's ability to absorb light. It is proportional to the amount of light reflected from or transmitted through a sample (GATF, 1995). The following equation represents the mathematical definition of optical density:

$$Density = -\log_{10}(F)$$

Where F is the fraction of light reflected and/or transmitted.

To measure optical density, an X-Rite reflection densitometer, Model # 408, was used. This instrument reads the percent reflectance of a light beam compared to a standard beam of light (GATF, 1995). The resolution of this instrument is 0.02 units of reflection density. Any variation below this resolution will not register. This equipment is equipped with color filters to identify the color being measured. For example, the green filter measures reflected light between 500 and 600 nanometers, the blue filter measures reflected light between 400 and 500 nanometers, and the red filter measures reflected light between 600 and 700 nanometers (GATF, 1995). In this way, the filters cover the visible portion of the electromagnetic spectrum.

Specular Gloss

Gloss is the characteristic responsible for the shiny or lustrous coverage of the printing ink. Specular gloss can be defined as the fraction of a specified incident beam of light which is reflected by a surface in and adjacent to the direction of mirror reflection (GAA, 1991). Standard print gloss measurements are done at a 60° angle. This means that a beam of light is aimed at the printing image, and the amount of light reflected to a mirror on the same instrument is recorded. For this measurement, a 60° angle instrument, Gardner Model BYK, was used. The resolution of this instrument is 0.1 units of reflected light. Any variation below this resolution will not register. Ink gloss is a property affected by the ink film thickness, smoothness, underlying surface used, and amount of light available (GATF, 1995). For these reasons, all the gloss measurements were performed under the same light conditions and with the same underlying surface.

Image Analysis

Image analysis is a powerful tool to determine the behavior of the printed image at the microstructure level. The instrument is capable of magnifying the printed image 50 to 100 times its original size. The image analyzer is composed of the following devices (Serafano, 1998):

1. <u>Input device:</u> This is the microscope where the image analyzer gets its optical information.

2. <u>Lamp controller:</u> Illumination is critical to magnify and detect microstructures. It is important to provide the same intensity of light for all measurements.

3. <u>Camera and lens system:</u> These instruments determine the resolution of the pictures being taken. Low quality cameras and lenses may not detect small variations at the microstructure level.

4. <u>Image capture:</u> This equipment converts the image into an electronic signal suitable for digital processing and storage. The image capturing process quantizes (subdivides or proportions) the image in both space and tone. Spatially, the image is divided into a rectangular grid of picture elements known as pixels or pels (Serafano, 1998).

5. <u>The software:</u> The strength of the software is in the use of statistical analysis. The software can capture an image with thousands of microstructures (dots) and can statistically calculate area, perimeter, roundness, and standard deviation for every measurement (Serafano, 1998). Image analysis systems convert images displayed by a camera into digital images that are processed by software algorithms. They can extract details on paper forming and print quality that are difficult to see using conventional means (Chaplin, 1998). For a particular image, mathematical

algorithms can determine maximum, minimum, and standard deviation of an array of printed dots. The software allows the viewer to filter out unwanted objects to maintain a low standard deviation within the dots.

For this project, measurements were performed to compare the influence of temperature control on printed dots "perimeter." The measurements were performed on cyan compressed cells, screen angle = 30° and 175 lines per inch, and on magenta elongated cells, screen angle = 60° and 175 lines per inch. For these measurements, an average of 100 to 120 dots were viewed.

Rub Resistance

Rub resistance is an important test for the packaging industry. Most printed packages undergo the influence of an external abrasion. For example, potato chip bags that rub against each other, food packages are microwaved, and packaged products are transported. For any of these products, it is important that the printed image be maintained intact, otherwise the package will not serve its purpose, which is to sell the product.

The rub resistance test is a measure of the scuffing or rubbing resistance of ink on a paper, paperboard, or film (Sun Chemical, 1996). To perform the test, a Sutherland Ink Rub Tester, Model # R-302, was used. The concept is to rub the printed film against a white surface for a specific amount of time. For this procedure, 50 seconds per stroke were selected. Measurements of reflection density were made on the white surface before and after the test to determine the amount of ink transferred from the printed film to the surface. The surface selected for the rubbing test was a conventional white bond paper for inkjet printers (Serafano, 1998). The density of the white paper before the rubbing was approximately 0.08 percent of reflected density.

Tone Steps Curve

Color is a result of an interaction between light, an object, and a viewer. Light is the visible part of the electromagnetic spectrum, and it varies in wavelength from 400 to 700 nanometers (X-Rite, 1998). When light strikes an object, a percentage of the light is absorbed and some is reflected. The percentage of the light reflected is the difference in color and tonal intensity.

As a measurement of quality, tone step curves were used to compare a standard signature from the press to prints at different ink temperatures. Tone steps can be defined as the variation in L* values from the CIE L*a*b* color communication standards for the manufacture of paints, inks, dyes, and other colorants. The CIE L*a*b* values provide a universal framework for color reproduction and matching. In other words, the variation in L* values is the change in color darkness of a specific wavelength.

In Figure 5, the density of the color increases with the tone percentage. For this procedure, the reflection density was recorded at each specific tone, then the values were compared to values at different ink temperatures. In gravure, halftones are susceptible to changes in ink viscosity, ink temperature, impression load, electrostatic assist, and percent solids of the ink. Any changes in these conditions may influence the reflection density of a particular tone step, especially the lower end of the tones. The lower ends of tones are produced from small cell configurations (between 10-30 microns at 175 lines per inch). These small cavities will transfer small amounts of ink to the substrate, which can dry, deform, or disappear before the ink is transferred to the substrate.

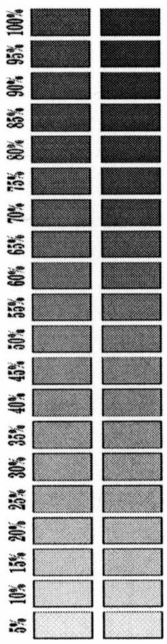

Figure 5. Representation of a Tone Step Image.

EXPERIMENTAL PROGRAM

The experimental design project was divided into three phases. Phase I of the project consisted of an ink printability study of packaging ink at a cold temperature (60°F). Phase II of the project consisted of an ink printability study of packaging ink at room temperature (72°F). Phase III of the project consisted of an ink printability study of packaging ink at a warm temperature (95°F). Before the experiment was conducted, several steps were taking to assure good performance of the heat exchanger, printability methods, and ink behavior.

Cooling System

To cool or heat the printing ink, two heat exchangers fitted for the ink sump were constructed, one for each printing color. The idea was to pump cold/hot water through a copper coil. The coil absorbed the heat from the ink when the ink was to be cooled, or provided the necessary energy when the ink was to be heated. When the coil was submerged into the ink sump, cold or hot water inside the coil adsorbed and or supply the necessary energy. The energy was transfer from the tap water to the coil wall and then from the coil wall to the ink system. This means of heat transfer is also known as convection. Fluid motion is associated with the fact that, at any instant, large numbers of molecules are moving collectively or as aggregates. Such motion, in the presence of a temperature gradient, contributes to heat transfer (Incropera, 1996). In other words, the external force of water flow rate causes continuous temperature difference between the fluid and surface wall, then the energy will travel from the hotter area to the colder area.

To improve the heat transfer process, several options are available (Incropera, 1996). First, improve the heat transfer coefficient of the heat exchanger by increasing the thermal conductivity (*K*). For this reason it was decided to used a material (copper) with high thermal conductivity:

$$K = 401 \left[\frac{W}{m * °K} \right]$$

Where *K* is the thermal conductivity of the material express in units of Watts over mass flow-per degree Kelvin. The second option is to improve the convection surface area of the heat exchanger (Incropera, 1996). Accordingly, the longest coil of copper tubing available was selected, 5/8" O.D. by 50 feet long.

Once the heat exchanger was built, the amount of energy necessary to cool/heat the printing ink was calculated as follows:

$$Q = m * c_p * (T_{out} - T_{in})$$

Where,

Q is the energy absorbed or transmitted by the heat exchanger, Watts

m is the mass flow rate of the water, 2.5 kg/second

c_p is the specific heat of water, 4184 J/kg*°K

T_{out} is the water outlet temperature, °C

T_{in} is the water inlet temperature, °C

The inlet water temperature, outlet water temperature, and ink temperature were measured using an infrared temperature thermometer, Model PM, from Rayteck Corporation. From the above equation, the necessary energy to control the temperature of the printing ink is presented in Table 2:

Table 2

Energy Applied to the Heat Exchanger

Variables	**Cold temperature**	**Normal temperature**	**Hot temperature**
Tin [Fahrenheit]	52	No heat applied	113
Tout [Fahrenheit]	54	No heat applied	108
Cp [J/kg*K]	4184	4184	4184
m [kg/sec]	2.5	No heat applied	2.5
Q [Watts]	**20920**	No heat applied	**52300**

The heat exchanger provided the necessary changes in ink temperature to evaluate changes in solvent consumption and print quality.

Preliminary Laboratory Work

The preliminary work for this project will be presented in the following four topics: (1) Heat Efficiency of the Heat Exchangers, (2) Solvent Consumption Test, (3) Image Analysis Test, and (4) Percent Solids Test.

Heat Efficiency of the Heat Exchangers

To ensure the performance of the heat exchanger, two preliminary tests were performed on the gravure press during idle, meaning that there was no printing involved, only rotating the printing cylinder. The test consisted of placing the heat exchanger in the ink sump. The sump was loaded with 15 gallons of gravure ink and the circulating system of the unit was turned on. Cold/hot water was pumped through the heat exchanger to cool/heat the ink for a period of 40 minutes. The idea was to record viscosity and temperature changes over time. Viscosity can be measured with an efflux cup. Efflux cups are cylindrical cups in which a capillary (Shell cup) or a machined hole (Zahn cup) controls the rate at which the liquid flows from the cup (GATF, 1995). Shell cups are a nipple-shaped stainless steel cup which contains 26.5 milliliters of fluid, Zahn cups are bullet-shaped with a fluid volume of 47 milliliters (GAA, 1991). The industry standard is that Shell cups are mainly for publication inks and Zahn cups mainly for packaging inks. Since the heat efficiency experiment was conducted on publication ink, a Shell cup was selected to determined viscosity. The ink viscosity was maintained at an average of 22 seconds. The viscosity readings and ink temperature was recorded every 2 minutes. In addition, the amount of solvent added to maintain viscosity was recorded. This preliminary test was useful to determine the necessary time to reach temperature equilibrium and to determine the necessary amount of solvent needed for the project. On the two preliminary tests, inlet water temperature, outlet water temperature, and flow rate of the water was recorded to determine the aforementioned heat energy calculation.

Appendix B shows the data collected for each of the temperatures during the preliminary experiments. Figure 6 shows the variation of temperature as a function of time for the cold preliminary experiment. As can be seen from Figure 6, after 30 minutes of applied cooling, the ink reaches equilibrium. This means that the heat exchanger will not absorb more heat from the ink system. At this point, 20,920 Watts of energy has been removed from the ink system. This preliminary test provided the important information that there should be no data collection within the first 30 minutes of cooling.

Figure 7 shows the variation of cold viscosity as a function of time. As can be seen from Figure 7, the behavior of the ink was as expected. As the ink gets colder, there is a thermal contraction of the fluid; thus, the viscosity of the ink increases. Through this preliminary experiment, the solvent added to the ink to maintain viscosity was recorded. For the cold preliminary test, 3.375 liters of solvent were consumed in 40 minutes. From this value, it was concluded that, after the ink reached equilibrium temperature, 0.5 liters of solvent during the last ten minutes of the test were added to maintain viscosity. An average of 3 liters per hour of solvent was evaporated from the system. It is important to note that there was no printing involved and that all the solvent consumed after 30 minutes of equilibrium time was solvent evaporated.

Figure 8 shows the variation of temperature as a function of time for the hot preliminary experiment. As can be seen from Figure 8, after about 20 minutes of heating, the ink reaches equilibrium. This means that the heat exchanger will not transfer more heat from the hot water. At this point, 52,300 Watts of energy are

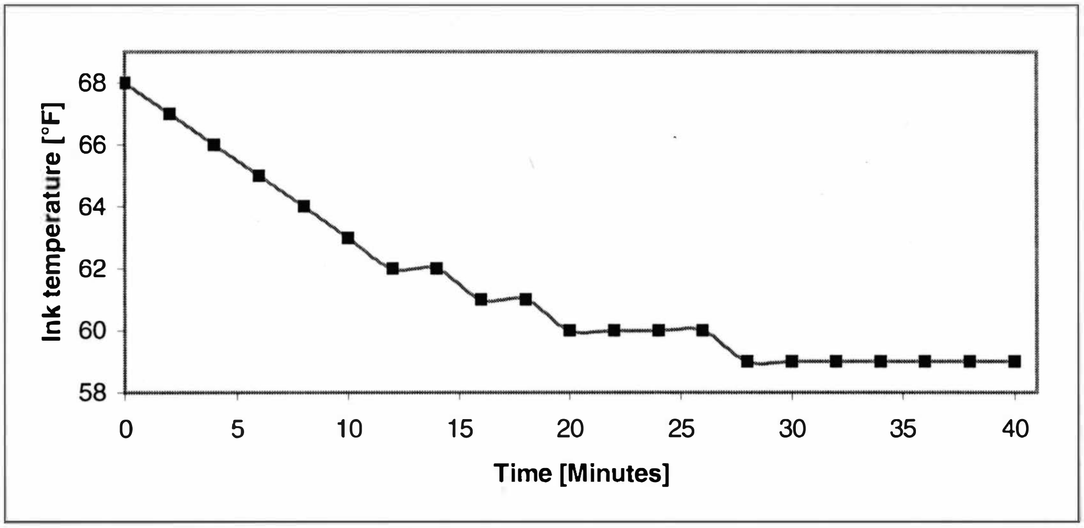

Figure 6. Variations of Cold Ink Temperature vs. Time.

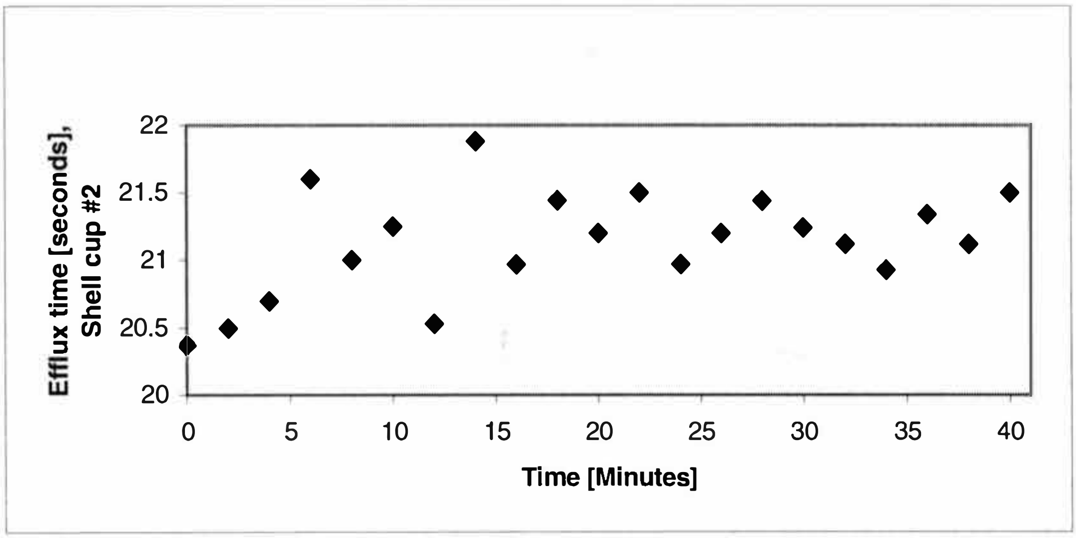

Figure 7. Variation of Cold Ink Viscosity vs. Time.

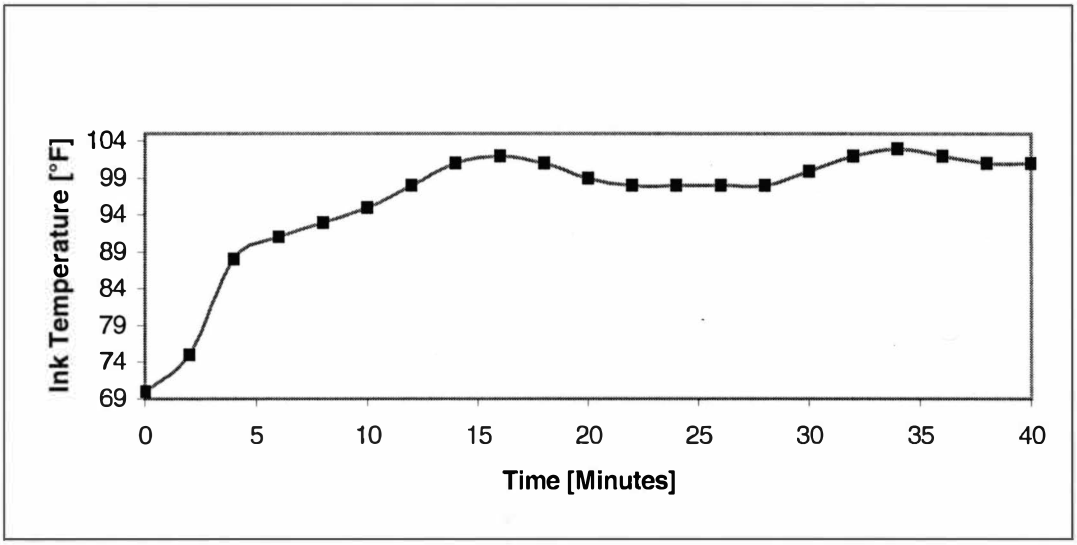

Figure 8. Variation of Hot Ink Temperature vs. Time.

added from the water to the ink system. This preliminary test provided important information that there should be no data collection within the first 20 minutes of heating. Figure 9 shows the variation of viscosity as a function of time for the hot ink. As can be seen from Figure 9, the behavior of the ink was as expected. As the ink gets warmer, there is less fluctuation in ink viscosity, and the average viscosity decreases. Through this preliminary experiment, the solvent added to the ink to maintain viscosity was recorded. For the hot preliminary test, 2.05 liters of solvent were consumed in 40 minutes. From this value, it was concluded that, after the ink reached equilibrium temperature, 0.75 liters of solvent were added to maintain viscosity after the ink reached the equilibrium temperature. An average of 3.15 liters per hour of solvent was evaporated from the system. It is important to note that there was no printing involved, and that all the solvent consumed after 20 minutes of equilibrium time was evaporated. Refer also to Appendix A for all the tabular tables.

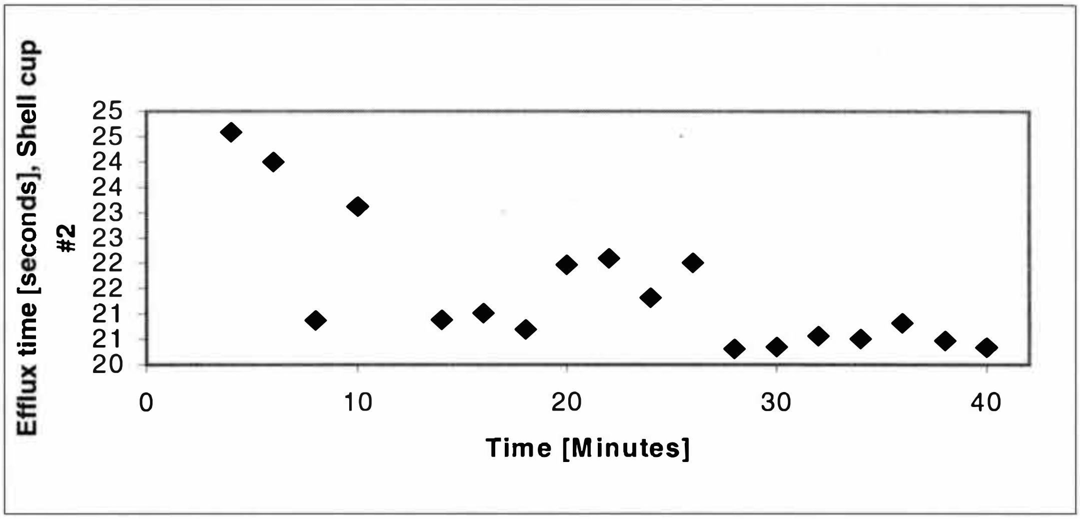

Figure 9. Variation of Hot Ink Viscosity vs. Time.

Preliminary Solvent Consumption Test

To confirm the solvent consumption data from the above experiment, an evaporation rate test was conducted in the laboratory. The idea was to evaporate a blend of 50% normal propyl alcohol with 50% normal propyl acetate at different temperatures. The samples were loaded on a small circular container, with an area of 1.77 inch^2. Exactly 15 grams of solvent were added to two different containers. One container was left at room ambient conditions (70°F, 40% RH), the other container was heated in a laboratory oven at 98°F. Both samples were weighed every two minutes for a period of 30 minutes. Figure 10 shows the variation of solvent consumption for the two different samples. As can be seen in Figure 10, the slope of the hotter sample is steeper than the room temperature sample. This means that there is almost 30% more solvent consumption at 98°F. On average, the solvent consumption for the 98°F sample was 4 grams/hour and for the room temperature sample was 2.85 grams/hour. If the data from both of the solvent consumption tests are combined and presented in Table 3 and Figure 10, the results demonstrated that the solvent consumption increases according to the following equation:

$$S_c = 0.0383 * T + 0.2433$$

Where,

S_c is solvent consumption, g/hr

T is the solvent temperature, °F

As can be seen from the equation, solvent consumption will have a linear relation with temperature.

Table 3

Results From Solvent Consumption Test

Sample	**Solvent Temperature [°F]**	**Solvent Consumption [g/hr]**
1	68	2.85
2	98	4

The same experiment was repeated using a commercial gravure packaging ink. A bigger beaker was used; the exposed area of the ink was 14.52 inch^2. The container

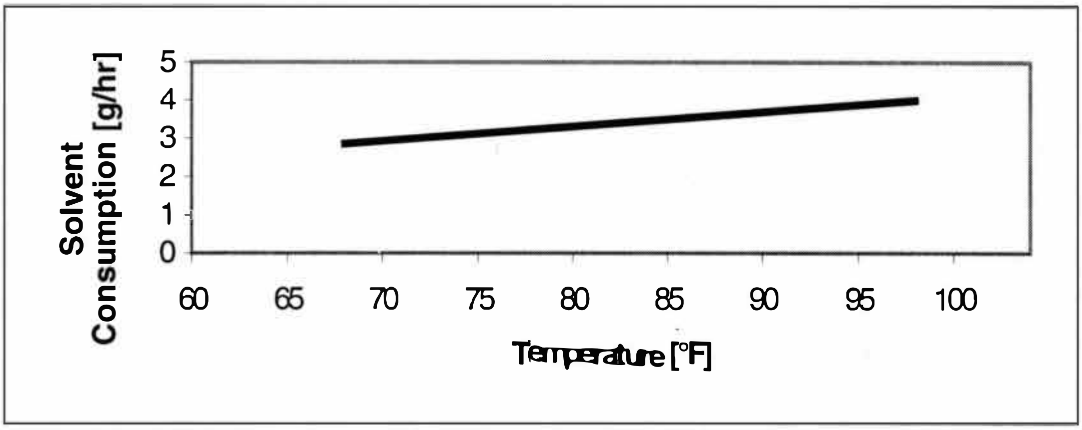

Figure 10. Variation in Solvent Consumption for the Preliminary Test.

was loaded with 400 grams of nitrocellulose ink and 115 grams of a blend of 50/50% of normal propyl alcohol and normal propyl acetate at 22 seconds using a Zahn cup #2. The sample was heated at 84°F for 35 minutes and every 5 minutes the sample was weighed. Figure 11 shows the variation in weight versus time. It was concluded from this preliminary test that an average of 4.28 grams/hour is solvent evaporated at 84°F.

From the preliminary solvent consumption test, it was concluded that there should be at least a 30-minute wait for the ink to reach equilibrium temperature before any data are collected. An average of 0.3 grams/hour per square inch of exposed area was solvent evaporated at 84°F. It is important to note that at the press runs, the agitation of the pump, airflow of the dryers, and cylinder rotation will increase the solvent consumption.

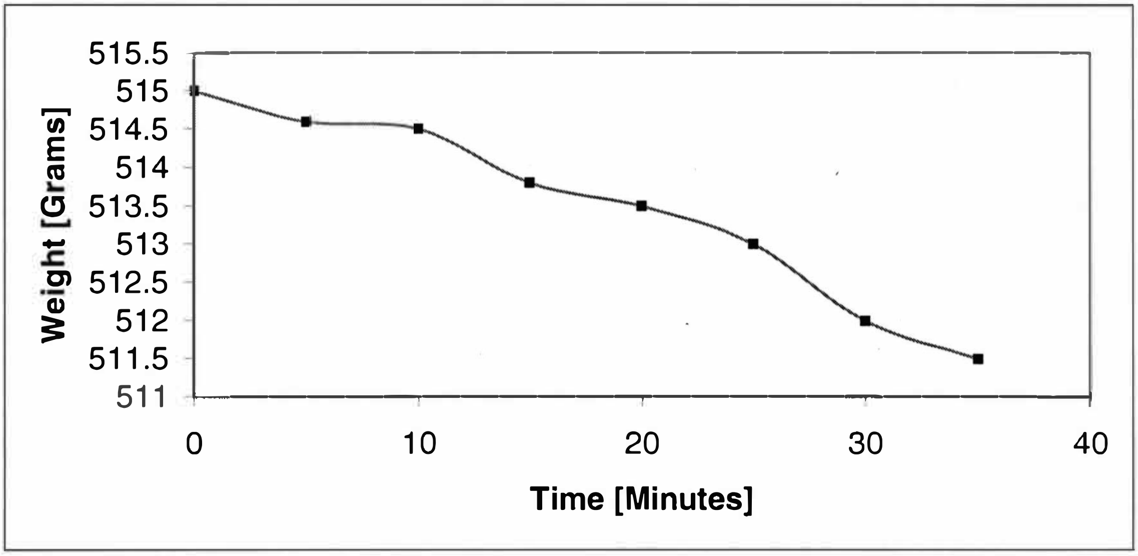

Figure 11. Ink Consumption in Preliminary Test.

Image Analysis Test

A small preliminary test was conducted to determine the best percent tone of the image. The idea was to determine the percent tone that produced the less standard deviation. The test consisted of analyzing the same image used for the research trial on different tone steps. The purpose was to measured dot area and compared the standard deviation of these measurements. The test consisted of analyzing tone steps from 7 percent to 46 percent. It was found that the 7 percent tone was unreadable for the image analyzer. In the 7 percent tone, the dots are too light in color with respect to the background. In the 12 percent, the contrast between the dot and the background was too low and almost no readings were derived from the software. The 20 percent tone presented a variation within data points of 536.46 microns. This variation is considered relative small compared to the area values of 7000 microns. The 28 and

37 percent also presented a low standard deviation, 745.57 and 755.10 microns, respectively, but the dot structure and dot formation at these values were better than the 20 percent tone. These variations are considered relative small compared to the area values of 9000 microns. At the 46 percent tone, it was noted that the dots were close to each other, thus the analysis of individual dots will become too difficult to detect. In conclusion, the 37 percent tone was selected due to the low standard deviation, better contrast of the dots with the background, and better dot structure than any other percent tone. With these measurements, the research trial was ready and all of the controllable variables were preset and ready to be analyzed.

Percent Solids Test

The percent solids test was used for both colors, cyan and magenta. The percent solids test is a measurement of the ratio of pigments, resins, varnish, and additives to the total mass of the ink, including the solvent. As mentioned before, inks are about 60% solvent and 40% solids. From this preliminary test, it was expected that the percent solid decreases with decreasing temperature. As the ink cools, it needs more solvent to reach the target viscosity (22 seconds in a Zahn cup). With a higher solvent to pigment ratio, the percent solid decreases. Table 4 shows the percent solids as a function of temperature. It can be seen that solids decreases with decreasing temperature. With this result, it was expected that ink at higher temperatures would print darker colors. Later in this research, it will be demonstrated that this statement is not true.

Table 4

Percent Solids as a Function of Temperature

Variables	Cold ink	Normal ink	Hot ink
Ink temperature [°F]	65 °F	72 °F	95 °F
Amount of ink added [l]	0.5	0.5	0.5
Amount of solvent added [l]	0.100	0.075	0.025
Solids of magenta [%]	25.02%	31.28%	33.63%
Solids of cyan [%]	27.12%	29.25%	33.42%

Phase I Cold Temperature

The experimental design in Phase I of the project consisted of running a test on the four-color gravure press (Cerutti, Model 118, 24 inches wide) at WMU for three hours. The test was conducted in two colors (magenta and cyan) to simplify the experiments. Solvent consumption and ink consumption will be presented in both cyan and magenta, but to simplify the results for this presentation, the printability data will be presented in one color only, cyan. The temperature target selected for the ink for Phase I of the project was 60°F at an ambient temperature for all the Phases of the project of 84°F. The relative humidities for all of the phases were between 30 and 38%. The idea of heating the room was to simulate an actual printing environments and to be able to compare with preliminary laboratory tests (Serafano, 1998).

To chill the ink, a heat exchanger was used. The idea was to pump cold (50-52°F) tap water through the 50 feet copper coil. Preliminary tests were performed to determine the range of cold temperature.

Table 5 shows the different running parameters selected for Phase I:

Table 5

Temperature and Running Parameters for Phase I

	Ink temperature	Impression nip	Speed	Dryer temperature	Ink viscosity, Zahn cup#2
Run #1	65 °F	3/8"	300 fpm	140 °F	22 sec

A standard packaging nitrocellulose ink with 50 percent normal propyl acetate and 50 percent normal propyl alcohol as the solvent base was used (Serafano, 1998). The substrate used was clear polyethylene with a surface tension of 36 $dynes/cm^2$ measured with an ACCU Dyne Tester by Diversified Enterprises.

During the print test runs, solvent added, viscosity, temperature, percent solids, and time were recorded every 5 minutes to determine solvent consumption at the given temperature. To control viscosity, a Zahn cup #2 was used. At the end of the run, five signatures were collected after each twenty minutes of printing time. Each set of signatures was analyzed using the previously described printability methods. The objective was to quantify solvent consumption at a given temperature and to establish a relationship with print quality.

Phase II Normal Temperature

The experimental design in Phase II of the project consisted of running a test on the four-color gravure press (Cerutti, Model 118, 24 inches wide) at WMU for three hours. The test was conducted in two colors (magenta and cyan) to simplify experiment. The ink temperature target selected for Phase II of the project was 72°F with an ambient temperature of 84°F. Table 6 shows the different running parameters selected for Phase II:

Table 6

Temperature and Running Parameters of Phase II

	Ink temperature	Impression nip	Speed	Dryer temperature	Ink viscosity, Zahn cup#2
Run #2	72 °F	3/8"	300 fpm	140 °F	22 sec

The same standard packaging nitrocellulose ink with 50 percent normal propyl acetate and 50 percent normal propyl alcohol as the solvent base was used. The substrate selected was the same as for Phase I.

Phase III Hot Temperature

The experimental design in Phase III of the project consisted of running a test on the four-color gravure press (Cerutti, Model 118, 24 inches wide) at WMU for three hours. The test was conducted in two colors (magenta and cyan) to simplify the experiment. The temperature target selected for the ink for Phase III of the project was 95°F with an ambient temperature of 84°F. Table 7 shows the different running parameters selected for Phase III.

The same standard packaging nitrocellulose ink with 50 percent normal propyl acetate and 50 percent normal propyl alcohol as the solvent base was used. The substrate was the same as for Phase I and Phase II:

Table 7

Temperature and Running Parameters of Phase III

	Ink temperature	**Impression nip**	**Speed**	**Dryer temperature**	**Ink viscosity, Zahn cup#2**
Run #2	95 °F	3/8"	300 fpm	140 °F	22 sec

RESULTS

After the test runs, the signatures were collected and analyzed using the previously described printability methods. 225 measurements of density and specular gloss per color per temperature were performed, a total of 2250 measurements. Three rub resistance measurements per color per temperature were also performed, and a total of 108 measurements using image analysis were done. The data were collected and the results are presented by the following nine analyses: (1) Variation in ink Viscosity as a Function of Time for a Particular Temperature, (2) Solvent Consumption as a Function of Temperature, (3) Ink Consumption as a Function of Temperature, (4) Reflection Density as a Function of Temperature, (5) Specular Gloss as a Function of Temperature, (6) Tone Step Curve as a Function of Temperature, (7) Dot Structure as a Function of Temperature, (8) Haze as a Function of Temperature, and (9) Rub Resistance as a Function of Temperature.

Variation in Ink Viscosity as a Function of Time

Viscosity depends on temperature. Every change in ink temperature will change ink viscosity. Throughout the experiment, viscosity readings were made every 5 minutes for each of the experimental Phases.

Figure 12 shows the variation in cyan cold ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold cyan ink was 22.8

seconds. The standard deviation from the fluctuation of viscosity was 0.54. The error reading on a Zahn cup is about 0.5 seconds (Ciucci, 1999). The fragmented lines

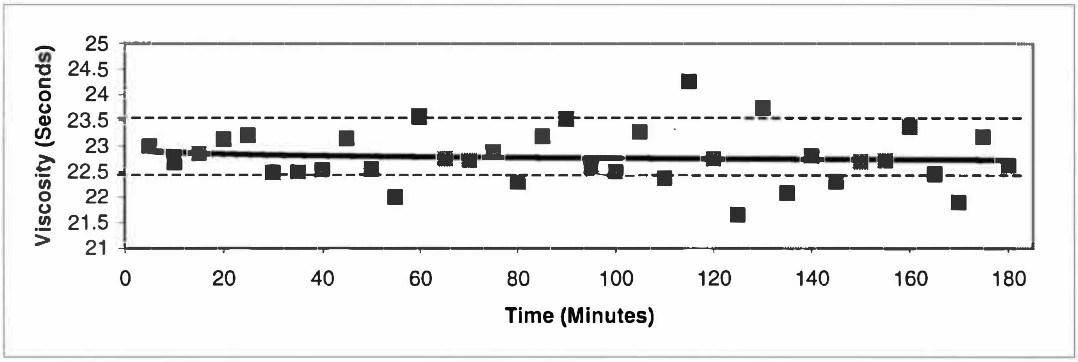

Figure 12. Variation in Cyan Cold Ink Viscosity.

around the average line in the graph represents a +/- 0.5 seconds of error in the cup. This means that the fluctuations of ink viscosity were almost the same as the error in the cup. The target viscosity was kept in target and no major errors were involved in the measurements.

Figure 13 shows the variation of cyan hot ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold magenta ink was 22.2 seconds. The standard deviation from the fluctuation of viscosity was 0.63. It can be seen that the standard deviation of the hot ink is higher than that at the cold ink. The fragmented lines around the average line in the graph represents a +/- 0.5 seconds of error in the cup. Although fluctuations of ink viscosity were almost the same as the error in the cup, the target viscosity was kept in target and no major errors were involved in this variable. It can also be noticed that a trend line is on top of the curve line. The trend line shows how the viscosity tends to drop as the temperature increases in the ink system.

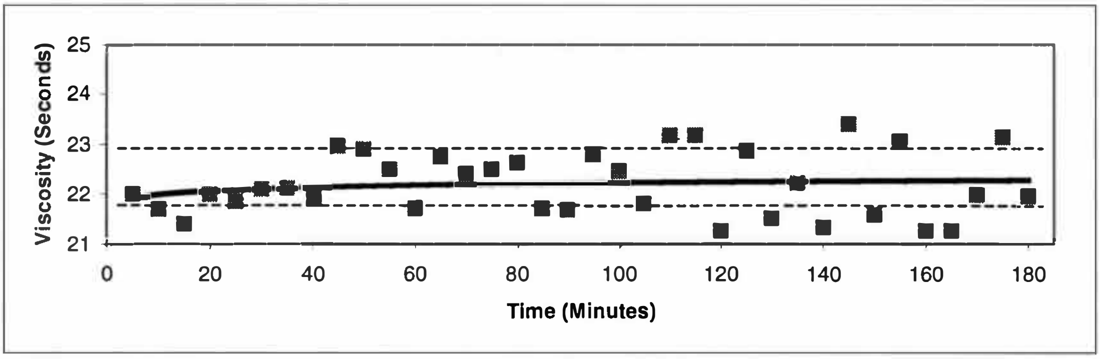

Figure 13. Variation in Cyan Hot Ink Viscosity.

Figure 14 shows the variation cyan normal ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold magenta ink was 22.5 seconds. The standard deviation from the fluctuation of viscosity was 0.66. It can be seen that the standard deviation of the normal ink is higher than that at the cold ink. Although fluctuations of ink viscosity were almost the same as the error in the cup, the target viscosity was kept in target and no major errors were involved in this variable. It can also be noted that a trend line is on top of the curve line. The trend line shows almost no change in the behavior of the ink. Any changes in the trend line may be because of error readings in the cup. Similar to the cyan results, viscosity depends on temperature. Every change in ink temperature will change ink viscosity. Throughout the experiment, viscosity readings were made every 5 minutes for each of the experimental Phases.

Figure 15 shows the variation in magenta cold ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold magenta ink was 22.7 seconds. The standard deviation from the fluctuation of viscosity was 0.34. The error reading on a Zahn cup is about 0.5 seconds (Ciucci, 1999). This means that the fluctuations of ink viscosity were less than the error in the cup. The target viscosity was kept in target and no major errors were involved in the measurements.

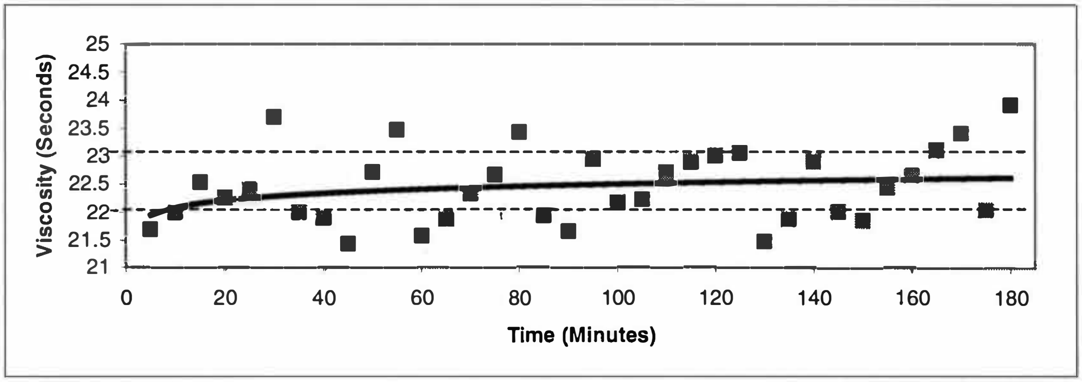

Figure 14. Variation in Cyan Normal Ink Viscosity.

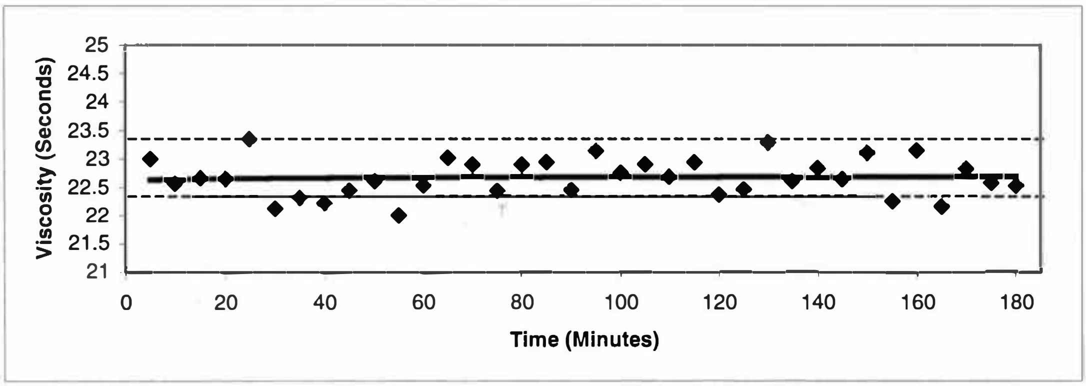

Figure 15. Variation in Magenta Cold Ink Viscosity.

Figure 16 shows the variation of magenta hot ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold magenta ink was 22.6 seconds. The standard deviation from the fluctuation of viscosity was 0.84. It can be seen that the standard deviation of the hot ink is higher than that at the cold ink. Although fluctuations in ink viscosity were almost the same as the error in the cup, the target viscosity was kept in target and no major errors were involved in this variable. It can also be noted that a trend line is on top of the curve line. The trend line shows how the viscosity tends to drop as the temperature increases in the ink system.

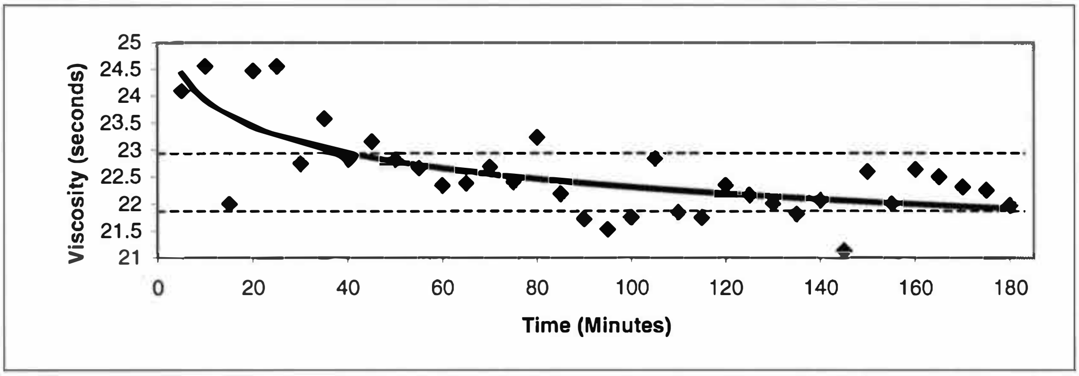

Figure 16. Variation in Magenta Hot Ink Viscosity.

Figure 17 shows the variation magenta normal ink viscosity as a function of time. As can be seen from the graph, the average efflux time for the cold magenta ink was 22.7 seconds. The standard deviation from the fluctuation of viscosity was 0.56. It can be seen that the standard deviation of the normal ink is higher than that at the cold ink. Fluctuations in ink viscosity were almost the same as the error in the cup,

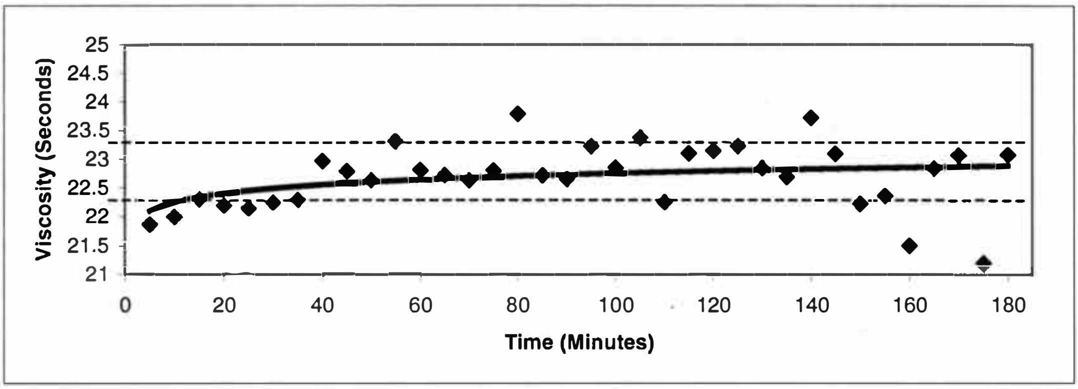

Figure 17. Variation in Magenta Normal Ink Viscosity.

the target viscosity was kept in target and no major errors were involved in this variable. It can also be noted that a trend line is on top of the curve line. The trend line shows almost no change in the behavior of the ink. Any changes in the trend line may be because of errors reading in the cup. Refer also to Appendix A for all the tabular tables.

Solvent Consumption as a Function of Temperature

Throughout the three phases of the project, the amount of solvent added to the systems to maintain viscosity was recorded after the ink reached equilibrium temperature. As mentioned before, viscosity was measured every 5 minutes for a period of 180 minutes per phase. The solvent was manually added to the ink system with a 1000 ml graduated beaker. The idea was to compare the amount of solvent consumed at each different temperature. Figure 18 shows the magenta solvent consumption throughout the entire project as a function of ink temperature on a lb/hr basis. As can be seen from Figure 18, the consumption of solvent increases with increasing temperature. As mentioned before, solvent evaporation depends on partial pressure between the air film layer on top of the ink system, partial pressure of the ink, the temperature of the ink, and the air temperature. The air temperature and ink

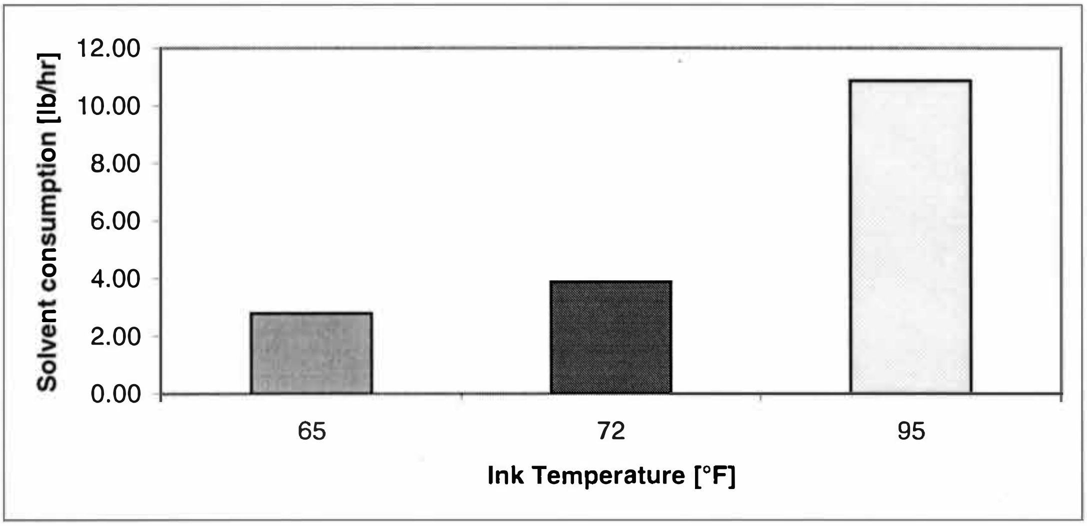

Figure 18. Magenta Solvent Consumption During Trial.

temperature were kept constant and the only variable changing was the partial pressure of the inner layer between the air and the ink. As the temperature of the solvent increases, the partial pressure of the solvent increases also. This means that at a higher partial pressure value, the inner layer of gases can hold more VOC's, thus evaporating more solvent from the ink for the same amount of time. In Figure 18, the equation for magenta solvent consumption as a function of temperature was determined as follows:

$$Solvent_{magenta} = 0.0049 * T^2 - 0.5199 * T + 15.76$$

Where T represents the ink temperature and $solvent_{magenta}$ represents solvent consumption on a lb/hr basis. Figure 19 represents the amount of cyan solvent consumed during the print trials on a lb/hr basis. As can be seen, solvent

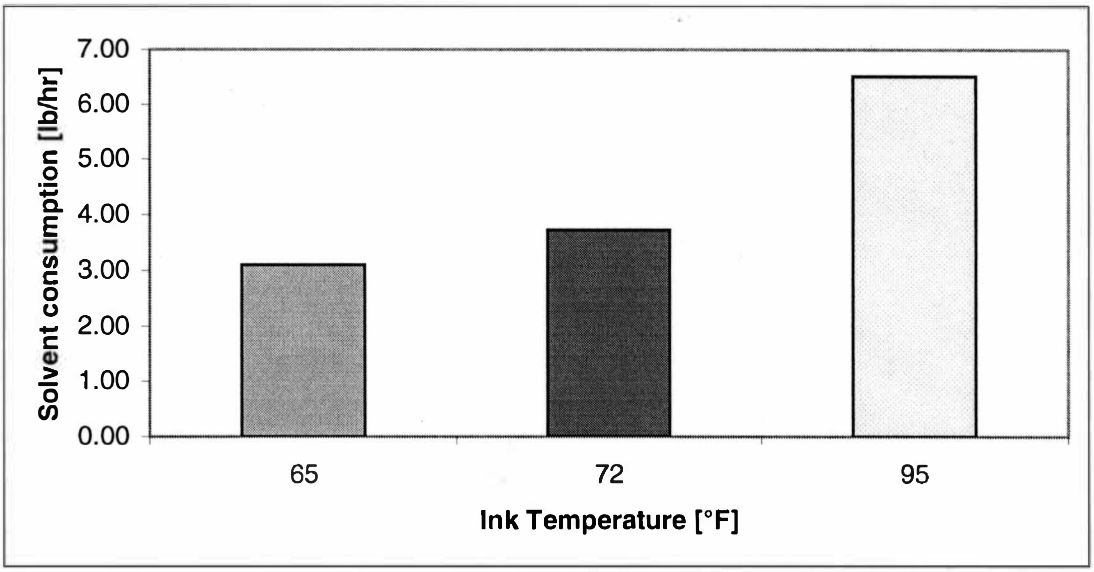

Figure 19. Cyan Solvent Consumption During Trial.

consumption increases with increasing temperature and both cyan and magenta follow the increasing curve. As mentioned before, solvent consumption is a function of evaporation of the solvent. At the higher temperature, there is 45.8% more solvent consumption for magenta and 64.1% more solvent consumption for cyan than at normal ink temperatures. The increase in solvent consumption is even higher compared to the cold temperature. It was found that, compared to the cold temperature, the hotter temperature consumed 54.2% more solvent for magenta and 73% more solvent for cyan. The difference between solvent consumption from magenta and cyan comes from the specific heat of each particular ink. Each particular ink pigment comes with a manufacture's resin; this changes the behavior of the ink under temperature conditions (Ciucci, 1999). In Figure 19, the equation for magenta solvent consumption as a function of temperature was determined as follows:

$$Solvent_{cyan} = 0.0011 * T^2 - 0.0633 * T + 2.54$$

Where T represents the ink temperature and $solvent_{cyan}$ represents solvent consumption on a lb/hr basis.

Ink Consumption as a Function of Temperature

Ink consumption is an important variable for any printer. Usually ink represents one of the major expenses in a printing plant since it costs about 4 times the cost of solvent (Ciucci, 1999). Printers like to use as little ink as possible because it reduces cost of raw materials. Less ink reduces paper work in inventory and storage areas with less explosion proof systems. Less ink means less clean-up time, less ink used, less pollution problem for the environment, and less hazard contact for the people working around the ink. By reducing the amount of ink consumed, not only the printing plant will benefit by reducing cost and safety precautions with workers, but also the environment will benefit by having less pollution.

Table 8 and Table 9 represent the total solvent and ink consumption throughout the research trial. As can be seen from the tables, the first column represents the color and ink temperature. The second column represents the initial ink weight of the color.

This is the initial amount of ink used for the trial. The third column represents the amount of solvent used to get viscosity to target (22 seconds on a Zahn cup # 2). The third column represents the amount of solvent added to the system. This is the previously discussed solvent consumption. The fourth column

Table 8

Consumption of Ink and Solvent for Magenta

Magenta	Initial ink weight (lbs)	Solvent added to reach viscosity (lbs)	Solvent added during trial (lbs)	Total solvent added (lbs)	Ending ink weight (lbs)	Total mass consumption (initial ink weight+total solvent added-final ink weight) (lbs)
Cold ink temperature	51.34	22.57	8.37	30.94	67.19	15.09
Normal ink temperature	74.90	2.38	11.64	14.02	67.87	21.05
Hot ink temperature	67.88	15.44	32.58	48.02	68.54	47.36

Table 9

Consumption of Ink and Solvent for Cyan

Cyan	Initial ink weight (lbs)	Solvent added to reach viscosity (lbs)	Solvent added during trial (lbs)	Total solvent added (lbs)	Ending ink weight (lbs)	Total mass consumption (initial ink weight+total solvent added-final ink weight) (lbs)
Cold ink temperature	59.66	14.26	9.30	23.56	57.12	26.10
Normal ink temperature	73.71	3.56	11.16	14.72	59.80	28.63
Hot ink temperature	76.19	7.13	19.53	26.66	57.79	45.06

represents the total amount of solvent used in the trial (solvent added to reach viscosity plus solvent added during the trial). The fifth column represents the final weight of the ink. This is how much ink was left in the ink sump at the end of the trial. The last column represents the total amount of mass consumed in the trial. This mass includes the initial weight of the ink plus the total amount of solvent consumed minus the final weight of the ink.

Figure 20 and Figure 21 are another representation of the last column of Table 8 and Table 9. As can be seen from Figure 20 and Figure 21, the total mass consumption for the two colors is almost the same at the cold and normal temperature, but increases abruptly for the hot temperature. The reason is that the ink at a colder temperature needs an excessive amount of solvent to reach target viscosity and prints a thinner layer of ink (Ciucci, 1999). In other words, at the colder temperature, the ink needs 27.4% of solvent of the amount of ink needed to print magenta and 17.1% of solvent of the amount of ink needed to print cyan in comparison to the percentage needed at the hottest temperature, that is only 13.3% for magenta and 6.9% for cyan.

The mass consumption is an important factor for the industry because it shows the real amount of solvent and ink consumption for different ink temperatures. From this point of view, it can be noted that overcooling the ink does not necessarily mean a significant reduction in mass consumption. The significant reduction in mass consumption comes in reducing ink temperature from hot to warm and or to the cold temperature.

The total ink consumption during the trial was also calculated. Figure 22 and Figure 23 represent the ink consumption for cyan and magenta, respectively, on a

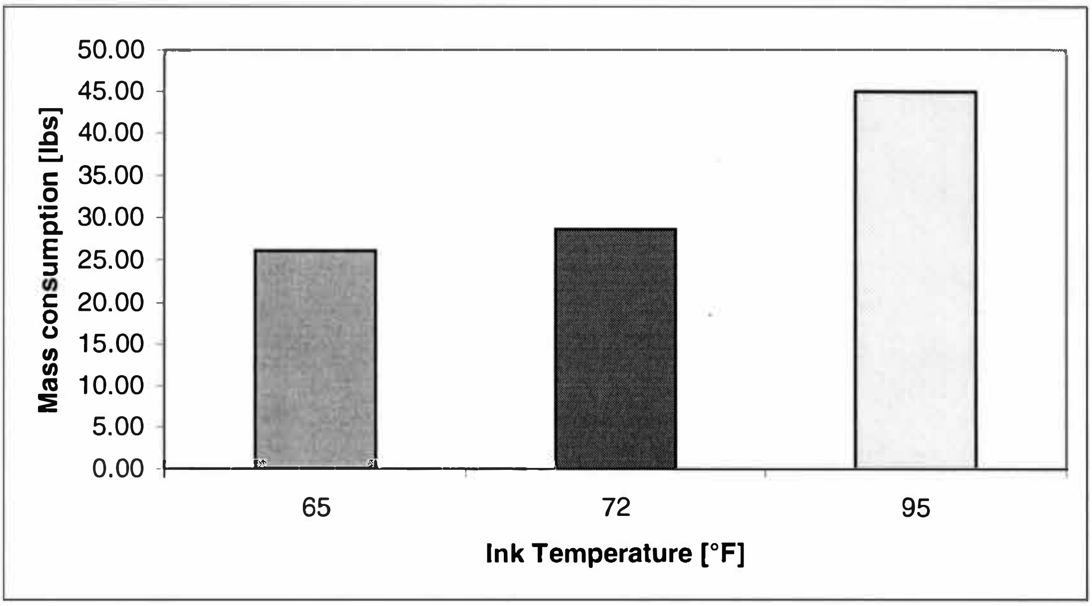

Figure 20. Total Mass Consumption (Ink Plus Solvent) for Cyan, lb.

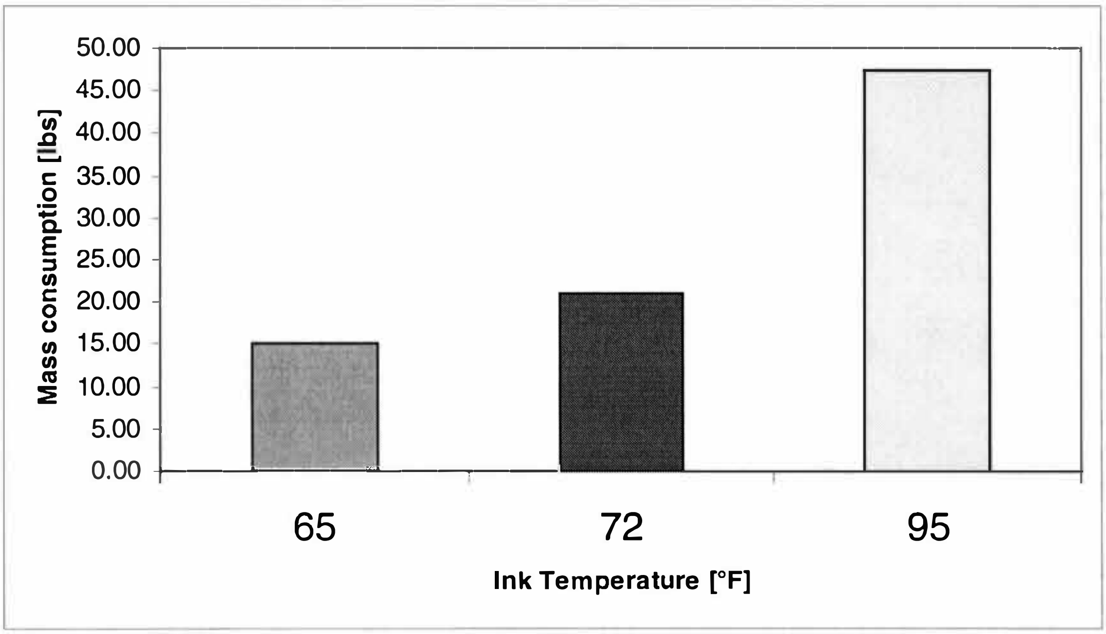

Figure 21. Total Mass Consumption (Ink Plus Solvent) for Magenta, lb.

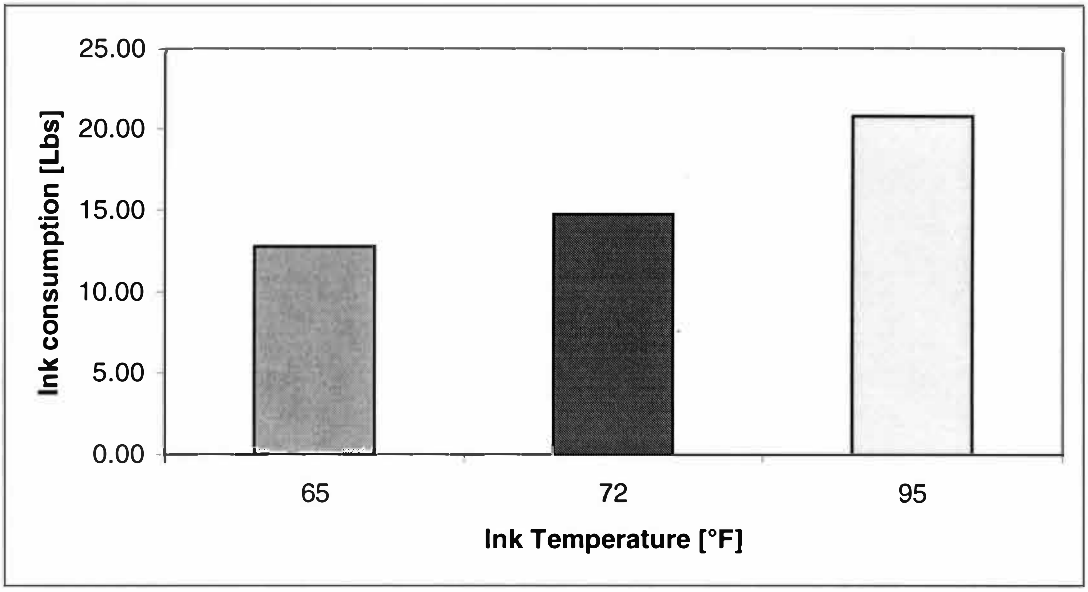

Figure 22. Cyan Ink Consumption, lb.

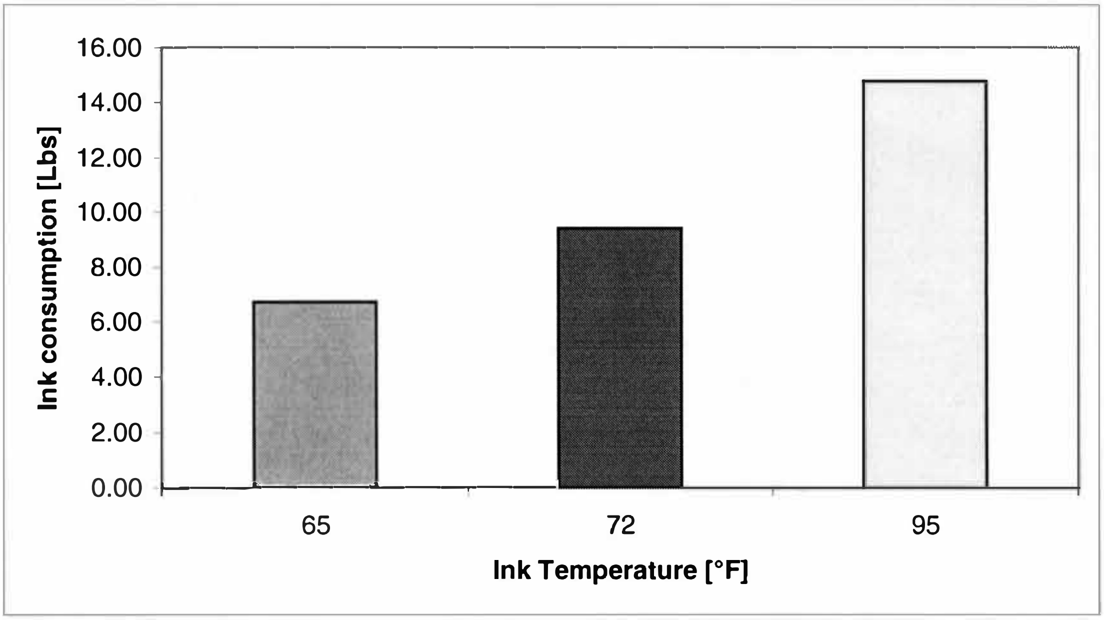

Figure 23. Magenta Ink Consumption, lb.

weight basis. It can be seen from Figure 22 and Figure 23 that the biggest effect on ink consumption comes from the difference between hot temperature and normal temperature. There is a 30% increase in ink consumption for the cyan and the increase for the magenta is 36%. The increase in ink consumption from cold temperature to normal temperature for the cyan is 28% and for the magenta 13.7%. The equation for ink consumption was determined as follows:

Ink consumption for cyan:

$$Ink_{cyan} = -0.0008 * T^2 + 0.4023 * T - 9.86$$

Ink consumption for magenta:

$$Ink_{magenta} = -0.005 * T^2 + 1.07 * T - 41.68$$

Reflection Density as a Function of Temperature

Reflection density is one of the printing industry's standards for measuring print quality. Reflection density sets a communication standard between the ink maker, the printer, and the client. If such standard is not set, variations in color strength will become a common problem for the industry. To correct this problem, the ink being studied is set to a specific percent of reflection density. Failure to reach this target for the client means that the ink maker and/or printer must repeat the job again. Many factors affect color density, for example, pigment concentration of the ink, viscosity of the ink, and temperature (Celio, 1998). As mentioned before, Celio stated that an increase in ink temperature of 1.5°C would cause the reflection density to decrease by 0.015 units using paper as a substrate and toluene as solvent. For this project, the primary substrate was clear polyethylene and the sensitivity of the densitometer was 0.02% of reflection density. This means that any variation less than the accuracy of the densitometer (0.02%) will not be accounted for.

Five density readings every twenty minutes for every color were taken to calculate the average reflection density. A total of 2250 density measurements were performed to increase the accuracy of the readings. Laboratory conditions (RH and temperature) were kept constant through the entire analysis and measurement areas were carefully selected to prevent high values of standard deviation. The instrument was calibrated for every new temperature to prevent influence of human manipulation on the equipment. In addition, it was critical to maintain the same underlying surface throughout the entire measurements since most of these variables are affected by light.

Figure 24 represents the total variation in cyan reflection density throughout the entire experiment. As can be seen from the graph, there is no major variation between the colder and normal temperature, but as the temperature gets warmer, the reflection density decreases. At the higher temperature, there is a higher pigment to solvent concentration ratio as shown in the preliminary test work. This means that at higher temperatures, less solvent is needed to reach the target viscosity. In theory, the ink at a higher temperature should print darker colors (Ciucci, 1998). In reality and as demonstrated throughout this project, the image looks as though it has been printed with lighter colors. Since there is less solvent in the ink system, the ink evaporates faster. Since the ink evaporates faster, there is a variation in dot formation because the ink film on top of the engraved cells dries before it reaches the dwell time (Ciucci, 1998). Dwell time can be considered as the period the web is in physical contact with the engraved cylinder (GAA, 1991). This drying causes a wettability problem of the ink on the substrate, which will be shown later. The ink dries before it is completely spread on the surface of the substrate (Serafano, 1999). This wettability problem causes screening. Screening is a print defect caused by uneven flow of ink between cells, usually caused by high ink viscosity or drying too fast (GAA, 1991). With screening, the shape of the cylinder cells show up in the print. This result in a mix of white and dark areas caused by screening, and this composes most of the printed solids. The overall printed solid area is reduced and the reflection density decreases.

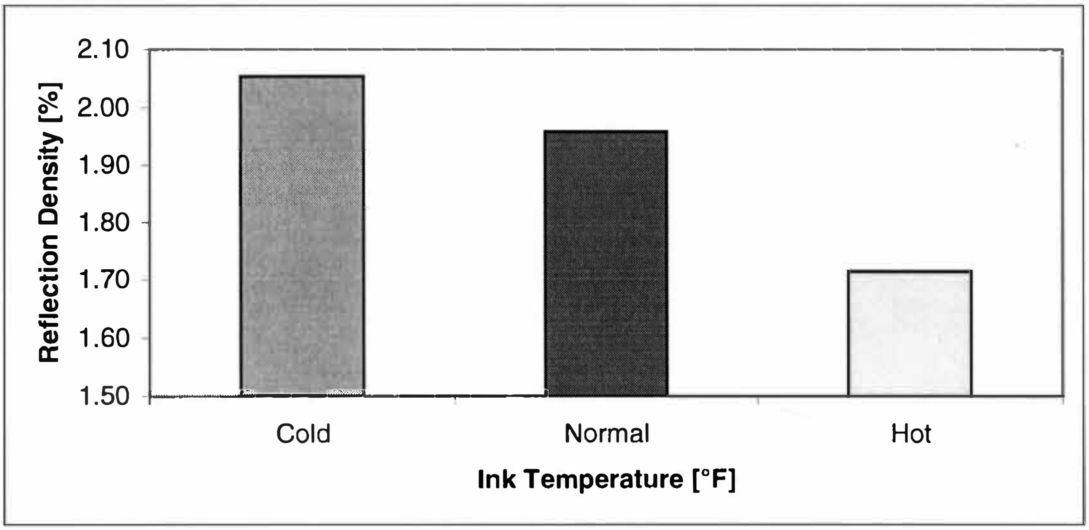

Figure 24. Variation in Cyan Reflection Density as a Function of Temperature.

Figure 25 is another representation of the effects of temperature in reflection density. From this graph, the polynomial equation of the curve was calculated.

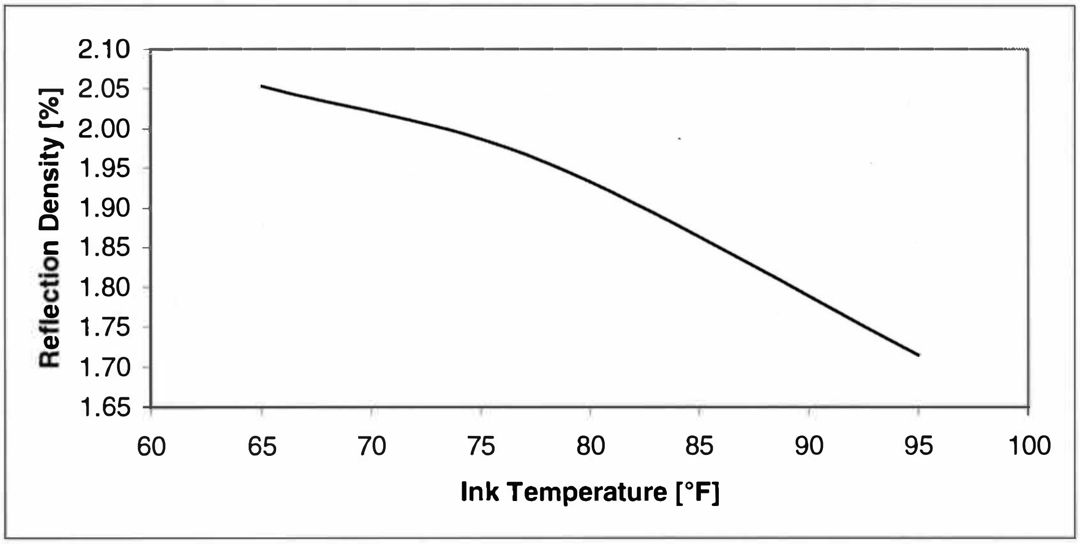

Figure 25. Cyan Reflection Density as a Function of Temperature.

$$D = -0.0002 * T^2 + 0.0257 * T + 1.361$$

Where D represents de reflection density in percentage of light reflected and T represents the ink temperature.

As can be seen from Figure 25, the cyan density can be predicted as a function of temperature. Figure 24 and Figure 25 demonstrate that the reflection density varies 0.09% of reflected light from the cold temperature to the normal temperature, but varies 0.24% of reflected light from normal temperature to hotter temperature. The total variation was 0.33% of reflected light and the biggest effect comes when the ink goes from the normal to the hottest temperature with an effect of 72.72% out of the total variation in reflected light. It can also be concluded that, on average, the reflection density varies 0.055% of reflected light every 5°F. This result is somewhat different from Celios' result (Celio, 1998). Celio stated that density varies 0.015% of reflected density every 5.1°F, but it is important to note that in his experiment, different conditions were used for printing.

Specular Gloss as a Function of Temperature

Specular gloss is an important print quality. Gloss is the characteristic responsible for the shiny or lustrous coverage of the printing ink. Specular gloss can be defined as the fraction of a specified incident beam of light which is reflected by a surface adjacent to the direction of a mirror reflection (GAA, 1991). Usually printing without gloss looks opaque and non-lustrous. This property helps consumers to choose the product that attracts their attention. Most likely, a consumer will pick a product that has good print quality and a good and even gloss in the overall print.

Specular gloss can be affected by different print factors. For example, specular gloss can be affected by viscosity, pigment to solvent load concentration, ink film thickness, and temperature. Printing at a higher temperature will lay down a thicker ink film thickness because there is a higher pigment to solvent concentration. As the film thickness increases, less light is reflected from the instrument, thus decreasing specular gloss. Figure 26 is a representation of light striking two different ink film thicknesses.

As can be seen from Figure 26, a higher portion of light is reflected at the thinner ink film thickness, thus the specular gloss is higher. For this project, the average specular gloss of the non-image area was 90%. This means that the specular gloss of the non-image area is higher than the specular gloss of the image areas.

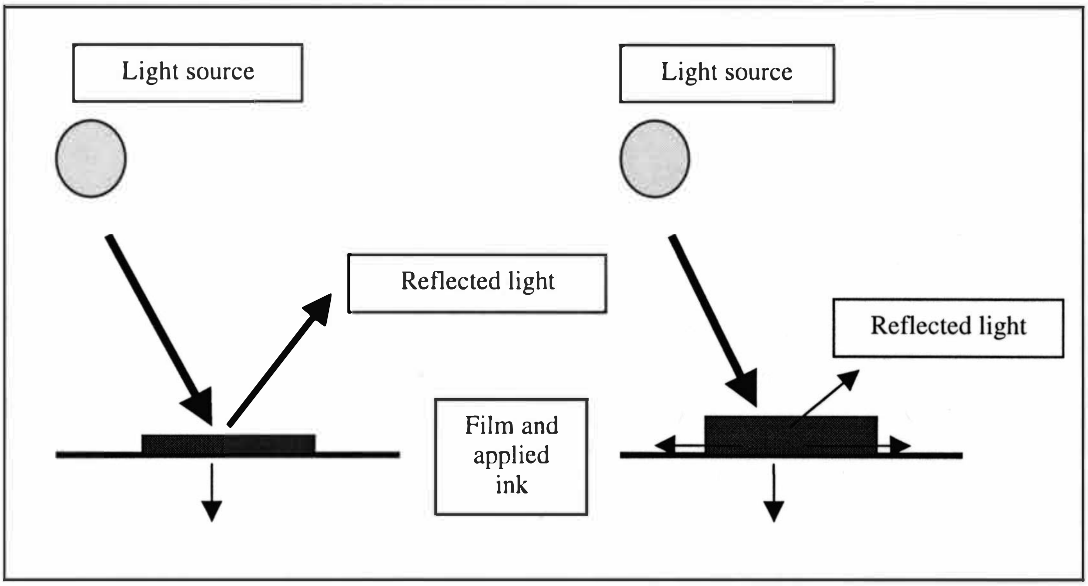

Figure 26. Representation of Light Heating Different Ink Film Thickness.

Figure 27 is a representation of the effects of ink temperature control on specular gloss. As can be seen from Figure 27, the biggest effect on specular gloss comes from the variation in cold temperature to normal or hot temperatures. It can also be noted that there was not much variation between normal to hotter temperatures. The specular gloss of the film approaches the gloss of the non-printed image, which is a higher value. From Figure 27, it was determined that specular gloss decreased by 20% from the cold ink temperature to the normal ink temperature; but, the change from normal ink to hot ink is less than 6%. It was concluded that the biggest effect on specular gloss comes from the ink film thickness and this increases with increasing temperature. One way to resolve the specular gloss problem is to reduce the viscosity at the hotter temperature, although reduction in temperature means more solvent consumption.

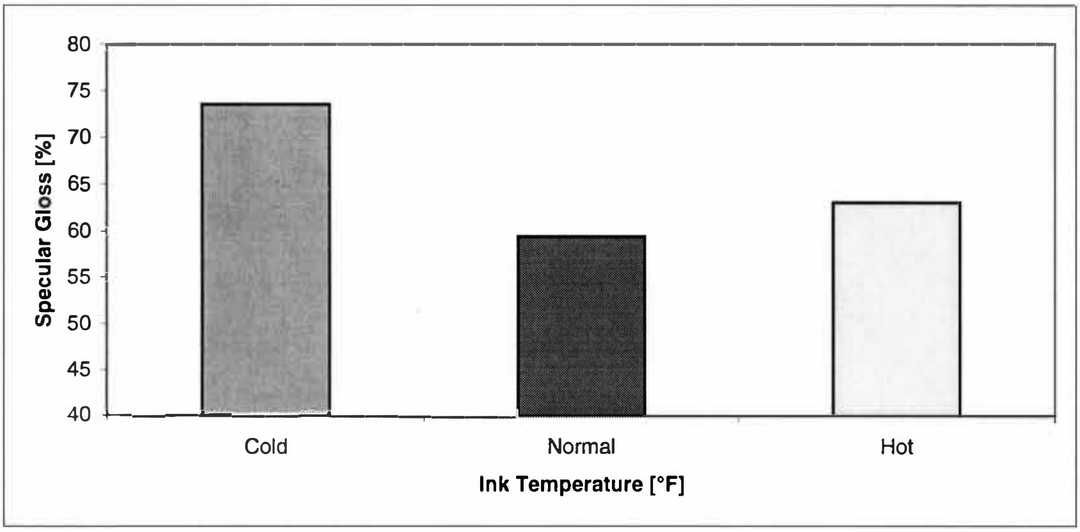

Figure 27. Variation of Specular Gloss as a Function of Ink Temperature.

Tone Step Curve as a Function of Temperature

Tone steps are a critical print characteristic that ensures halftone reproduction for any process color application. In most of the printing images, tone steps are necessary to reproduce picture and images similar to that of a photograph. The combination of printed tone steps reproduces a dot pattern that tricks the human eye by simulating changes in color density. Tone steps are measured as a function of reflected light. The larger the ratio of the area of dots to the total area on a measured surface and the higher the ink film thickness of a given printing ink, the higher the reflection density value (Heidelberg, 1995). In the gravure process, engraving different cell sizes on the printing cylinder creates tone steps. This is accomplished by moving a cutting tool or stylus toward or away from the printing cylinder. Cell size must be variable, from nonexistent to maximum, so that the amount of ink laid down will produce cells with sizes (reflection density) from zero to 100% when printing. At the 100% cell size, there is a bigger cell volume, thus carrying more ink and transferring to the substrate a thicker ink film thickness. At the lower end, 5% to 7%, cell sizes are smaller, thus carrying and transferring smaller portions of ink volume. The reflection density will be higher with thicker ink film thickness and lower at the lower end of the tone steps with lower ink film thickness.

For this part of the project, reflection densities were made on tone steps every 20 minutes for 180 minutes for each ink temperature. For the image selected, tone steps vary from 7% to 100% of ink coverage. Table 10 is a representation of a measurement made at the cold temperature at 100 minutes of the trial run. As can be seen from Table 10, reflection density decreases with decreasing tone step percentage. At the higher end, 100% tone, the cyan density was 1.88% of reflected light. This means that at the 100% tone, most of the light from the instrument its absorb by a thick ink film and almost no light is reflected back. At the lower end, 7% tone, the reflection density is 0.1%. This means that with a thinner ink film thickness, most of the light is reflected back to the instrument, thus reducing the reflected density value.

To clarify this concept the reflection density equation is:

$$Density = -\log_{10}(F)$$

It can be noted from the density equation that as F, the percent of light reflected, decreases, the reflection density increases.

Table 10

Representation of Tone Step Measurements

Tone steps [%]	**Reflection density for cyan [%]**
100.00	1.88
95.00	1.82
76.00	0.95
63.00	0.78
46.00	0.49
37.00	0.40
28.00	0.34
20.00	0.29
12.00	0.19
7.00	0.10

To compare the effects of ink temperature control on tone steps, the tone step values of every 20 minutes were average for a particular ink temperature. The total average of a particular ink temperature was compared to the total average of another ink temperature. Figure 28 shows the variation in reflection density for the tone steps for the different ink temperatures. As can be seen from Figure 28, all the different ink temperatures follow the same curve path, although at a different reflection density value. For most of the tone steps, the reflection density for the cold ink and for the normal ink were on the same range of values. This means that there was no big

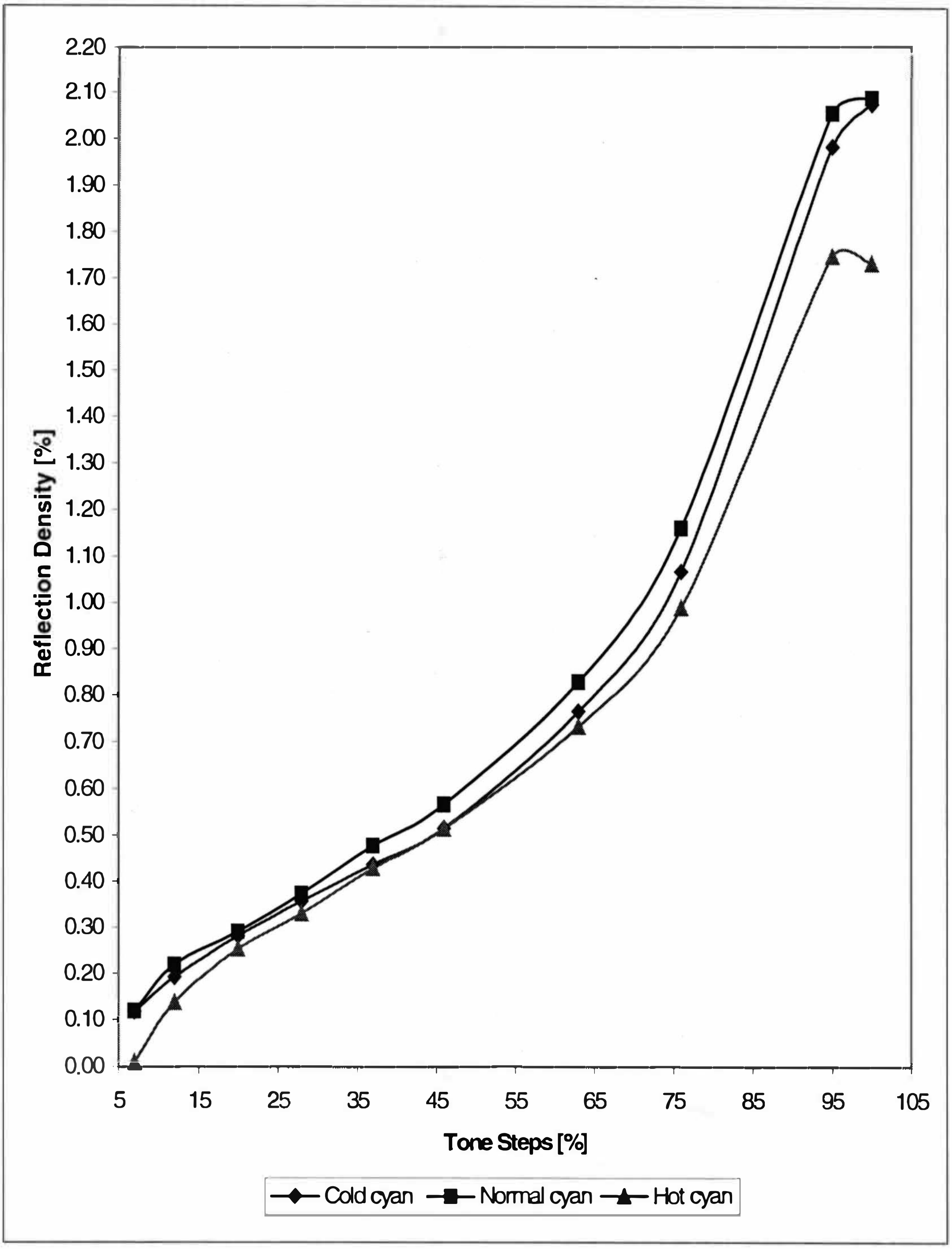

Figure 28. Cyan Tone Step Curve for All Ink Temperatures.

difference in reflection density between the cold ink and the normal ink. From cold ink to normal ink, 50% of the tone steps (5 out of 10) were not affected.

All of the tone steps (10 of them) change with a higher value than the accuracy of the instrument. At the high end of the tone steps (100% tone), the reflection density dropped 16.7% when the ink temperature changed from normal and/or cold to hot. At the low end, the reflection density dropped 36.4% and the last tone step (7%) was completely lost at the hot ink temperature. At the low end, small volumes of ink are transferred to the substrate. Since the solvent to pigment ratio is low at the warmer temperature, the ink dries before it adheres to the substrate. (Ciucci, 1999). As the ink dries, it will not print on the film.

It was concluded that printing with a hot ink temperature would decrease the quality of process colors and images, especially if the product requires detailed images (like highlights) in the 7 to 5% tone step. At the high end, the 70 to 100% tones, the images reduce reflection density at about 16%. This means that printed images will not look as dark as they are supposed to look. To recover the lower end of the tones, more solvent can be added to the system, although this means more solvent consumption.

Haze as a Function of Temperature

Haze is another common printability problem in gravure. Haze can be defined as an unwanted printed ink film resulting from the doctor blade failing to wipe fully in the non-image areas of the cylinder (GAA, 1991). Although haze was not a quantifiable variable for this research project, it was noted that haze increases with decreasing temperature. At the colder temperature, there is a higher solvent to pigment concentration, thus the ink does not dry as fast as at a higher temperature

For this reason, the ink film that covers the printing cylinder after the blade wipes the excess ink is transferred to the substrate (Ciucci, 1999). At the higher temperature, the ink dries faster and there is no ink transferred in the non-image areas. From this

qualitative measurement, it was concluded that haze may increase with decreasing temperature, although decreasing efflux time and/or doctor blade pressure may solve the problem.

Rub Resistance as a Function of Temperature

Abrasion resistance (rub) is an important characteristic for packaging printing. The majority of packaging products rub against other surfaces peeling, scratching, or removing the ink from the package. Ink makers formulate special inks to improve abrasion resistance. Inorganic filler, flattening agents, and latex binder composition all play a role in determining the abrasive characteristic of a substrate (Bradley, 1998).

For this printability test, a Sutherland rub tester was used. Three samples per each ink temperature were analyzed and the average is reported in the following graph. The testing procedure consists of rubbing a printed sample against a white piece of paper. Reflection density is measured before and after the test and the difference is directly related to the amount of ink transferred to the paper.

As can be seen from Figure 29, there was no major change between the abrasion test at different temperatures. It can be noted that the difference between the

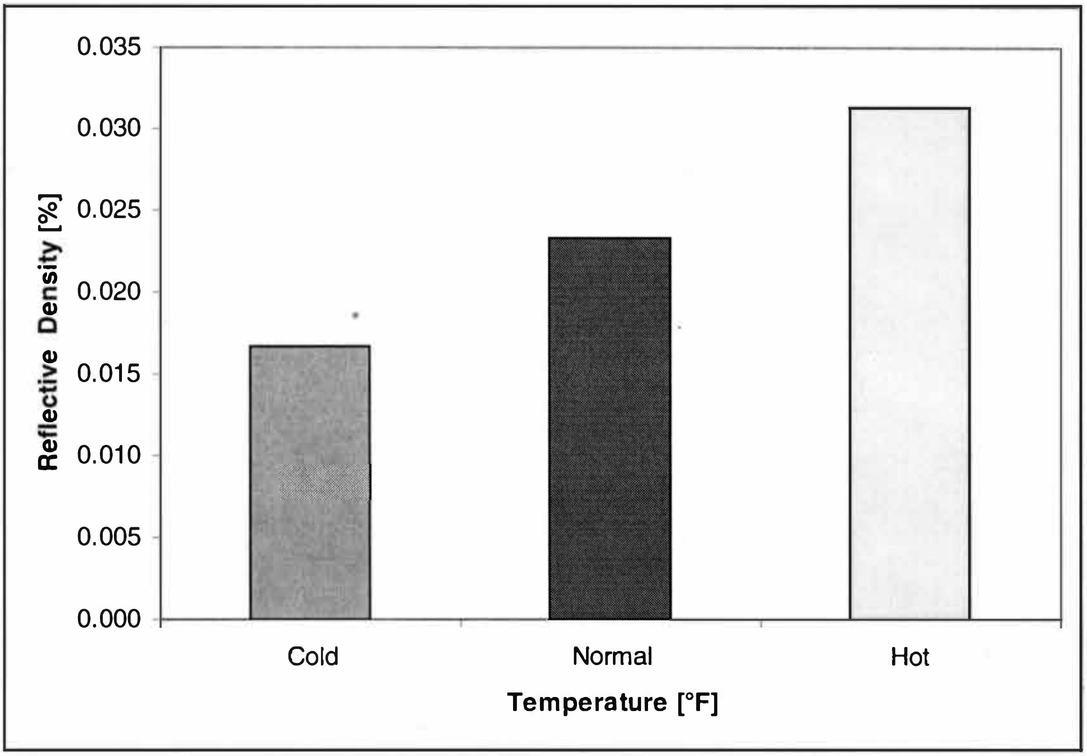

Figure 29. Rub Resistance as a Function of Ink Temperature.

hottest temperature and the coldest temperature is less than 0.02% of reflection density. This means that any variation between the ink temperature can be noise in the densitometer. Although a difference was noted, it was insignificant and for this reason, no further conclusions were made from the abrasion test.

Dot Structure as a Function of Temperature

This is the part of the project where microstructure analysis of the printed dots was conducted. The idea was to analyze the effects of ink temperature control on dot structure, dot behavior, and wettability. One sample every twenty minutes for each ink temperature was analyzed at the 37% tone. The average values of each ink temperature were compared and two graphs were analyzed, dot area and dot perimeter as a function of ink temperature.

It was found that one of the biggest effects of ink temperature on dot structure was the deformation of the dots caused by the "donut effect." The donut is a common gravure problem. The donut effect is caused by the concave curve of a non-turbulent liquid on top of a container. In this case, the containers are the small-engraved cells of the printing cylinder. As the ink fills the cells, it forms a concave shape leaving a small volume of air to be trapped between the ink and the substrate. The air prevents the ink from being transferred to the middle of the printed dot; on the contrary, it forces the ink to be spread outward. As the ink gets warmer, the ink becomes less viscous and more fluid. A less viscous ink will produce a bigger concave meniscus shape on the cell, thus letting more air to be trapped between the ink and the substrate (Ciucci, 1998). With more air trapped, the donut becomes bigger.

As the donut effect increases with temperature, the amount of printed image decreases and the printed dot becomes bigger. Ciucci stated that the air trapped between the meniscus and the substrate forces the ink outward creating another common printing problem in gravure known as whiskering. Whiskering is defined as fine, hair like lines that appear dragged from solid print areas into non-printed areas. It was found that the bigger the donut effect, the bigger the whiskering effect on the dots. Figures 30, 31, and 32 are pictures taken at the 37% tone. These pictures show the effect of ink temperature on donut and whiskering effects.

Figure 33 represents the variation in dot perimeter as a function of ink temperature. As can be seen form Figure 33, dot perimeter increases with increasing temperature. It was found that as the ink temperature increases, dots deformed, producing a bigger perimeter. At higher ink temperature, donut effects increase the average perimeter of dots. The increase in dot perimeter is a straight relation between dot gain and mottle, and results in a decrease in print quality.

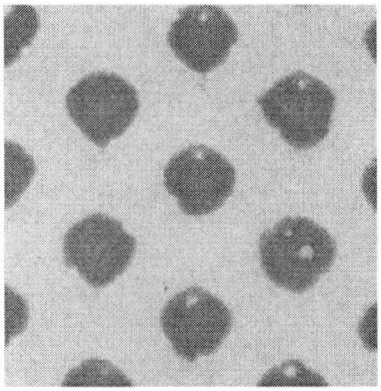

Figure 30. Cold Cyan Dots at 37% Tone.

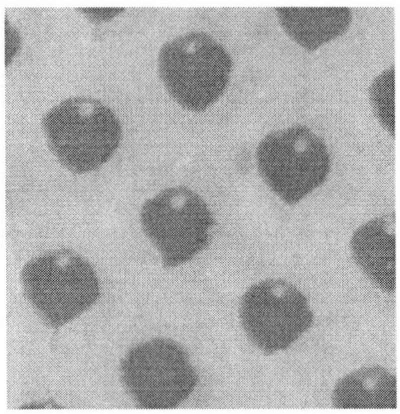

Figure 31. Normal Cyan Dots at 37% Tone.

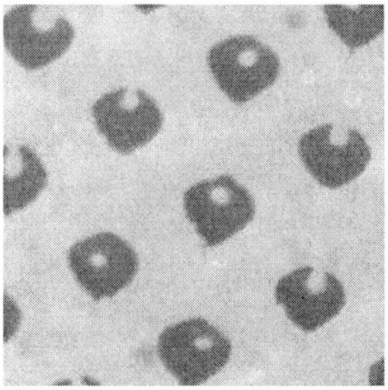

Figure 32. Hot Cyan Dots at 37% Tone.

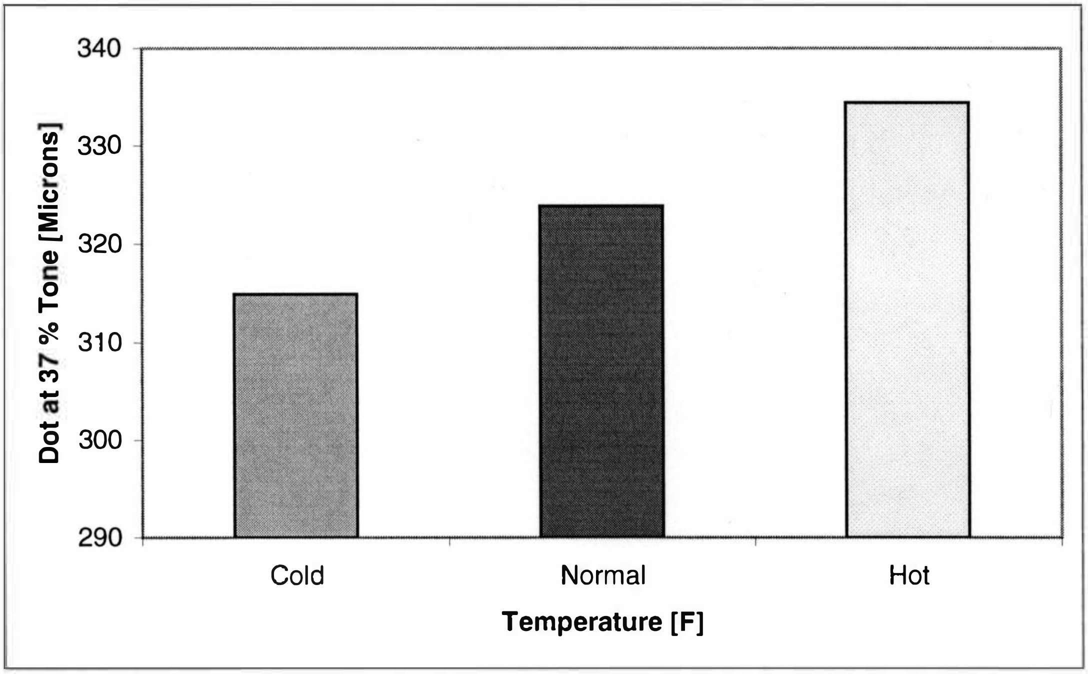

Figure 33. Cyan Dot Perimeter as a Function of Ink Temperature.

The image analyzer was also used to prove the effects of ink temperature control on wettability that consequently affects reflection density. Figures 34, 35, and 36 are pictures taken in solids areas. As can be seen, the white, non-printed areas of the solids increase with increasing ink temperature. The white areas are portions of the substrate not covered by the ink film; indeed, they represent the cell shape of the printing cylinder. As the ink gets warmer, it reduces the solvent to pigment ratio, and thus dries faster. With a faster drying time, the volume of ink transferred from the cell to the substrate has no time to be spread. At this temperature, the ink from a particular cell dries before it reaches the vicinity of another cell. Furthermore, it leaves valleys of non-printed image between the cells; this is known as screening. This phenomenon reduces the overall reflection density of the color.

Figures 34, 35, and 36 also show that for ink at colder temperature the printing is at lighter colors. It can be noted that the image at the colder temperature looks like a lighter cyan color. On the other hand, the color at normal and hot temperature looks darker. It is also important to mention that at the higher temperature there is a thicker ink film, thus the color reflects less light to the instrument making it a darker color. From this part of the research project, it was concluded that wettability overcomes the effects of printing with thicker ink films or printing with a higher pigment to solvent concentration. For this reason, wettability changes color density as a function of temperature.

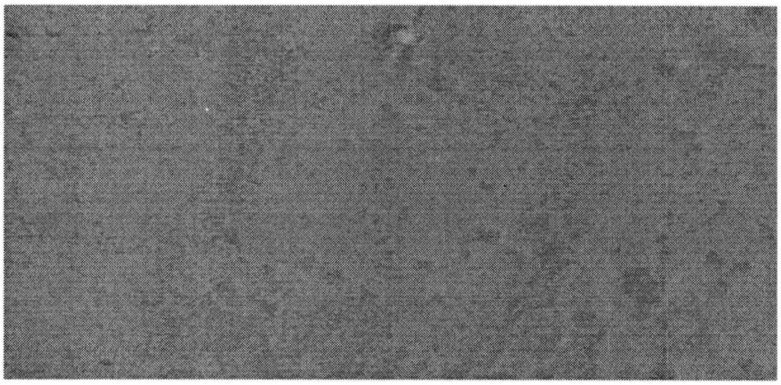

Figure 34. Picture of Cyan Cold Solids.

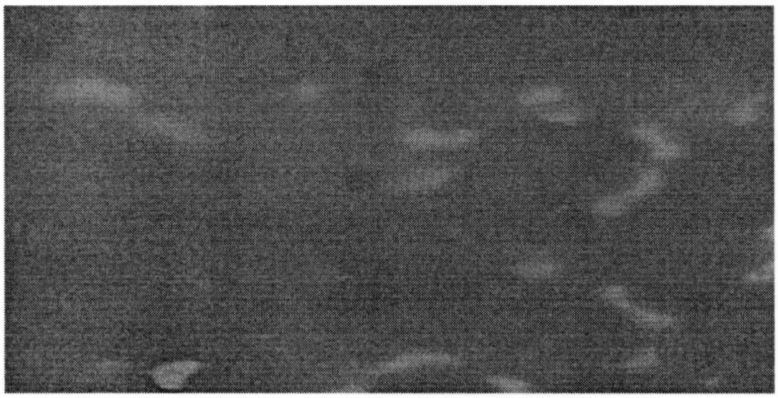

Figure 35. Picture of Cyan Normal Solids.

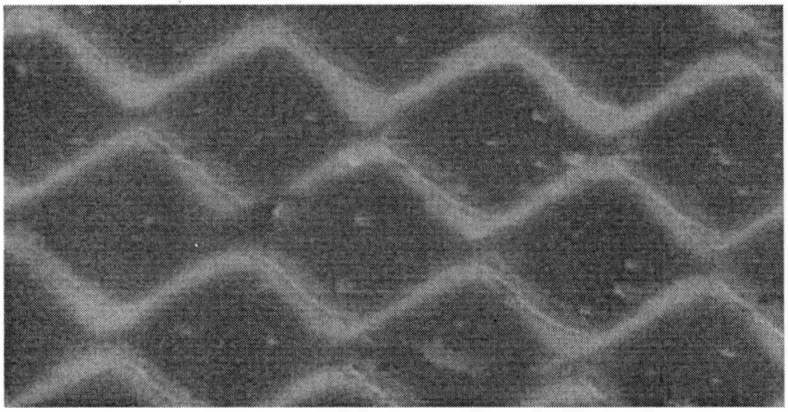

Figure 36. Picture of Cyan Hot Solids.

COST ANALYSIS

The following is an example of the application of the information in this thesis to an assumed operational plant. A press model consists of the following five variables: (1) Size: 23 inches wide, (2) Number of units: 6 colors, (3) Production hours per year (EPA, 1998): 7200 hours/year, (4) Production rate: 300 fpm, and (5) Liner foot of production: 13,333 feet/hour or 96,000,000 feet/year.

Solvent Cost

With this model, costs of solvent and ink consumption were calculated on a yearly basis. It is assumed that an average of 10 lbs/hr of solvent was consumed during the trial. Ten lbs/hr equals 40.32 tons/year of solvent consumed. Figure 15 shows the cost of tons of solvent per year used in magenta, assuming a cost of $0.50/lb of solvent (Ciucci, 1999). As can be seen in Figure 37, the cost increases with increasing temperature. It can be noted that at the highest temperature, an extra $30,000/year per magenta color is spent. This cost does not include any environmental damage, storage for extra solvent, and EPA regulation fees, which increase the cost dramatically.

The same calculations were done for the cyan color. Figure 38 shows the cost of solvent consumption per year for cyan, assuming a cost of $0.50/lb of solvent (Ciucci, 1999). As can be seen in Figure 38, the cost increases with increasing

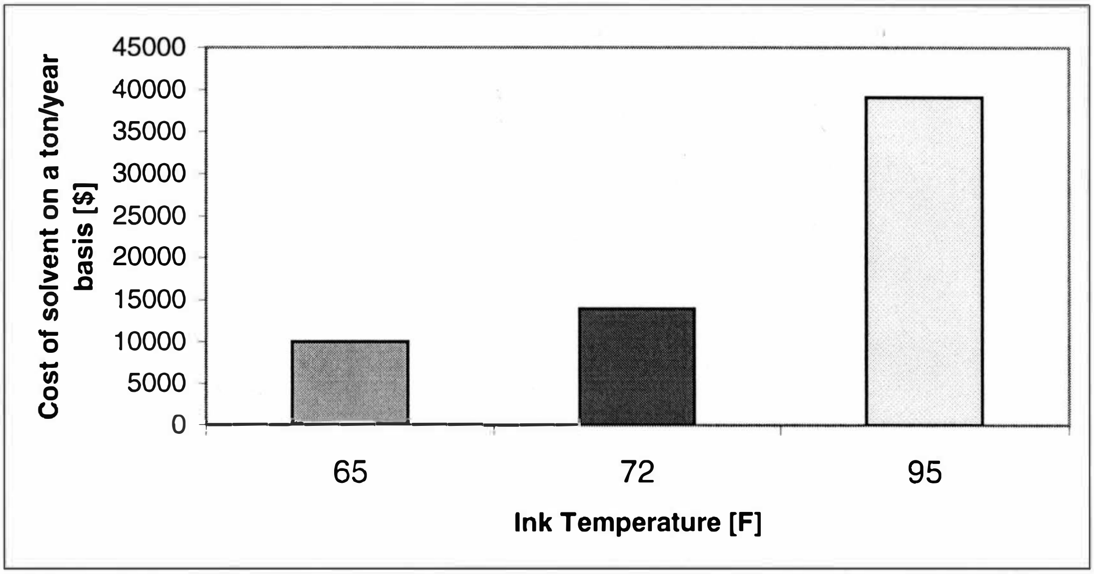

Figure 37. Cost of Solvent Used in Magenta on a Ton/Year Basis.

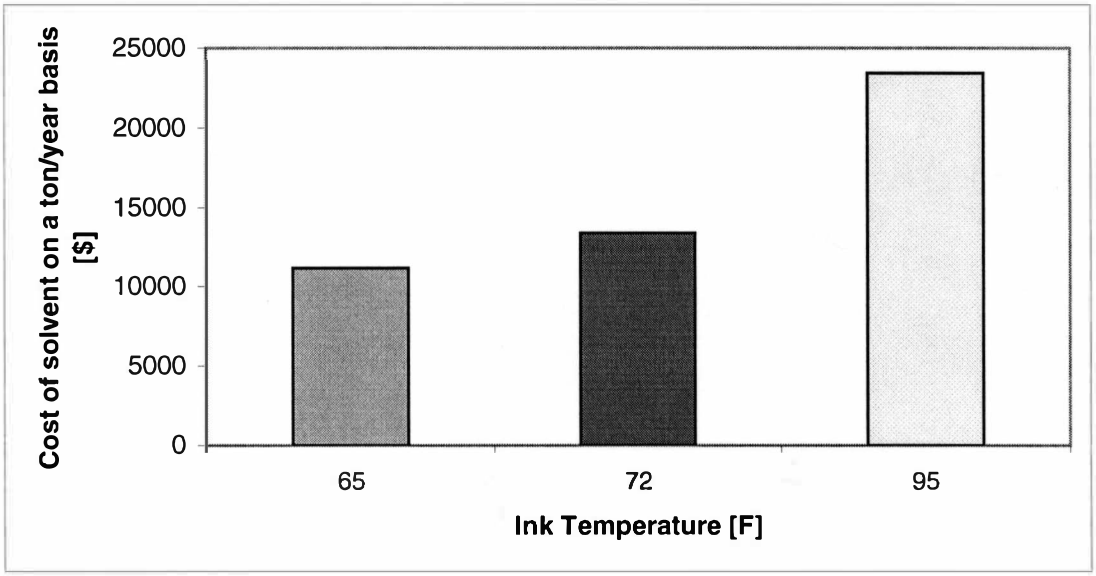

Figure 38. Cost of Solvent Used in Cyan on a Ton/Year Basis.

temperature. Note that at the highest temperature, an extra $15,000/year per cyan color is spent. This cost does not include any environmental damage, storage for extra solvent, and EPA regulation fees, which increase costs dramatically. If both of the costs are added together ($45,000) and multiplied by the number of printing units per press (6), the model company may save about $270,000/year. It is also important to note that the amount of solvent needed to get the viscosity to target was not included in this cost. This amount of solvent was considered in ink consumption as a function of temperature.

Ink Cost

The total cost for ink consumption was also determined as a function of temperature. Ink cost increases with increasing temperature. If it is assumed that a pound of ink costs $4, then the reduction in cost is significant when the ink in temperature is reduced. Figure 39 and Figure 40 show the cost of cyan and magenta on a tons/year basis. It can be noted that the biggest effect on ink cost comes from the hottest temperature, with an increase of $174,156 per year for the cyan and $154,817 per year for the magenta compared to the cost at normal temperature. The difference in cost from normal temperature to cold temperature was around $70,000 for magenta and less than $60,000 for cyan.

From these results, it was concluded that consumption can be regarded from two points of view. The first one is individual consumption of ink and solvent. The second one is total mass consumption combining ink and solvent. It was concluded from these two points of view that the biggest effect in mass consumption and cost comes from the difference in hot temperature to normal and/or cold temperature. It was also concluded that the changes from normal to cold temperature were somewhat lower, although different inks may react differently at different ink temperatures. For example, it was noted that there was a bigger mass consumption at the normal and cold temperatures for cyan than the consumption for magenta. In conclusion, it was shown that a reduction in ink temperature could save a model company about $1,200,000 per press ($165,000 of ink per 6 color and $35,000 of solvent per 6 colors).

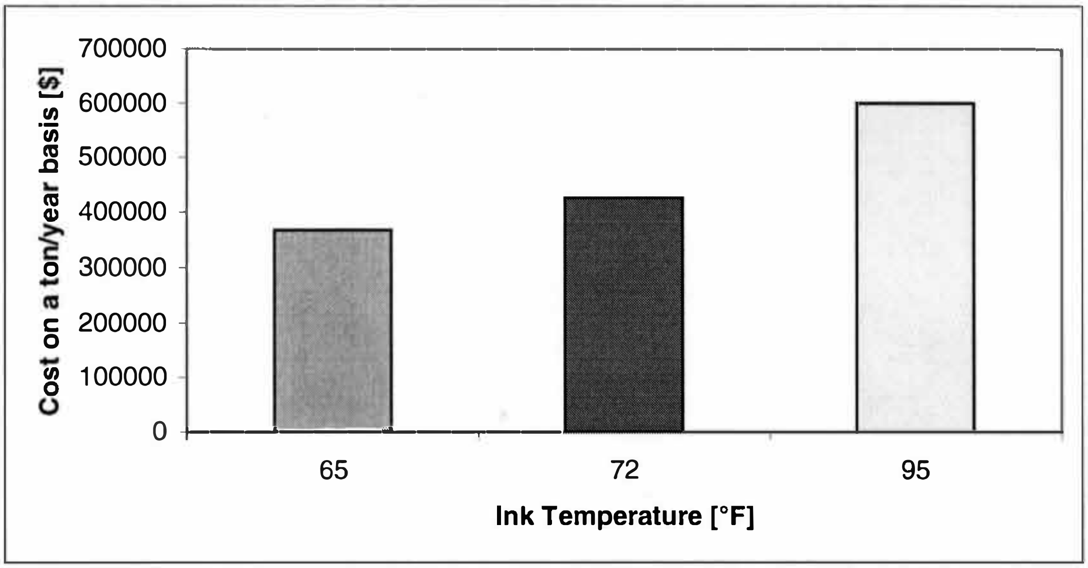

Figure 39. Cost of Cyan Ink.

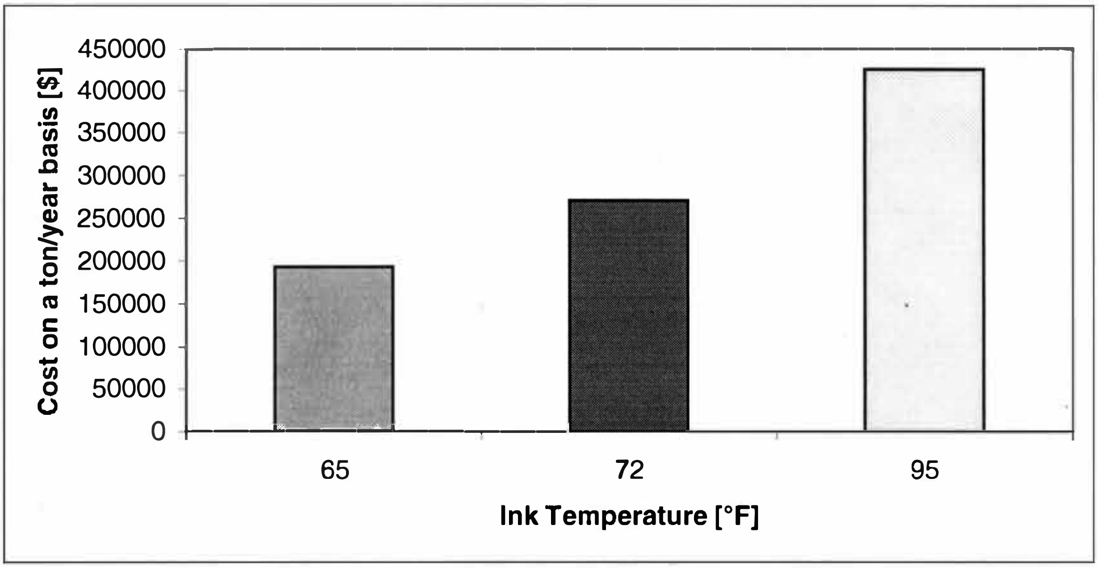

Figure 40. Cost of Magenta Ink.

CONCLUSIONS

The results of this thesis are primarily directed to the small to medium size printer, looking for added solvent reduction benefits. Medium to large companies may also benefit from this study or any printer looking to lower cost and be environmentally more conscious.

Based on this research project, I conclude for solvent based packaging gravure inks printed on film substrates:

1. From the printability analysis tests, it was concluded that the biggest effect comes from wettability. At higher temperature, the ink dries faster, preventing the ink from spreading outward in the substrate. Wettability causes a reduction in reflection density due to screening problems, and this is a direct relation to mottle problems. Reflection density decrease 0.055% of reflected light every 5°F.

2. Wettability also causes change in tone step curves because the ink in the small cells dries before it reaches the substrate. At the low end, reflection density dropped 36.4% and the last tone step (7%) was completely lost with the hot ink.

3. Rub resistance was not affected by ink temperature. Although a difference was noted, it was insignificant (less than 0.02%), and, for this reason, no further conclusions were made from the abrasion test.

4. Specular gloss was also affected by wettability. Specular gloss is measured in the solids areas. Screening changes the reflection of light from the solids

areas, thus it reduces the specular gloss. Specular gloss decreased 20% from cold to normal ink temperature.

5. One of the biggest effects of temperature control measurements was on dot structure. Higher temperature causes the ink to form a bigger meniscus on the engraved cell. With higher meniscus, there is more air trap between the cell and the substrate. The bigger the air pocket, the bigger the donut effect. It was also noted that at higher temperatures, bleeding increases because the air forces the ink out into the non-image areas. It was concluded that reducing ink temperature could dramatically reduce the donut effect, thus decreasing dot deformation and dot gain.

6. The preliminary test for solvent and ink consumption provides good information about solvent and ink behavior at different room temperatures, but the data collected during the preliminary test was off by 30 to 40% compared to that of the research trial. The differences in data are due to differences in open areas, flow rate of the air around the ink system, heat absorption by other components of the press like the dryers, rotation of the printing cylinder, and agitation of the ink pump.

7. The heat exchanger test provided essential information about the heat flux. From this test, it was concluded that it takes about 20,000-Watts of energy to cool the ink and about 50,000-Watts of energy to heat the ink. It takes less energy to cool the ink than it takes to heat it up. The difference in energy is due to a higher temperature difference between the inlet and outlet water temperatures. This is also the case because the difference in temperature between the hot ink and room

temperature is 23°F, but the difference between the colder temperature and ambient temperature is 7°F.

8. From the solvent consumption test it was concluded that the model company presented in this project can reduce its solvent consumption by 40 to 60% just by reducing the ink temperature from 95°F to ambient temperature, 72°F. It was estimated that the same company would save approximately $400,000 a year in solvent consumption per press. From this part of the research, it was also concluded that the biggest difference in solvent consumption does not come from cooling the ink, but by reducing its temperature to a range close to ambient temperature.

9. From the ink and mass consumption test it was concluded that the model company presented in this project can reduce its ink consumption by 20 to 30% just by reducing the ink temperature from 95°F to ambient temperature, 72°F. It is important to note that these values may change depending on the ink system. The difference in ink consumption comes at the colder temperature, where there is a higher solvent to pigment ratio. At this temperature, printing occurs with less pigment, resins, and additives of the ink, but with more solvent. On the other hand, printing at higher temperature uses more pigment and ink components, thus printing with a higher ink film thickness. It was estimated that the same model company would save approximately $60,000 to $70,000 a year in ink consumption per color. It was also estimated that the model company would save $1.2 million per press in mass consumption, this value considers solvent and ink consumption. From this part of the research, it was also concluded that the biggest difference in ink consumption does

not come from cooling the ink, but by reducing its temperature to a range close to ambient temperature.

From the printability analysis, it was concluded that the wettability problems could be fixed by adjusting the viscosity of the ink at different temperatures, for example, by reducing the efflux time at the hottest temperature. Although a reduction in efflux time means more solvent consumption and more solvent evaporation. The most important conclusion from this part of the research is that temperature control measurements helps control print quality because there are fewer viscosity fluctuations in the ink. At the range of temperature control, performing a fingerprinting on the press can maximize the pigment to solvent ratio. This optimization of pigment/solvent ratios and the help of temperature control measurements can increase print quality dramatically.

The increase in fossil fuel prices has alerted the printing industry to take actions regarding solvent waste. Waste is not only an economic problem, but also an environmental issue. The EPA will continue to increase control of VOC's. Incinerators and recovery systems may no longer be the only option. For these reasons, new "environmentally friendly" ink systems must be developed. This study will provide the first steps in designing a better and less polluting way of printing. Temperature control for ink systems may not be the only solution, but it has been demonstrated that temperature control can reduce the amount of emission from VOC's while maintaining a constant ink viscosity and thus good printability results.

SUGGESTIONS FOR FUTURE RESEARCH

For future research, I propose the following studies:

1. Perform an evaporation rate study on liquid inks. The evaporation rate study should measure the parts per million (ppm) evaporated from the ink at different locations. To measure ppm of solvent evaporated, a flame ionization detector can be used. The instrument uses a probe to collect carbon molecules in the atmosphere. The higher the carbon content in the probe, the higher the evaporation rate in that location. To perform measurements at different locations, the gravure unit under study should be completely enclosed. The airflow going in and out of the gravure unit should be from a fixed entrance with a known value in m^3/minutes. With this set up system, ppm measurements should be done at the sump, engraved cylinder, exhaust duct, all at different ink temperatures. The probe will be place at these different locations and the values will be compared at different ink temperatures.

2. Perform a solvent and ink consumption study with a different packaging ink system. Throughout this project, it was noticed that different pigment changes the thermal conductivity of the ink, thus changes the evaporation rate of it. It may be beneficial to perform the test using different ink systems. Most of the packaging inks uses different solvent blends to performed a specific task. These blends affects printability and evaporation rate. For this thesis, a 50/50 ratio was used for the experiments. For future experiments, the ratio of solvents may be change to

detect the relation between evaporation rate and solvent blend. With the new data collected, compared the results with this research project.

3. With a more sophisticated heat exchanger system, increase/decrease the temperature of the ink by 5°F to increase the accuracy of solvent and ink consumption and printability analysis as a function of ink temperature. For this thesis, extrapolation of data was used to detect the effects of temperature on different values. With a more detail analysis, actual data can be used to determine the effects of temperature on different values. This experiment is also important because it will resemble an actual heat exchanger use in printing plants. With this study, actual data can be used to improve the efficiency of such heat exchangers.

Appendix A

Tabular Tables for Phase I, II, III, and Printability Analysis
Cold Trial Data

				initial solvent added magenta (lts):				9.5
Date: 12/02/98				initial solvent added cyan (lts):				6
Run #1 Room temp:		82F		Amount of magenta ink consumed (lts):				4.24
R.H:		30%		Amount of cyan ink consumed (lts):				6.22
Measurements		Value						
Type of cylinder		Fruit & wine						
Color		Red & Blue						
Time of the trial:		3hrs						
Press speed								
Type of substrate		Polyethylene						
Final volume of ink								
ESA		off						
Target viscosity: 22 seconds								
Measured time	Magenta	Magenta	Magenta	Mage solids	Cyan	Cyan	Cyan solids	Cyan
Time (5 minutes)	Visco (sec)	Solv (liters)	Ink tem (F)	%	Visco (sec)	Solv (liters)	%	ink temp (F)
5	23	0.5	63	0	23	1	0	64
10	22.56	0.5	65	0	22.67	0	0	66
15	22.66	0.5	64	0	22.86	0	0	65
20	22.65	0	65	0	23.13	1	29.51	66
25	23.35	0.5	65	25.41	23.22	1	0	67
30	22.12	0	66	0	22.47	0	0	67
35	22.31	0	66	0	22.5	0	0	68
40	22.22	0	67	0	22.53	0	0	68
45	22.44	0	66	0	23.15	0	0	68
50	22.61	0	67	0	22.54	0	0	69
55	22	0	66	0	22	0	0	67
60	22.53	0	64	0	23.57	1	0	67
65	23	0.5	64	0	22.75	0	0	67
70	22.88	0	65	0	22.72	0	0	67
75	22.43	0	64	17.99	22.88	0	0	67
80	22.88	0	64	0	22.3	0	32.92	67
85	22.93	0	65	0	23.19	0	0	67
90	22.44	0	65	0	23.53	1	0	68
95	23.13	0.5	66	24.56	22.59	0	0	68
100	22.75	0	66	0	22.5	0	0	68
105	22.9	0.5	66	0	23.28	1	0	68
110	22.69	0	66	0	22.37	0	0	68
115	22.94	0	66	0	24.26	1	0	69

120	22.37	0	66	0	22.75	0	0	69
125	22.47	0	67	0	21.66	0	0	68
130	23.29	0.5	65	0	23.75	1	0	66
135	22.62	0	65	0	22.09	0	0	67
140	22.85	0	66	0	22.81	0	0	68
145	22.66	0	66	0	22.31	0	0	68
150	23.12	0	66	0	22.7	0	0	68
155	22.25	0	66	0	22.72	0	0	68
160	23.15	0.5	66	0	23.38	1	17.25	68
165	22.16	0	66	0	22.46	0	0	67
170	22.81	0	66	25.93	21.9	0	0	66
175	22.58	0	66	0	23.19	1	35.27	67
180	22.53	0	66	0	22.63	0	0	68
ge & tota	22.67	4.50	65.50	0.00	22.79	5	0.00	67.33
td deviati	0.33				0.54			

lvent consumption of magenta (Lts/hr):	1.50
Solvent consumption of cyan (Lts/hr):	1.67
1 Liter of solvent blend = 0.846 Kg	
lvent consumption of magenta (lbs/hr):	2.79
Solvent consumption of cyan (lbs/hr):	3.10

Normal Trial Data

initial solvent added magenta:		1
initial solvent added cyan:		1.5
Amount of magenta ink consumed (lts):		3.68
Amount of cyan ink consumed (lts):		5.94

Date: 12/03/98	
Run #1 Room temp:	82F
R.H:	38%
Measurements	Value
Type of cylinder	Fruit & wine
Color	Red & Blue
Time of the trial:	3hrs
Press speed	
Type of substrate	Polyethylene
Final volume of ink	
ESA	off
Target viscosity: 22 seconds	

Measured time	**Magenta**	**Magenta**	**Magenta**	**Mage solids**	**Cyan**	**Cyan**	**Cyan solids**	**Cyan**
Time (5 minutes)	**Visco (sec)**	**Solv (liters)**	**Ink tem (F)**	**%**	**Visco (sec)**	**Solv (liters)**	**%**	**ink temp (F)**
5	21.87	0	77	0	21.69	1	0	77
10	22	0	77	0	22	0	0	77
15	22.31	0.5	77	0	22.53	0	0	77
20	22.2	0	77	0	22.25	0	22.09	78
25	22.15	0	78	0	22.4	0	0	79
30	22.25	0	78	24.23	23.7	1	0	79
35	22.3	0	78	0	22	0	0	79
40	22.97	0.5	78	0	21.9	0	0	79
45	22.79	0	78	0	21.43	0	0	80
50	22.63	0	78	0	22.72	0	0	79
55	23.31	0.5	79	0	23.47	1	35.07	80
60	22.81	0	79	0	21.58	0	0	80
65	22.72	0	79	0	21.88	0	0	80
70	22.63	0	79	0	22.34	0	0	80
75	22.8	0	79	0	22.67	0	0	80
80	23.78	0.5	79	0	23.43	1	0	80
85	22.72	0	79	28.32	21.94	0	0	80
90	22.66	0	79	0	21.65	0	0	80
95	23.22	0.5	79	0	22.95	1	0	80
100	22.84	0	80		22.18	0	35.84	80
105	23.37	0.5	79	0	22.24	0	0	80
110	22.25	0	79	0	22.71	0	0	80
115	23.1	0.5	79	0	22.9	1	0	80
120	23.15	0	79	0	23.01	0	0	80
125	23.22	0.5	79	0	23.06	1	0	80
130	22.84	0	79	0	21.47	0	0	80

135	22.69	0	79	0	21.87	0	0	80
140	23.72	0.5	79	31.45	22.9	1	0	80
145	23.09	0.5	79	0	22	0	0	80
150	22.23	0	79	0	21.84	0	37.1	80
155	22.37	0	80	0	22.44	0	0	81
160	21.5	0	80	24.68	22.66	0	0	81
165	22.84	0.25	79	0	23.1	1	36.98	81
170	23.06	0.5	80	0	23.41	1	0	81
175	21.19	0	80	27.28	22.03	0	0	82
180	23.07	0.5	80	0	23.91	1	0	81
ge & total	**22.68**	**6.25**	**78.78**		**22.45**	**6**		**79.75**
stand dev	**0.56**				**0.66**			

lvent consumption of magenta (Lts/hr):	2.08
Solvent consumption of cyan (Lts/hr):	2.00
1 Liter of solvent blend = 0.846 Kg	
lvent consumption of magenta (lbs/hr):	3.88
Solvent consumption of cyan (lbs/hr):	3.72

Hot Trial Data

140	22.06	0	93	29.24	21.34	0	0	92
145	21.13	0	92	0	23.41	1	0	91
150	22.59	0.5	93	0	21.6	0	34.93	92
155	22	0.5	93	28	23.07	1	0	90
160	22.63	0.5	92	0	21.29	0	37.04	89
165	22.5	0.5	92	0	21.28	0	0	92
170	22.31	0.5	94	27.29	22	0	0	89
175	22.25	0.5	92	0	23.16	1	0	89
180	21.97	0	92	0	21.97	0	36.34	92
Average	**22.55**	**17.50**	**92.22**		**22.20**	**11**		**90.83**
stand dev	**0.84**				**0.63**			

lvent consumption of magenta (Lts/hr):	5.83
Solvent consumption of cyan (Lts/hr):	3.50
1 Liter of solvent blend = 0.846 Kg	
lvent consumption of magenta (lbs/hr):	10.86
Solvent consumption of cyan (lbs/hr):	6.51

HEATING
Date: 12/01/98
Run #1 R 80F
R.H: 35%
Measurer Value
Type of c Fruit & wine
Color Red & Blue
Time of t 3hrs

Initial magenta ink volume: 40L of ink +6L if ext + 6.5L of solvent
Initial cyan ink volume: 40L of ink +6L if ext + 3L of solvent
final magenta ink volume: 47L
final cyan ink volume: 38L
Amount of magenta ink consumed (lts): 6
Amount of cyan ink consumed (lts): 9

Press speed
Type of substrate Polyethylene
Final volume of ink
ESA off
Target viscosity: 22 seconds

Measured time	Magenta	Magenta	Magenta	Mage solids	Cyan	Cyan	Cyan solids	Cyan
Time (5 minutes)	Visco (sec)	Solv (liters)	Ink tem (F)	%	Visco (sec)	Solv (liters)	%	ink temp (F)
5	24.09	0.5	92	0	22	1	0	92
10	24.56	0.5	90	0	21.7	0	0	91
15	22	0.5	90	0	21.4	0	0	89
20	24.47	0.5	90	0	22	0	0	88
25	24.56	1.5	89	0	21.85	0	0	90
30	22.74	0	89	0	22.1	0	0	93
35	23.58	0.5	92	30.12	22.13	0	26.96	92
40	22.81	0.5	92	0	21.91	0	0	91
45	23.15	0.5	92	0	22.97	1	0	91
50	22.81	0.5	95	0	22.91	1	0	91
55	22.66	0.5	92	0	22.5	1	0	90
60	22.34	0.5	92	0	21.72	0	8	92
65	22.38	0.5	94	0	22.76	0	0	91
70	22.68	0.5	92	0	22.41	1	27.39	90
75	22.41	0.5	95	0	22.5	1	0	92
80	23.23	1	93	0	22.63	1	0	90
85	22.18	0.5	93	25.07	21.72	0	0	92
90	21.72	0.5	92	0	21.68	0	0	91
95	21.53	0.5	92	0	22.8	1	31.01	90
100	21.75	0.5	92	32.66	22.46	1	0	89
105	22.83	0.5	92	0	21.81	0	0	90
110	21.84	0.5	92	0	23.18	1	37.86	89
115	21.74	0.5	91	33.08	23.19	1	0	91
120	22.34	0.5	91	0	21.25	0	36.32	88
125	22.16	0.5	93	0	22.87	1	0	91
130	22	0.5	95	41.47	21.52	0	0	96
135	21.81	0.5	95	0	22.22	1	31.82	94

HEATING
Date: 12/01/98
Run #1 R 80F
R.H: 35%
Measurer Value
Type of c Fruit & wine
Color Red & Blue
Time of t 3hrs

Initial magenta ink volume: 40L of ink +6L if ext + 6.5L of solvent
Initial cyan ink volume: 40L of ink +6L if ext + 3L of solvent
final magenta ink volume: 47L
final cyan ink volume: 38L
Amount of magenta ink consumed (lts): 6
Amount of cyan ink consumed (lts): 9

Press speed
Type of substrate Polyethylene
Final volume of ink
ESA off
Target viscosity: 22 seconds

Measured time	Magenta	Magenta	Magenta	Mage solids	Cyan	Cyan	Cyan solids	Cyan
Time (5 minutes)	Visco (sec)	Solv (liters)	Ink tem (F)	%	Visco (sec)	Solv (liters)	%	ink temp (F)
5	24.09	0.5	92	0	22	1	0	92
10	24.56	0.5	90	0	21.7	0	0	91
15	22	0.5	90	0	21.4	0	0	89
20	24.47	0.5	90	0	22	0	0	88
25	24.56	1.5	89	0	21.85	0	0	90
30	22.74	0	89	0	22.1	0	0	93
35	23.58	0.5	92	30.12	22.13	0	26.96	92
40	22.81	0.5	92	0	21.91	0	0	91
45	23.15	0.5	92	0	22.97	1	0	91
50	22.81	0.5	95	0	22.91	1	0	91
55	22.66	0.5	92	0	22.5	1	0	90
60	22.34	0.5	92	0	21.72	0	8	92
65	22.38	0.5	94	0	22.76	0	0	91
70	22.68	0.5	92	0	22.41	1	27.39	90
75	22.41	0.5	95	0	22.5	1	0	92
80	23.23	1	93	0	22.63	1	0	90
85	22.18	0.5	93	25.07	21.72	0	0	92
90	21.72	0.5	92	0	21.68	0	0	91
95	21.53	0.5	92	0	22.8	1	31.01	90
100	21.75	0.5	92	32.66	22.46	1	0	89
105	22.83	0.5	92	0	21.81	0	0	90
110	21.84	0.5	92	0	23.18	1	37.86	89
115	21.74	0.5	91	33.08	23.19	1	0	91
120	22.34	0.5	91	0	21.25	0	36.32	88
125	22.16	0.5	93	0	22.87	1	0	91
130	22	0.5	95	41.47	21.52	0	0	96
135	21.81	0.5	95	0	22.22	1	31.82	94

140	22.06	0	93	29.24	21.34	0	0	92
145	21.13	0	92	0	23.41	1	0	91
150	22.59	0.5	93	0	21.6	0	34.93	92
155	22	0.5	93	28	23.07	1	0	90
160	22.63	0.5	92	0	21.29	0	37.04	89
165	22.5	0.5	92	0	21.28	0	0	92
170	22.31	0.5	94	27.29	22	0	0	89
175	22.25	0.5	92	0	23.16	1	0	89
180	21.97	0	92	0	21.97	0	36.34	92
Average	**22.55**	**17.50**	**92.22**		**22.20**	**11**		**90.83**
stand dev	**0.84**				**0.63**			

lvent consumption of magenta (Lts/hr):	5.83
Solvent consumption of cyan (Lts/hr):	3.50
1 Liter of solvent blend = 0.846 Kg	
lvent consumption of magenta (lbs/hr):	10.86
Solvent consumption of cyan (lbs/hr):	6.51

Cold Reflection Density

Printability of cold ink **Printability of cold ink**

20 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	20 minutes	% tone	tone step cyan [%]	tone step magenta [%]
1	1	20	2.14	1.65	79.90	**1**	100.00	2.06	1.71
	2	20	2.02	1.65	76.30		95.00	1.89	1.53
	3	20	1.95	1.63	72.90		76.00	1.04	0.96
	4	20	1.95	1.66	79.40		63.00	0.69	0.64
	5	20	1.90	1.65	69.00		46.00	0.53	0.42
2	1	20	1.95	1.64	64.20	**2**	37.00	0.46	0.36
	2	20	2.08	1.65	69.30		28.00	0.34	0.29
	3	20	2.02	1.63	71.50		20.00	0.29	0.23
	4	20	2.08	1.65	68.20		12.00	0.21	0.18
	5	20	1.98	1.62	66.50		7.00	0.12	0.11
3	1	20	2.05	1.61	70.40	**3**			
	2	20	1.92	1.65	71.00				
	3	20	1.92	1.65	71.40				
	4	20	2.00	1.66	72.10				
	5	20	1.96	1.60	75.40				
4	1	20	2.16	1.60	67.80	**4**			
	2	20	1.98	1.64	68.40				
	3	20	2.07	1.66	64.90				
	4	20	2.00	1.63	67.70				
	5	20	1.97	1.64	65.10				
5	1	20	2.12	1.60	62.70	**5**		**Mage solids**	**Cyan solids**
	2	20	2.00	1.63	75.00			%	%
	3	20	2.10	1.66	68.50			25.41	29.51
	4	20	1.99	1.65	65.10			17.99	32.92
	5	20	1.87	1.67	70.50			24.56	31.23
average @20 minutes			**2.01**	**1.64**	**70.13**	**average @20 minutes**		25.93	35.27
Stan. Devi @20 minutes			**0.08**	**0.02**	**4.52**	**Stan. Devi @20 minutes**		**23.47**	**32.23**

40 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	40 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1	1	40	2.12	1.66	62.80	**1**	100.00	2.13	1.70
	2	40	2.17	1.64	75.10		95.00	2.01	1.49

	3	40	1.97	1.65	67.50		76.00	1.08	0.92
	4	40	2.02	1.66	79.90		63.00	0.80	0.67
	5	40	2.07	1.68	79.00		46.00	0.50	0.45
2	1	40	2.18	1.67	67.70	**2**	37.00	0.44	0.35
	2	40	1.97	1.63	74.20		28.00	0.38	0.26
	3	40	2.07	1.66	78.30		20.00	0.27	0.22
	4	40	2.05	1.66	76.30		12.00	0.18	0.18
	5	40	1.98	1.69	76.90		7.00	0.11	0.11
3	1	40	2.15	1.66	73.00	**3**			
	2	40	2.14	1.63	75.40				
	3	40	2.02	1.65	79.60				
	4	40	2.02	1.65	74.90				
	5	40	2.08	1.68	71.20				
4	1	40	1.93	1.67	67.20	**4**			
	2	40	2.05	1.63	76.20				
	3	40	2.02	1.64	77.40				
	4	40	1.97	1.64	94.00				
	5	40	1.95	1.66	94.20				
5	1	40	2.01	1.69	67.50	**5**			
	2	40	2.15	1.66	75.40				
	3	40	1.97	1.66	79.70				
	4	40	1.93	1.63	70.20				
	5	40	2.03	1.66	65.00				
average @40 minutes			**2.04**	**1.66**	**75.14**	**average @40 minutes**			
Stan devi @40 minutes			**0.08**	**0.02**	**7.51**	**Stan devi @40 minutes**			

60 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**60 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1	1	60	1.94	1.68	80.70	**1**	100.00	2.14	1.74
	2	60	2.15	1.65	82.50		95.00	2.08	1.51
	3	60	2.13	1.67	81.20		76.00	1.06	0.88
	4	60	2.00	1.67	74.70		63.00	0.73	0.60
	5	60	2.01	1.68	78.20		46.00	0.51	0.40
2	1	60	2.15	1.63	82.30	**2**	37.00	0.44	0.36
	2	60	2.16	1.67	84.30		28.00	0.33	0.27
	3	60	2.01	1.68	82.40		20.00	0.26	0.22
	4	60	1.96	1.61	68.50		12.00	0.18	0.17
	5	60	1.99	1.68	71.90		7.00	0.12	0.12
3	1	60	2.02	1.60	70.90	**3**			
	2	60	2.10	1.67	81.90				
	3	60	2.06	1.67	83.60				

60 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	60 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1	1	60	1.94	1.68	80.70	**1**	100.00	2.14	1.74
	2	60	2.15	1.65	82.50		95.00	2.08	1.51
	3	60	2.13	1.67	81.20		76.00	1.06	0.88
	4	60	2.00	1.67	74.70		63.00	0.73	0.60
	5	60	2.01	1.68	78.20		46.00	0.51	0.40
2	1	60	2.15	1.63	82.30	**2**	37.00	0.44	0.36
	2	60	2.16	1.67	84.30		28.00	0.33	0.27
	3	60	2.01	1.68	82.40		20.00	0.26	0.22
	4	60	1.96	1.61	68.50		12.00	0.18	0.17
	5	60	1.99	1.68	71.90		7.00	0.12	0.12
3	1	60	2.02	1.60	70.90	**3**			
	2	60	2.10	1.67	81.90				
	3	60	2.06	1.67	83.60				
	4	60	2.19	1.66	77.20				
	5	60	1.97	1.67	86.40				
4	1	60	2.18	1.68	81.50	**4**			
	2	60	2.14	1.64	84.40				
	3	60	1.95	1.66	78.70				
	4	60	1.95	1.67	84.40				
	5	60	2.10	1.61	82.70				
5	1	60	2.05	1.64	67.40	**5**			
	2	60	2.06	1.62	84.50				
	3	60	2.11	1.67	77.70				
	4	60	2.02	1.69	77.20				
	5	60	2.11	1.66	72.30				
average @60 minutes			**2.06**	**1.66**	**79.10**	**average @60 minutes**			
Stan devi @60 minutes			**0.08**	**0.03**	**5.39**	**Stan devi @60 minutes**			

	4	60	2.19	1.66	77.20				
	5	60	1.97	1.67	86.40				
4	1	60	2.18	1.68	81.50	**4**			
	2	60	2.14	1.64	84.40				
	3	60	1.95	1.66	78.70				
	4	60	1.95	1.67	84.40				
	5	60	2.10	1.61	82.70				
5	1	60	2.05	1.64	67.40	**5**			
	2	60	2.06	1.62	84.50				
	3	60	2.11	1.67	77.70				
	4	60	2.02	1.69	77.20				
	5	60	2.11	1.66	72.30				
average @60 minutes			**2.06**	**1.66**	**79.10**	**average @60 minutes**			
Stan devi @60 minutes			**0.08**	**0.03**	**5.39**	**Stan devi @60 minutes**			

80 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**80 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1	1	80	2.10	1.66	75.90	**1**	100.00	2.05	1.70
	2	80	1.99	1.69	70.10		95.00	1.89	1.43
	3	80	1.98	1.67	80.80		76.00	0.99	0.84
	4	80	1.81	1.65	78.20		63.00	0.70	0.59
	5	80	1.87	1.60	86.40		46.00	0.52	0.44
2	1	80	1.95	1.65	74.80	**2**	37.00	0.40	0.34
	2	80	2.04	1.67	79.20		28.00	0.38	0.30
	3	80	2.14	1.60	76.50		20.00	0.30	0.24
	4	80	1.92	1.68	76.20		12.00	0.19	0.20
	5	80	2.00	1.68	83.40		7.00	0.13	0.15
3	1	80	2.01	1.60	64.10	**3**			
	2	80	2.15	1.65	74.30				
	3	80	2.04	1.60	73.00				
	4	80	1.90	1.69	67.30				
	5	80	1.98	1.68	81.50				
4	1	80	2.09	1.63	76.70	**4**			
	2	80	2.00	1.65	72.80				
	3	80	1.91	1.60	77.40				
	4	80	1.96	1.60	64.20				
	5	80	2.00	1.69	75.50				
5	1	80	2.07	1.68	65.50	**5**			
	2	80	2.03	1.62	73.90				
	3	80	1.95	1.66	67.80				
	4	80	1.92	1.69	73.30				

	5	80	2.13	1.69	72.60				
average @80 minutes			**2.00**	**1.65**	**74.46**	**average @80 minutes**			
Stand Devi @80 minutes			**0.09**	**0.03**	**5.74**	**Stand Devi @80 minutes**			

100 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**100 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1	1	100	1.98	1.63	74.90	**1**	100.00	2.03	1.69
	2	100	2.11	1.64	82.30		95.00	1.99	1.46
	3	100	2.10	1.67	72.80		76.00	1.20	0.86
	4	100	2.03	1.68	80.00		63.00	0.78	0.61
	5	100	2.06	1.67	76.90		46.00	0.49	0.39
2	1	100	2.05	1.59	65.20	**2**	37.00	0.41	0.32
	2	100	2.14	1.60	69.80		28.00	0.34	0.25
	3	100	1.84	1.66	69.60		20.00	0.26	0.21
	4	100	1.91	1.67	69.00		12.00	0.18	0.16
	5	100	1.92	1.66	67.80		7.00	0.10	0.13
3	1	100	2.11	1.60	68.90	**3**			
	2	100	2.10	1.61	67.60				
	3	100	1.99	1.67	67.70				
	4	100	2.05	1.67	68.20				
	5	100	1.99	1.64	69.40				
4	1	100	2.13	1.65	69.90	**4**			
	2	100	2.16	1.66	68.00				
	3	100	2.10	1.68	70.30				
	4	100	1.99	1.62	69.90				
	5	100	2.10	1.67	72.80				
5	1	100	2.13	1.61	65.20	**5**			
	2	100	2.02	1.60	69.60				
	3	100	2.01	1.66	74.30				
	4	100	1.96	1.66	70.30				
	5	100	2.09	1.66	69.90				
average @100 minutes			**2.04**	**1.65**	**70.81**	**average @100 minutes**			
Stand Devi @100 minutes			**0.08**	**0.03**	**4.15**	**Stand Devi @100 minutes**			

120 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	120 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1	1	120	2.15	1.67	99.00	**1**	100.00	1.88	1.66
	2	120	2.17	1.65	89.70		95.00	1.82	1.45
	3	120	1.98	1.67	103.00		76.00	0.95	0.84
	4	120	1.94	1.68	93.10		63.00	0.78	0.64
	5	120	1.96	1.67	89.20		46.00	0.49	0.38
2	1	120	2.17	1.60	86.60	**2**	37.00	0.40	0.33
	2	120	1.91	1.67	102.40		28.00	0.34	0.26
	3	120	2.05	1.69	67.30		20.00	0.29	0.23
	4	120	1.97	1.63	81.50		12.00	0.19	0.18
	5	120	2.15	1.68	97.30		7.00	0.10	0.12
3	1	120	2.15	1.69	78.80	**3**			
	2	120	2.02	1.66	71.90				
	3	120	2.04	1.67	83.60				
	4	120	1.99	1.68	86.90				
	5	120	2.09	1.67	78.50				
4	1	120	2.09	1.66	76.20	**4**			
	2	120	1.94	1.60	79.80				
	3	120	2.15	1.65	81.30				
	4	120	2.05	1.66	69.90				
	5	120	1.90	1.67	77.70				
5	1	120	1.96	1.65	72.30	**5**			
	2	120	2.05	1.64	72.10				
	3	120	2.08	1.68	71.30				
	4	120	2.11	1.65	72.00				
	5	120	1.96	1.67	67.80				
average @120 minutes			**2.04**	**1.66**	**81.97**	**average @120 minutes**			
Stand devi @120 minutes			**0.09**	**0.02**	**10.83**	**Stand devi @120 minutes**			

140 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	140 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1	1	140	2.18	1.65	64.30	**1**	100.00	2.16	1.75
	2	140	2.06	1.69	75.10		95.00	2.09	1.51
	3	140	2.01	1.69	72.00		76.00	1.20	0.90
	4	140	2.04	1.61	64.80		63.00	0.84	0.62
	5	140	2.00	1.69	73.40		46.00	0.55	0.43
2	1	140	2.13	1.66	73.90	**2**	37.00	0.46	0.35

	2	140	2.22	1.67	68.10		28.00	0.37	0.30
	3	140	2.15	1.61	74.60		20.00	0.28	0.24
	4	140	2.03	1.67	69.30		12.00	0.20	0.19
	5	140	2.14	1.60	73.80		7.00	0.12	0.12
3	1	140	2.21	1.61	67.30	**3**			
	2	140	2.20	1.67	66.00				
	3	140	2.13	1.69	73.10				
	4	140	2.13	1.61	73.40				
	5	140	2.15	1.61	74.00				
4	1	140	2.16	1.67	70.40	**4**			
	2	140	2.15	1.61	69.60				
	3	140	2.10	1.60	72.90				
	4	140	2.00	1.68	74.80				
	5	140	2.12	1.69	74.90				
5	1	140	2.09	1.66	66.10	**5**			
	2	140	2.17	1.60	72.50				
	3	140	2.15	1.60	74.20				
	4	140	2.07	1.68	67.90				
	5	140	2.15	1.69	70.30				
average @140 minutes			**2.12**	**1.65**	**71.07**	**average @140 minutes**			
Stand devi @140 minutes			**0.06**	**0.04**	**3.46**	**Stand devi @140 minutes**			

160 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**160 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1	1	160	2.14	1.64	63.00	**1**	100.00	2.13	1.77
	2	160	2.12	1.67	69.90		95.00	2.07	1.55
	3	160	2.10	1.60	72.50		76.00	1.07	0.93
	4	160	2.01	1.66	73.20		63.00	0.79	0.62
	5	160	2.09	1.68	67.20		46.00	0.54	0.44
2	1	160	2.12	1.61	68.20	**2**	37.00	0.50	0.39
	2	160	2.14	1.63	71.70		28.00	0.38	0.29
	3	160	2.14	1.66	70.90		20.00	0.28	0.23
	4	160	2.08	1.69	73.40		12.00	0.20	0.18
	5	160	2.09	1.60	66.10		7.00	0.13	0.13
3	1	160	2.17	1.62	66.10	**3**			
	2	160	2.04	1.67	68.50				
	3	160	2.10	1.60	62.40				
	4	160	1.97	1.60	68.90				
	5	160	2.09	1.63	60.90				
4	1	160	1.99	1.60	63.50	**4**			
	2	160	2.12	1.65	61.30				

	3	160	2.05	1.69	74.50				
	4	160	2.08	1.61	72.60				
	5	160	2.07	1.68	71.60				
5	1	160	2.12	1.64	69.40	**5**			
	2	160	2.21	1.68	72.90				
	3	160	2.12	1.60	69.70				
	4	160	2.08	1.65	71.20				
	5	160	2.09	1.61	67.60				
average @160 minutes			**2.09**	**1.64**	**68.69**	**average @160 minutes**			
Stand devi @160 minutes			**0.05**	**0.03**	**4.01**	**Stand devi @160 minutes**			

180 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**180 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1	1	180	2.15	1.68	66.40	**1**	100.00	2.13	1.74
	2	180	2.08	1.61	72.40		95.00	2.05	1.55
	3	180	2.05	1.69	66.80		76.00	1.03	0.92
	4	180	2.02	1.60	67.80		63.00	0.78	0.61
	5	180	2.01	1.63	67.90		46.00	0.52	0.42
2	1	180	2.16	1.65	61.50	**2**	37.00	0.43	0.35
	2	180	2.04	1.68	68.30		28.00	0.36	0.28
	3	180	2.08	1.69	71.20		20.00	0.30	0.23
	4	180	2.10	1.61	68.70		12.00	0.21	0.18
	5	180	2.09	1.63	69.20		7.00	0.13	0.12
3	1	180	2.10	1.64	61.30	**3**			
	2	180	2.20	1.69	68.70				
	3	180	2.08	1.61	71.20				
	4	180	2.04	1.62	70.30				
	5	180	2.10	1.69	70.00				
4	1	180	2.11	1.68	63.90	**4**			
	2	180	2.10	1.69	62.10				
	3	180	2.02	1.61	79.20				
	4	180	2.03	1.60	79.90				
	5	180	2.08	1.68	73.30				
5	1	180	2.12	1.63	68.20	**5**			
	2	180	2.09	1.60	76.60				
	3	180	2.01	1.60	70.10				
	4	180	2.08	1.64	82.20				
	5	180	2.05	1.67	80.60				

average @180 minutes			**2.08**	**1.64**	**70.31**	**average @180 minutes**			
Stand Devi @180 minutes			**0.05**	**0.04**	**5.75**	**Stand Devi @180 minutes**			

Total average cold			**2.05**	**1.65**	**73.52**	**Total average cold**

Normal Reflection Density

20 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	20 minutes			
1	1	20	2.05	1.58	33.6	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	20	2.05	1.58	37.5		100	2.06	1.77
	3	20	1.93	1.61	54.6		95	2.05	1.62
	4	20	1.87	1.57	52.6		76	1.2	0.92
	5	20	2.03	1.52	27.5		63	0.8	0.6
2	1	20	2.03	1.7	38	**2**	46	0.61	0.41
	2	20	1.99	1.6	37.4		37	0.44	0.34
	3	20	1.94	1.57	60.9		28	0.35	0.29
	4	20	2.01	1.55	62.6		20	0.28	0.25
	5	20	1.91	1.6	47.8		12	0.17	0.19
3	1	20	2.05	1.82	50	**3**	7	0.11	0.12
	2	20	1.86	1.62	58.9				
	3	20	2.01	1.69	36.8				
	4	20	2.01	1.7	55.7				
	5	20	1.82	1.49	38.9				
4	1	20	1.89	1.61	53.2	**4**			
	2	20	1.81	1.89	46.2				
	3	20	2.09	1.66	70				
	4	20	2.11	1.69	48.7				
	5	20	1.89	1.6	51.2				
5	1	20	2	1.59	45.2	**5**			
	2	20	1.78	1.63	59.5				
	3	20	2.04	1.65	44.6				
	4	20	1.74	1.69	33.8				
	5	20	1.91	1.69	28.7				
average @20 minutes			**1.95**	**1.64**	**46.96**	**average @20 minutes**			
Stan. Devi @20 minutes			**0.10**	**0.09**	**11.20**	**Stan. Devi @20 minutes**			

40 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	40 minutes of trial time			
1	1	40	1.86	1.47	65	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	40	1.84	1.54	57.8		100	2.1	1.78
	3	40	1.98	1.59	66.3		95	2.07	1.6

	4	40	1.69	1.62	57.9		76	1.19	0.92
	5	40	1.88	1.73	67.9		63	0.86	0.67
2	1	40	1.97	1.5	49.2	**2**	46	0.54	0.46
	2	40	1.84	1.59	70.3		37	0.44	0.35
	3	40	1.94	1.6	77.1		28	0.41	0.28
	4	40	1.84	1.69	77.9		20	0.29	0.23
	5	40	2	1.59	52		12	0.21	0.19
3	1	40	1.98	1.6	49.1	**3**	7	0.16	0.12
	2	40	1.9	1.67	76.5				
	3	40	1.73	1.64	50.7				
	4	40	1.83	1.79	77.9				
	5	40	1.99	1.62	52.7				
4	1	40	2.03	1.71	43.4	**4**			
	2	40	2.01	1.6	78.6				
	3	40	2	1.68	59.5				
	4	40	2	1.65	67.3				
	5	40	1.68	1.54	79.2				
5	1	40	2.11	1.65	54.3	**5**			
	2	40	2.05	1.63	78.9				
	3	40	1.86	1.89	53.4				
	4	40	2.12	1.58	63.8				
	5	40	1.9	1.54	52.8				
average @40 minutes			**1.92**	**1.63**	**63.18**	**average @40 minutes**			
Stan devi @40 minutes			**0.12**	**0.09**	**11.51**	**Stan devi @40 minutes**			

60 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**60 minutes of trial time**			
1	1	60	1.97	1.66	71.2	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	60	2.02	1.69	79		100	2.04	1.73
	3	60	1.77	1.58	67.9		95	2.01	1.59
	4	60	1.99	1.6	79.1		76	1.07	0.89
	5	60	1.96	1.89	71.3		63	0.76	0.67
2	1	60	1.91	1.7	60.3	**2**	46	0.57	0.45
	2	60	2.06	1.59	53.7		37	0.51	0.4
	3	60	1.86	1.68	48.2		28	0.37	0.29
	4	60	1.62	1.59	54		20	0.28	0.24
	5	60	1.8	1.63	63.7		12	0.21	0.19
3	1	60	2.07	1.64	44.5	**3**	7	0.16	0.12
	2	60	2.04	1.62	56.5				
	3	60	2.02	1.75	53.9				

	4	60	2.01	1.58	47.3				
	5	60	1.96	1.6	57.3				
4	1	60	2.12	1.61	22.2	**4**			
	2	60	2.12	1.58	64.3				
	3	60	2.05	1.56	54.5				
	4	60	2.1	1.62	55.6				
	5	60	1.81	1.67	72.8				
5	1	60	2.06	1.7	57.8	**5**			
	2	60	1.98	1.57	71.1				
	3	60	2.02	1.6	81.9				
	4	60	2.05	1.8	80.9				
	5	60	1.69	1.6	84.8				
average @60 minutes			**1.96**	**1.64**	**62.15**	**average @60 minutes**			
Stan devi @60 minutes			**0.13**	**0.08**	**14.34**	**Stan devi @60 minutes**			

80 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**80 minutes of trial time**			
1	1	80	2.02	1.66	48.9	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	80	2.02	1.54	63.5		100	2.12	1.77
	3	80	1.78	1.67	68.5		95	2.1	1.63
	4	80	1.97	1.79	59.3		76	1.25	0.93
	5	80	1.87	1.55	56.9		63	0.94	0.62
2	1	80	2.1	1.89	62.2	**2**	46	0.58	0.41
	2	80	1.98	1.6	82.9		37	0.47	0.35
	3	80	1.91	1.58	60.8		28	0.39	0.28
	4	80	1.88	1.68	74.9		20	0.32	0.24
	5	80	1.84	1.64	72.3		12	0.24	0.19
3	1	80	1.97	1.61	70.5	**3**	7	0.18	0.12
	2	80	1.72	1.61	61.8				
	3	80	1.82	1.66	50.5				
	4	80	2.09	1.61	68.4				
	5	80	1.94	1.62	68.2				
4	1	80	2.05	1.71	72.5	**4**			
	2	80	1.94	1.6	78.8				
	3	80	1.93	1.69	56.8				
	4	80	1.99	1.55	62.6				
	5	80	2.04	1.58	77.7				
5	1	80	2.13	1.6	61.6	**5**			
	2	80	1.98	1.61	70.5				
	3	80	1.95	1.69	54.9				

	4	80	2.03	1.57	65.4				
	5	80	2.06	1.58	56.6				
average @80 minutes			**1.96**	**1.64**	**65.08**	**average @80 minutes**			
Stand Devi @80 minutes			**0.10**	**0.08**	**8.75**	**Stand Devi @80 minutes**			

100 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**100 minutes of trial time**			
1	1	100	2.09	1.63	52.1	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	100	2.16	1.61	50.5		100	2.02	1.75
	3	100	2.1	1.67	68.4		95	2.02	1.55
	4	100	2.17	1.76	68.2		76	1.15	0.89
	5	100	2.2	1.58	72.5		63	0.77	0.62
2	1	100	1.82	1.61	66.5	**2**	46	0.52	0.43
	2	100	2	1.62	56.1		37	0.43	0.35
	3	100	1.91	1.67	65.4		28	0.36	0.31
	4	100	2	1.67	56.6		20	0.29	0.24
	5	100	1.91	1.66	52.1		12	0.24	0.18
3	1	100	2.02	1.66	63.5	**3**	7	0.15	0.1
	2	100	2.14	1.54	68.5				
	3	100	1.98	1.67	59.3				
	4	100	2.1	1.79	56.9				
	5	100	1.78	1.65	62.2				
4	1	100	1.88	1.54	69.2	**4**			
	2	100	2.11	1.65	54.3				
	3	100	2.05	1.53	78.9				
	4	100	1.96	1.67	63.4				
	5	100	2.12	1.54	63.8				
5	1	100	1.81	1.7	60.3	**5**			
	2	100	1.966	1.59	43.7				
	3	100	1.86	1.68	58.2				
	4	100	1.62	1.69	54				
	5	100	1.8	1.53	63.6				
average @100 minutes			**1.98**	**1.64**	**61.13**	**average @100 minutes**			
Stand Devi @100 minutes			**0.15**	**0.07**	**7.89**	**Stand Devi @100 minutes**			

120 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	120 minutes of trial time			
1	1	120	2.08	1.69	58.2	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	120	1.89	1.59	51.5		100	2.09	1.73
	3	120	1.93	1.65	55.4		95	2.04	1.57
	4	120	1.94	1.57	55.1		76	1.04	1.01
	5	120	1.8	1.63	45		63	0.87	0.69
2	1	120	1.76	1.69	61.2	**2**	46	0.53	0.47
	2	120	2.03	1.61	71.9		37	0.44	0.35
	3	120	2.04	1.6	48.6		28	0.36	0.28
	4	120	1.95	1.8	45.3		20	0.29	0.24
	5	120	1.84	1.55	59.1		12	0.22	0.19
3	‘	120	2.11	1.74	52.7	**3**	7	0.12	0.12
	2	120	1.92	1.61	54.7				
	3	120	1.93	1.66	48.3				
	4	120	2.08	1.58	59				
	5	120	1.97	1.6	43.7				
4	1	120	2.03	1.67	43.2	**4**			
	2	120	2.06	1.52	67.3				
	3	120	1.74	1.63	53.9				
	4	120	1.84	1.82	61.5				
	5	120	1.89	1.59	54.2				
5	1	120	2.09	1.68	58.1	**5**			
	2	120	2.07	1.74	72.8				
	3	120	1.74	1.55	69.9				
	4	120	1.85	1.57	58.1				
	5	120	2.1	1.66	56.8				
average @120 minutes			**1.95**	**1.64**	**56.22**	**average @120 minutes**			
Stand devi @120 minutes			**0.12**	**0.08**	**8.29**	**Stand devi @120 minutes**			

140 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	140 minutes of trial time			
1	1	140	2.06	1.69	62.8	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	140	2.04	1.6	60.9		100	2.15	1.7
	3	140	1.74	1.64	59.7		95	2.1	1.62

	4	140	2.1	1.79	53.5		76	1.19	1.02
	5	140	1.92	1.86	67.1		63	0.89	0.69
2	1	140	2.14	1.73	66.9	**2**	46	0.62	0.43
	2	140	2.01	1.61	74.1		37	0.52	0.4
	3	140	1.96	1.61	45		28	0.36	0.32
	4	140	2.11	1.56	56.2		20	0.32	0.25
	5	140	2.06	1.83	45.3		12	0.23	0.19
3	1	140	2.02	1.57	63.8	**3**	7	0.15	0.12
	2	140	1.95	1.55	52.8				
	3	140	1.93	1.65	71.2				
	4	140	2.02	1.7	79				
	5	140	1.87	1.57	60.3				
4	1	140	1.99	1.61	67.9	**4**			
	2	140	1.98	1.81	53.7				
	3	140	1.92	1.71	48.2				
	4	140	2.05	1.78	71.3				
	5	140	1.85	1.69	79.1				
5	1	140	2.07	1.74	48.1	**5**			
	2	140	1.9	1.61	75.7				
	3	140	1.93	1.73	53.5				
	4	140	1.88	1.64	73				
	5	140	2.11	1.79	60.3				
average @140 minutes			**1.98**	**1.68**	**61.98**	**average @140 minutes**			
Stand devi @140 minutes			**0.10**	**0.09**	**10.39**	**Stand devi @140 minutes**			

160 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**160 minutes of trial time**			
1	1	160	2.1	1.63	63.6	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	160	2.02	1.62	72		100	2.16	1.8
	3	160	1.96	1.65	45		95	2.13	1.63
	4	160	2.02	1.67	67.1		76	1.12	0.97
	5	160	1.87	1.66	71.7		63	0.81	0.64
2	1	160	2.03	1.76	58.3	**2**	46	0.61	0.43
	2	160	2.09	1.61	56.4		37	0.54	0.36
	3	160	1.97	1.62	64.3		28	0.36	0.29
	4	160	1.69	1.72	58.8		20	0.28	0.26
	5	160	1.73	1.67	54.4		12	0.22	0.2
3	1	160	2.15	1.65	59	**3**	7	0.15	0.13
	2	160	1.86	1.79	47.8				

	3	160	1.88	1.63	52.8				
	4	160	2.08	1.67	61.7				
	5	160	1.95	1.64	55.2				
4	1	160	2.1	1.68	55.7	**4**			
	2	160	1.93	1.61	64.2				
	3	160	2	1.62	62.3				
	4	160	1.94	1.68	68.3				
	5	160	1.87	1.62	60.6				
5	1	160	2.02	1.7	48.2	**5**			
	2	160	2.1	1.64	60.6				
	3	160	1.91	1.62	55.2				
	4	160	1.97	1.64	53				
	5	160	1.95	1.65	47				
average @160 minutes			**1.97**	**1.66**	**58.53**	**average @160 minutes**			
Stand devi @160 minutes			**0.11**	**0.05**	**7.36**	**Stand devi @160 minutes**			

180 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**180 minutes of trial time**			
1	1	180	2.01	1.69	45.2	**1**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
	2	180	1.78	1.64	59.5		100	2.16	1.8
	3	180	2.03	1.66	44.6		95	2.13	1.63
	4	180	1.75	1.7	33.8		76	1.12	0.97
	5	180	1.9	1.71	28.7		63	0.81	0.64
2	1	180	1.87	1.57	65	**2**	46	0.61	0.43
	2	180	1.83	1.64	57.8		37	0.54	0.36
	3	180	1.97	1.79	66.3		28	0.36	0.29
	4	180	1.7	1.62	57.9		20	0.28	0.26
	5	180	1.87	1.73	67.9		12	0.22	0.2
3	1	180	1.96	1.65	49.2	**3**	7	0.15	0.13
	2	180	1.85	1.69	70.3				
	3	180	1.95	1.75	77.1				
	4	180	1.85	1.69	77.9				
	5	180	2.01	1.85	52				
4	1	180	1.96	1.69	49.1	**4**			
	2	180	1.92	1.77	76.5				
	3	180	2.76	1.73	50.7				
	4	180	2.05	1.79	77.9				
	5	180	1.99	1.62	52.7				
5	1	180	2.02	1.71	43.4	**5**			

	2	180	1.87	1.73	77.9				
	3	180	1.96	1.65	52				
	4	180	1.85	1.69	49.1				
	5	180	1.96	1.75	76.5				
average @180 minutes			1.8972295	1.598872666	57.6533	**average @180 minutes**			
Stand Devi @180 minutes			**1.94**	**1.70**	**58.86**	**Stand Devi @180 minutes**			
			0.19	**0.07**	**14.16**				
Total average Normal						**Total average normal**			
			1.95	**1.66**	**61.13**				

Hot Reflection Density

Printability of hot ink | **Printability of hot ink**

20 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	20 minutes	% tone	tone step cyan [%]	tone step magenta [%]
1.00	1.00	20.00	1.62	1.6	36.5	**1.00**	100	1.55	1.44
	2.00	20.00	1.67	1.58	42.8		95	1.54	1.31
	3.00	20.00	1.53	1.67	35		76	0.96	0.8
	4.00	20.00	1.55	1.7	42.5		63	0.71	0.6
	5.00	20.00	1.43	1.8	33.7		46	0.44	0.4
2.00	1.00	20.00	1.56	1.33	61.3	**2.00**	37	0.42	0.33
	2.00	20.00	1.61	1.67	71.1		28	0.32	0.27
	3.00	20.00	1.7	1.6	70.6		20	0.22	0.2
	4.00	20.00	1.52	1.89	64.6		12	0.11	0.13
	5.00	20.00	1.44	1.81	76.5		7	0.09	0.09
3.00	1.00	20.00	1.47	1.63	67.7	**3.00**			
	2.00	20.00	1.48	1.56	64.9				
	3.00	20.00	1.56	1.68	70.2			**Mage solids**	**Cyan solids**
	4.00	20.00	1.53	1.59	72.9			**%**	**%**
	5.00	20.00	1.52	1.68	66.7			30.12	26.96
4.00	1.00	20.00	1.49	1.55	70.2	**4.00**		27.39	31.01
	2.00	20.00	1.47	1.75	72.2			25.07	37.86
	3.00	20.00	1.52	1.61	72.3			32.66	36.32
	4.00	20.00	1.53	1.88	70.1			33.08	31.82
	5.00	20.00	1.57	1.89	69.5			41.47	34.93
5.00	1.00	20.00	1.54	1.67	66	**5.00**		29.24	37.04
	2.00	20.00	1.49	1.66	69.4			28	36.34
	3.00	20.00	1.47	1.74	62.3		ave	30.87875	34.035
	4.00	20.00	1.54	1.67	55.2				
	5.00	20.00	1.5	1.62	65.8				
average @20 minutes			**1.53**	**1.67**	**62.00**	**average @20 minutes**			
Stan. Devi @20 minutes			**0.07**	**0.12**	**13.04**	**Stan. Devi @20 minutes**			

40 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	40 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1.00	1.00	40.00	1.63	1.42	80.4	**1.00**	100	1.63	1.65
	2.00	40.00	1.5	1.61	68.8		95	1.68	1.54
	3.00	40.00	1.69	1.62	74.3		76	0.9	0.88

	4.00	40.00	1.58	1.78	74.4		63	0.75	0.68
	5.00	40.00	1.59	1.54	70.9		46	0.55	0.44
2.00	1.00	40.00	1.91	1.74	70.5	**2.00**	37	0.4	0.34
	2.00	40.00	1.64	1.53	87.7		28	0.3	0.22
	3.00	40.00	1.74	1.69	73.2		20	0.24	0.15
	4.00	40.00	1.73	1.59	75.3		12	0.11	0.12
	5.00	40.00	1.63	1.74	80.1		7	0.09	0.09
3.00	1.00	40.00	1.58	1.65	69.6	**3.00**			
	2.00	40.00	1.68	1.75	74.1				
	3.00	40.00	1.58	1.52	77.7				
	4.00	40.00	1.8	1.44	76				
	5.00	40.00	1.68	1.65	72.7				
4.00	1.00	40.00	1.78	1.64	58.5	**4.00**			
	2.00	40.00	1.5	1.58	65.4				
	3.00	40.00	1.73	1.61	73.8				
	4.00	40.00	1.74	1.66	76.9				
	5.00	40.00	1.57	1.53	69.4				
5.00	1.00	40.00	1.73	1.51	66	**5.00**			
	2.00	40.00	1.65	1.44	74.6				
	3.00	40.00	1.61	1.59	68.5				
	4.00	40.00	1.57	1.74	65.4				
	5.00	40.00	1.54	1.54	74.9				
average @40 minutes			**1.66**	**1.60**	**72.76**	**average @40 minutes**			
Stan devi @40 minutes			**0.10**	**0.10**	**5.88**	**Stan devi @40 minutes**			

60 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**60 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1.00	1.00	60.00	1.79	1.8	79.2	**1.00**	100	1.62	1.52
	2.00	60.00	1.67	1.62	81.6		95	1.65	1.41
	3.00	60.00	1.74	1.58	78.3		76	0.91	0.85
	4.00	60.00	1.62	1.9	86.9		63	0.69	0.6
	5.00	60.00	1.69	1.41	91.3		46	0.49	0.41
2.00	1.00	60.00	1.85	1.62	71.4	**2.00**	37	0.43	0.34
	2.00	60.00	1.67	1.53	77.6		28	0.32	0.27
	3.00	60.00	1.52	1.51	73.3		20	0.24	0.18
	4.00	60.00	1.65	1.57	55.5		12	0.12	0.12
	5.00	60.00	1.75	1.5	68.2		7	0.09	0.09
3.00	1.00	60.00	1.92	1.4	74.7	**3.00**			
	2.00	60.00	1.7	1.54	73.3				
	3.00	60.00	1.56	1.61	76.1				
	4.00	60.00	1.69	1.55	71.6				

	5.00	60.00	1.75	1.44	81.6				
4.00	1.00	60.00	1.65	1.43	81.8	**4.00**			
	2.00	60.00	1.68	1.48	80.6				
	3.00	60.00	1.72	1.67	66.8				
	4.00	60.00	1.59	1.68	71.3				
	5.00	60.00	1.62	1.47	76.4				
5.00	1.00	60.00	1.65	1.66	59.3	**5.00**			
	2.00	60.00	1.7	1.42	74.2				
	3.00	60.00	1.5	1.59	74.2				
	4.00	60.00	1.65	1.59	89.9				
	5.00	60.00	1.52	1.55	87.1				
average @60 minutes			**1.67**	**1.56**	**76.09**	**average @60 minutes**			
Stan devi @60 minutes			**0.10**	**0.12**	**8.50**	**Stan devi @60 minutes**			

80 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**80 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1.00	1.00	80.00	1.67	1.65	77.1	**1.00**	100	1.62	1.63
	2.00	80.00	1.54	1.66	83.7		95	1.59	1.51
	3.00	80.00	1.72	1.46	75		76	1	0.9
	4.00	80.00	1.55	1.5	78.8		63	0.74	0.68
	5.00	80.00	1.67	1.61	75.6		46	0.47	0.45
2.00	1.00	80.00	1.77	1.64	68.6	**2.00**	37	0.44	0.37
	2.00	80.00	1.71	1.53	90.6		28	0.36	0.28
	3.00	80.00	1.77	1.55	67		20	0.24	0.23
	4.00	80.00	1.52	1.51	68		12	0.13	0.16
	5.00	80.00	1.89	1.55	71.1		7	0.09	0.09
3.00	1.00	80.00	1.79	1.61	76.7	**3.00**			
	2.00	80.00	1.75	1.5	76.6				
	3.00	80.00	1.59	1.65	73.6				
	4.00	80.00	1.57	1.46	77.1				
	5.00	80.00	1.75	1.65	90.2				
4.00	1.00	80.00	1.7	1.55	71.1	**4.00**			
	2.00	80.00	1.78	1.46	90.3				
	3.00	80.00	1.75	1.54	75.8				
	4.00	80.00	1.55	1.58	78.2				
	5.00	80.00	1.64	1.6	73.3				
5.00	1.00	80.00	1.85	1.54	63.6	**5.00**			
	2.00	80.00	1.63	1.54	73.3				
	3.00	80.00	1.79	1.56	80				
	4.00	80.00	1.57	1.58	66				
	5.00	80.00	1.53	1.47	89.9				

average @80 minutes			**1.68**	**1.56**	**76.45**	**average @80 minutes**			
Stand Devi @80 minutes			**0.11**	**0.06**	**7.70**	**Stand Devi @80 minutes**			

100 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**100 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1.00	1.00	100.00	1.75	1.56	75.2	**1.00**	100	1.69	1.7
	2.00	100.00	1.66	1.58	76.6		95	1.68	1.52
	3.00	100.00	1.57	1.52	80.9		76	1.07	0.98
	4.00	100.00	1.59	1.56	69.5		63	0.76	0.69
	5.00	100.00	1.7	1.69	83.4		46	0.48	0.42
2.00	1.00	100.00	1.84	1.66	65.1	**2.00**	37	0.41	0.38
	2.00	100.00	1.8	1.55	81.6		28	0.33	0.3
	3.00	100.00	1.73	1.46	82.5		20	0.27	0.23
	4.00	100.00	1.62	1.65	70		12	0.13	0.16
	5.00	100.00	1.66	1.59	70.4		7	0.09	0.09
3.00	1.00	100.00	1.75	1.54	69.3	**3.00**			
	2.00	100.00	1.67	1.59	79.2				
	3.00	100.00	1.58	1.64	75.6				
	4.00	100.00	1.61	1.5	89.4				
	5.00	100.00	1.84	1.54	66.7				
4.00	1.00	100.00	1.85	1.64	75.7	**4.00**			
	2.00	100.00	1.84	1.53	87.2				
	3.00	100.00	1.72	1.61	80.3				
	4.00	100.00	1.6	1.59	81.4				
	5.00	100.00	1.56	1.59	85.6				
5.00	1.00	100.00	1.83	1.58	84.6	**5.00**			
	2.00	100.00	1.77	1.52	76.7				
	3.00	100.00	1.83	1.62	80.4				
	4.00	100.00	1.51	1.59	69.9				
	5.00	100.00	1.7	1.61	72.5				
average @100 minutes			**1.70**	**1.58**	**77.19**	**average @100 minutes**			
Stand Devi @100 minutes			**0.10**	**0.05**	**6.70**	**Stand Devi @100 minutes**			

120 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	120 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1.00	1.00	120.00	1.74	1.62	44.7	**1.00**	100	1.89	1.8
	2.00	120.00	1.84	1.53	50.4		95	1.85	1.63
	3.00	120.00	1.97	1.59	41		76	1.01	0.94
	4.00	120.00	1.77	1.67	40.5		63	0.73	0.66
	5.00	120.00	1.79	1.7	55.6		46	0.58	0.46
2.00	1.00	120.00	1.83	1.62	60.1	**2.00**	37	0.47	0.39
	2.00	120.00	1.73	1.45	44.3		28	0.35	0.29
	3.00	120.00	1.95	1.59	54.3		20	0.26	0.24
	4.00	120.00	1.72	1.7	52.2		12	0.13	0.18
	5.00	120.00	1.9	1.6	38.4		7	0.09	0.09
3.00	1.00	120.00	1.87	1.6	42	**3.00**			
	2.00	120.00	1.76	1.55	45.9				
	3.00	120.00	1.9	1.55	54.7				
	4.00	120.00	1.84	1.55	48.5				
	5.00	120.00	1.61	1.63	46.1				
4.00	1.00	120.00	1.63	1.64	42.2	**4.00**			
	2.00	120.00	1.83	1.67	54.3				
	3.00	120.00	1.59	1.6	52.8				
	4.00	120.00	1.63	1.64	52.9				
	5.00	120.00	1.74	1.59	45.4				
5.00	1.00	120.00	1.82	1.59	59.6	**5.00**			
	2.00	120.00	1.87	1.66	47.6				
	3.00	120.00	1.72	1.61	57.1				
	4.00	120.00	1.94	1.67	52.5				
	5.00	120.00	1.66	1.68	49.1				
average @120 minutes			**1.79**	**1.61**	**49.29**	**average @120 minutes**			
Stand devi @120 minutes			**0.11**	**0.06**	**6.13**	**Stand devi @120 minutes**			

140 minutes of trial time	samples	minutes	density cyan [%]	density magenta [%]	gloss cyan [%]	140 minutes of trial time	% tone	tone step cyan [%]	tone step magenta [%]
1.00	1.00	140.00	1.96	1.57	56.2	**1.00**	100	1.82	1.79
	2.00	140.00	1.86	1.61	51.4		95	1.83	1.59
	3.00	140.00	1.85	1.63	50.7		76	0.95	0.92
	4.00	140.00	1.64	1.63	59.2		63	0.7	0.62
	5.00	140.00	1.82	1.72	57.8		46	0.5	0.44
2.00	1.00	140.00	1.87	1.63	53.2	**2.00**	37	0.4	0.36

	2.00	140.00	1.9	1.53	47		28	0.32	0.29
	3.00	140.00	1.71	1.5	55.1		20	0.24	0.25
	4.00	140.00	1.48	1.65	57.3		12	0.15	0.18
	5.00	140.00	1.82	1.76	49.1		7	0.09	0.09
3.00	1.00	140.00	1.88	1.59	41.2	**3.00**			
	2.00	140.00	1.47	1.47	50				
	3.00	140.00	1.83	1.61	53.8				
	4.00	140.00	1.56	1.67	45.1				
	5.00	140.00	1.84	1.56	49.6				
4.00	1.00	140.00	1.95	1.56	53.1	**4.00**			
	2.00	140.00	1.57	1.55	53.6				
	3.00	140.00	1.93	1.48	37.8				
	4.00	140.00	1.46	1.61	49.2				
	5.00	140.00	1.74	1.62	46.7				
5.00	1.00	140.00	1.68	1.55	56.4	**5.00**			
	2.00	140.00	1.92	1.66	48.2				
	3.00	140.00	1.54	1.51	50				
	4.00	140.00	1.56	1.63	47.8				
	5.00	140.00	1.98	1.61	43.8				
average @140 minutes			**1.75**	**1.60**	**50.53**	**average @140 minutes**			
Stand devi @140 minutes			**0.17**	**0.07**	**5.26**	**Stand devi @140 minutes**			

160 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**160 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1.00	1.00	160.00	1.98	1.56	52.4	**1.00**	100	2	1.76
	2.00	160.00	1.96	1.58	45.9		95	2	1.62
	3.00	160.00	1.86	1.68	50.2		76	1.04	0.93
	4.00	160.00	1.98	1.61	37.7		63	0.8	0.68
	5.00	160.00	1.98	1.43	64.2		46	0.61	0.43
2.00	1.00	160.00	1.72	1.57	60.8	**2.00**	37	0.47	0.36
	2.00	160.00	1.92	1.51	49.2		28	0.33	0.27
	3.00	160.00	1.55	1.65	55.2		20	0.29	0.22
	4.00	160.00	1.88	1.53	54.5		12	0.18	0.12
	5.00	160.00	1.91	1.59	45.2		7	0.09	0.09
3.00	1.00	160.00	1.81	1.64	57.9	**3.00**			
	2.00	160.00	2.04	1.72	56.8				
	3.00	160.00	1.8	1.53	58.3				
	4.00	160.00	1.93	1.52	61.3				
	5.00	160.00	1.81	1.56	52.4				
4.00	1.00	160.00	1.95	1.65	42.1	**4.00**			
	2.00	160.00	1.73	1.67	42.7				

	3.00	160.00	1.98	1.59	47.4				
	4.00	160.00	1.49	1.57	55.1				
	5.00	160.00	1.81	1.61	44.2				
5.00	1.00	160.00	1.88	1.56	55.1	**5.00**			
	2.00	160.00	1.93	1.53	47.4				
	3.00	160.00	1.72	1.65	58.3				
	4.00	160.00	1.84	1.57	60.8				
	5.00	160.00	1.91	1.65	56.8				
average @160 minutes			**1.85**	**1.59**	**52.48**	**average @160 minutes**			
Stand devi @160 minutes			**0.13**	**0.06**	**6.97**	**Stand devi @160 minutes**			

180 minutes of trial time	**samples**	**minutes**	**density cyan [%]**	**density magenta [%]**	**gloss cyan [%]**	**180 minutes of trial time**	**% tone**	**tone step cyan [%]**	**tone step magenta [%]**
1.00	1.00	180.00	2	1.61	54.9	**1.00**	100	1.8	1.78
	2.00	180.00	1.89	1.62	65.6		95	1.94	1.6
	3.00	180.00	2	1.47	64.5		76	1.07	0.94
	4.00	180.00	1.71	1.49	58.5		63	0.73	0.63
	5.00	180.00	1.86	1.65	38.8		46	0.52	0.43
2.00	1.00	180.00	1.98	1.64	50	**2.00**	37	0.43	0.36
	2.00	180.00	1.98	1.63	47.8		28	0.35	0.28
	3.00	180.00	1.72	1.53	43.8		20	0.28	0.23
	4.00	180.00	1.92	1.52	52.4		12	0.18	0.18
	5.00	180.00	1.55	1.56	45.9		7	0.09	0.09
3.00	1.00	180.00	1.96	1.64	52.2	**3.00**			
	2.00	180.00	1.86	1.53	38.4				
	3.00	180.00	1.85	1.5	42				
	4.00	180.00	1.64	1.65	45.9				
	5.00	180.00	1.82	1.59	54.7				
4.00	1.00	180.00	1.56	1.63	42.8	**4.00**			
	2.00	180.00	1.61	1.58	35				
	3.00	180.00	1.7	1.68	42.5				
	4.00	180.00	1.52	1.59	33.7				
	5.00	180.00	1.44	1.68	61.3				
5.00	1.00	180.00	2	1.49	39.6	**5.00**			
	2.00	180.00	1.61	1.62	59.9				
	3.00	180.00	1.9	1.66	67.6				
	4.00	180.00	1.9	1.63	58.6				
	5.00	180.00	1.93	1.78	64.3				

average @180 minutes			**1.80**	**1.60**	**50.43**	**average @180 minutes**			
Stand Devi @180 minutes			**0.17**	**0.07**	**10.21**	**Stand Devi @180 minutes**			

Total average hot			**1.72**	**1.60**	**63.02**	**Total average hot**

Rub Resistance Data

b Resistance								
Hot								
Un-printed Density [%]		**20**	**100**	**180**				
1		0.07	0.07	0.07				
2		0.07	0.07	0.07				
3		0.07	0.07	0.07				
4		0.07	0.07	0.07				
5		0.07	0.07	0.07				
average		**0.07**	**0.07**	**0.07**				
Printed Density [%]		**20**	**100**	**180**				
1		0.09	0.11	0.08				
2		0.12	0.09	0.11				
3		0.12	0.12	0.11				
4		0.08	0.11	0.08				
5		0.11	0.08	0.11				
average		**0.10**	**0.10**	**0.10**				
Total hot average		**0.10**						
Delta density hot [%]		**0.03**						
Normal								
Un-printed Density [%]		**20**	**100**	**180**				
1		0.07	0.07	0.07				
2		0.07	0.07	0.07				
3		0.07	0.07	0.07				
4		0.07	0.07	0.07				
5		0.07	0.07	0.07				
average		**0.07**	**0.07**	**0.07**				
Printed Density [%]		20.00	100.00	180.00				
1		0.09	0.12	0.09				
2		0.10	0.11	0.08				
3		0.08	0.08	0.09				
4		0.08	0.09	0.11				
5		0.11	0.08	0.09				
average		**0.09**	**0.10**	**0.09**				
Total normal average		**0.09**						
Delta density normal [%]		**0.02**						
Cold								
Un-printed Density [%]		**20**	**100**	**180**				
1		0.07	0.07	0.07				
2		0.07	0.07	0.07				
3		0.07	0.07	0.07				
4		0.07	0.07	0.07				
5		0.07	0.07	0.07				
average		**0.07**	**0.07**	**0.07**				
Printed Density [%]		**20**	**100**	**180**				
1		0.08	0.08	0.08				
2		0.08	0.11	0.08				
3		0.08	0.08	0.08				

4			0.08	0.08	0.12				
5			0.08	0.11	0.08				
average			**0.08**	**0.09**	**0.09**				
Total cold average			**0.09**						
Delta density cold [%]			**0.02**						

Average Percent Solids

Percent Solids of ink at different temperatures:

Magent a	Cold	Normal	Hot
Solids	23.47	28.62	30.88

Cyan	Cold	Normal	Hot
Solids	32.23	31.82	34.04

Average Cold Reflection Density

Cold density and mottle:

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	2.01	1.64	70.13
40	2.04	1.66	75.14
60	2.06	1.65	79.10
80	2.00	1.65	74.46
100	2.04	1.66	70.81
120	2.04	1.66	81.97
140	2.12	1.65	71.07
160	2.09	1.64	68.69
180	2.08	1.64	70.31

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	0.08	0.02	4.52
40	0.08	0.02	7.51
60	0.08	0.03	5.39
80	0.09	0.03	5.74
100	0.08	0.03	4.15
120	0.09	0.02	10.83
140	0.06	0.04	3.46
160	0.05	0.03	4.01
180	0.05	0.04	5.75

	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
Ave	2.05	1.65	73.52

	Mottle Cyan	Mottle Magenta	Standard Deviation Gloss Cyan
Ave	0.07	0.03	5.71

Average Normal Reflection density

Normal density and mottle

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	1.95	1.64	46.96
40	1.92	1.63	63.18
60	1.96	1.64	62.15
80	1.96	1.64	65.08
100	1.98	1.64	61.13
120	1.95	1.64	56.22
140	1.98	1.68	61.98
160	1.97	1.66	58.53
180	1.94	1.70	58.86

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	0.10	0.09	11.20
40	0.12	0.09	11.51
60	0.13	0.08	14.34
80	0.10	0.08	8.75
100	0.15	0.07	7.89
120	0.12	0.08	8.29
140	0.10	0.09	10.39
160	0.11	0.05	7.36
180	0.19	0.07	14.16

	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
Ave	1.96	1.65	59.34

	Mottle Cyan	Mottle Magenta	Standard Deviation Gloss Cyan
Ave.	0.12	0.08	10.43

Average Hot Reflection Density

Hot density and mottle

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	1.53	1.60	62.00
40	1.66	1.64	72.76
60	1.67	1.58	76.09
80	1.68	1.57	76.45
100	1.70	1.61	77.19
120	1.79	1.62	49.29
140	1.75	1.62	50.53
160	1.85	1.60	52.48
180	1.80	1.63	50.43

Time (minutes)	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
20	0.07	0.13	13.04
40	0.10	0.13	5.88
60	0.10	0.13	8.50
80	0.11	0.08	7.70
100	0.10	0.09	6.70
120	0.11	0.07	6.13
140	0.17	0.09	5.26
160	0.13	0.08	6.97
180	0.17	0.10	10.21

	Average Cyan Density [%]	Average Magenta Density [%]	Average Cyan Gloss [%]
Ave.	1.72	1.62	63.02

	Mottle Cyan	Mottle Magenta	Standard Deviation Gloss Cyan
Ave.	0.12	0.10	7.82

Average density, mottle, and gloss for all the temperatures:					
Cyan:					
Readings [F]			**65**	**78**	**95**
Cyan Density [%]			2.05	1.96	1.72
Cyan Mottle [%]			0.072	0.124	0.118
Cyan Gloss [%]			73.52	59.34	63.02
Gloss standard Deviation			5.71	10.43	7.82

Magenta:				
Readings [F]		**65**	**78**	**95**
Magenta density [%]		1.65	1.65	1.62
Magenta Mottle		0.03	0.08	0.10
Temperature [F]		**65**	**78**	**95**
Cyan Mottle		0.07	0.12	0.12
Temperature [F]		**65**	**78**	**95**
Magenta Mottle		0.03	0.08	0.10

Cold Tone Steps

Cold tone steps

% Tone at trial time [minutes]	tone step cyan @20	tone step cyan @40	tone step cyan @60	tone step cyan @80	tone step cyan @100	tone step cyan @120	tone step cyan @140	tone step cyan @160	tone step cyan @180
100	2.06	2.13	2.14	2.05	2.03	1.88	2.16	2.13	2.13
95	1.89	2.01	2.08	1.89	1.99	1.82	2.09	2.07	2.05
76	1.04	1.08	1.06	0.99	1.20	0.95	1.20	1.07	1.03
63	0.69	0.80	0.73	0.70	0.78	0.78	0.84	0.79	0.78
46	0.53	0.50	0.51	0.52	0.49	0.49	0.55	0.54	0.52
37	0.46	0.44	0.44	0.40	0.41	0.40	0.46	0.50	0.43
28	0.34	0.38	0.33	0.38	0.34	0.34	0.37	0.38	0.36
20	0.29	0.27	0.26	0.30	0.26	0.29	0.28	0.28	0.30
12	0.21	0.18	0.18	0.19	0.18	0.19	0.20	0.20	0.21
7	0.12	0.11	0.12	0.13	0.10	0.10	0.12	0.13	0.13

% Tone at trial time [minutes]	tone step magenta @20	tone step magenta @40	tone step magenta @60	tone step magenta @80	tone step magenta @100	tone step magenta @120	tone step magenta @140	tone step magenta @160	tone step magenta @180
100	1.71	1.70	1.74	1.70	1.69	1.66	1.75	1.77	1.74
95	1.53	1.49	1.51	1.43	1.46	1.45	1.51	1.55	1.55
76	0.96	0.92	0.88	0.84	0.86	0.84	0.90	0.93	0.92
63	0.64	0.67	0.60	0.59	0.61	0.64	0.62	0.62	0.61
46	0.42	0.45	0.40	0.44	0.39	0.38	0.43	0.44	0.42
37	0.36	0.35	0.36	0.34	0.32	0.33	0.35	0.39	0.35
28	0.29	0.26	0.27	0.30	0.25	0.26	0.30	0.29	0.28
20	0.23	0.22	0.22	0.24	0.21	0.23	0.24	0.23	0.23
12	0.18	0.18	0.17	0.20	0.16	0.18	0.19	0.18	0.18
7	0.11	0.11	0.12	0.15	0.13	0.12	0.12	0.13	0.12

% Tone at trial time [minutes]	**Average Cyan % tone cold [%]**
100	**2.08**
95	**1.99**
76	**1.07**
63	**0.77**
46	**0.52**
37	**0.44**
28	**0.36**
20	**0.28**
12	**0.19**

% Tone at trial time [minutes]	**Average Magenta % tone cold [%]**
100	**1.72**
95	**1.50**
76	**0.89**
63	**0.62**
46	**0.42**
37	**0.35**
28	**0.28**
20	**0.23**
12	**0.18**

Normal Tone Step

Normal tone steps

% Tone at trial time [minutes]	tone step cyan @20	tone step cyan @40	tone step cyan @60	tone step cyan @80	tone step cyan @100	tone step cyan @120	tone step cyan @140	tone step cyan @160	tone step cyan @180
100.00	2.06	2.1	2.04	2.12	2.02	2.09	2.15	2.16	2.1
95.00	2.05	2.07	2.01	2.1	2.02	2.04	2.1	2.13	2.01
76.00	1.2	1.19	1.07	1.25	1.15	1.04	1.19	1.12	1.25
63.00	0.8	0.86	0.76	0.94	0.77	0.87	0.89	0.81	0.77
46.00	0.61	0.54	0.57	0.58	0.52	0.53	0.62	0.61	0.53
37.00	0.44	0.44	0.51	0.47	0.43	0.44	0.52	0.54	0.52
28.00	0.35	0.41	0.37	0.39	0.36	0.36	0.36	0.36	0.41
20.00	0.28	0.29	0.28	0.32	0.29	0.29	0.32	0.28	0.28
12.00	0.17	0.21	0.21	0.24	0.24	0.22	0.23	0.22	0.24
7.00	0.11	0.12	0.12	0.12	0.15	0.12	0.12	0.12	0.12

% Tone at trial time [minutes]	tone step magenta @20	tone step magenta @40	tone step magenta @60	tone step magenta @80	tone step magenta @100	tone step magenta @120	tone step magenta @140	tone step magenta @160	tone step magenta @180
100.00	1.77	1.78	1.73	1.77	1.75	1.73	1.7	1.8	1.78
95.00	1.62	1.6	1.59	1.63	1.55	1.57	1.62	1.63	1.59
76.00	0.92	0.92	0.89	0.93	0.89	1.01	1.02	0.97	0.93
63.00	0.6	0.67	0.67	0.62	0.62	0.69	0.69	0.64	0.62
46.00	0.41	0.46	0.45	0.41	0.43	0.47	0.43	0.43	0.47
37.00	0.34	0.35	0.4	0.35	0.35	0.35	0.4	0.36	0.4
28.00	0.29	0.28	0.29	0.28	0.31	0.28	0.32	0.29	0.28
20.00	0.25	0.23	0.24	0.24	0.24	0.24	0.25	0.26	0.24
12.00	0.19	0.19	0.19	0.19	0.18	0.19	0.19	0.2	0.18
7.00	0.12	0.12	0.12	0.12	0.1	0.12	0.12	0.13	0.12

% Tone at trial time [minutes]	***Average Cyan % tone normal [%]***
100.00	**2.09**
95.00	**2.06**
76.00	**1.16**
63.00	**0.83**
46.00	**0.57**
37.00	**0.48**
28.00	**0.37**
20.00	**0.29**
12.00	**0.22**

% Tone at trial time [minutes]	***Average* Magenta % tone normal [%]**
100.00	**1.76**
95.00	**1.60**
76.00	**0.94**
63.00	**0.65**
46.00	**0.44**
37.00	**0.37**
28.00	**0.29**
20.00	**0.24**
12.00	**0.19**

Hot Tone Step

Hot tone steps

% Tone at trial time [minutes]	tone step cyan @20	tone step cyan @40	tone step cyan @60	tone step cyan @80	tone step cyan @100	tone step cyan @120	tone step cyan @140	tone step cyan @160	tone step cyan @180
100.00	1.55	1.63	1.62	1.62	1.69	1.89	1.82	2	1.8
95.00	1.54	1.68	1.65	1.59	1.68	1.85	1.83	2	1.94
76.00	0.96	0.9	0.91	1	1.07	1.01	0.95	1.04	1.07
63.00	0.71	0.75	0.69	0.74	0.76	0.73	0.7	0.8	0.73
46.00	0.44	0.55	0.49	0.47	0.48	0.58	0.5	0.61	0.52
37.00	0.42	0.4	0.43	0.44	0.41	0.47	0.4	0.47	0.43
28.00	0.32	0.3	0.32	0.36	0.33	0.35	0.32	0.33	0.35
20.00	0.22	0.24	0.24	0.24	0.27	0.26	0.24	0.29	0.28
12.00	0.11	0.11	0.12	0.13	0.13	0.13	0.15	0.18	0.18
7.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

% Tone at trial time [minutes]	tone step magenta @20	tone step magenta @40	tone step magenta @60	tone step magenta @80	tone step magenta @100	tone step magenta @120	tone step magenta @140	tone step magenta @160	tone step magenta @180
100.00	1.44	1.65	1.52	1.63	1.7	1.8	1.79	1.76	1.78
95.00	1.31	1.54	1.41	1.51	1.52	1.63	1.59	1.62	1.6
76.00	0.8	0.88	0.85	0.9	0.98	0.94	0.92	0.93	0.94
63.00	0.6	0.68	0.6	0.68	0.69	0.66	0.62	0.68	0.63
46.00	0.4	0.44	0.41	0.45	0.42	0.46	0.44	0.43	0.43
37.00	0.33	0.34	0.34	0.37	0.38	0.39	0.36	0.36	0.36
28.00	0.27	0.22	0.27	0.28	0.3	0.29	0.29	0.27	0.28
20.00	0.2	0.15	0.18	0.23	0.23	0.24	0.25	0.22	0.23
12.00	0.13	0.12	0.12	0.16	0.16	0.18	0.18	0.12	0.18
7.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

% Tone at trial time [minutes]	**Average Cyan % tone hot [%]**
100.00	**1.74**
95.00	**1.75**
76.00	**0.99**
63.00	**0.73**
46.00	**0.52**
37.00	**0.43**
28.00	**0.33**
20.00	**0.25**
12.00	**0.14**

% Tone at trial time [minutes]	**Average Magenta % tone hot [%]**
100.00	**1.67**
95.00	**1.53**
76.00	**0.90**
63.00	**0.65**
46.00	**0.43**
37.00	**0.36**
28.00	**0.27**
20.00	**0.21**
12.00	**0.15**

7.00	**0.01**

7.00	**0.01**

Image Analyzer Data

Average values of image analyzer

Magenta Average Area:

lues of Area		Cold	Normal	Hot
Min [microns]		183.95	7744.44	4758.02
Obj#		73.78	44.67	21.44
Max [microns]		10438.27	10870.37	7672.84
Obj#		76.22	66.67	85.56
Range [microns]		10254.32	3125.93	3437.04
Mean [microns]		6510.72	9174.52	7510.71
Standard Deviation		2177.41	537.32	556.60
Sum		1038995.13	1004670.30	734839.47
Samples		138.44	109.56	113.89
Magenta Average Perimeter:				
lues of Area		**Cold**	**Normal**	**Hot**
Min [microns]		49.90	323.08	249.22
Obj#		93.44	37.67	41.56
Max [microns]		456.07	432.23	391.73
Obj#		67.11	82.22	85.56
Range [microns]		406.16	109.15	163.62
Mean [microns]		327.99	356.29	331.75
Standard Deviation		64.80	14.53	29.12
Sum		45394.62	39024.41	37733.59
Samples		138.44	109.56	113.89
Cyan Average Area:				
lues of Area		**Cold**	**Normal**	**Hot**
Min {microns]		897.53	6402.47	3153.09
Obj#		110.00	39.33	79.56
Max [microns]		9214.82	8809.88	9679.01
Obj#		136.89	70.78	59.11
Range [microns]		8317.28	2407.41	6525.93
Mean [microns]		6701.39	7699.81	7810.82
Standard Deviation		1662.11	488.81	1029.58
Sum		902159.22	856840.70	900723.39
Samples		134.89	111.33	116.78
Cyan Average Perimeter:				
lues of Area		**Cold**	**Normal**	**Hot**
Min {microns]		88.62	290.50	158.42
Obj#		103.00	41.44	76.44
Max [microns]		417.32	375.35	440.52
Obj#		134.89	68.22	71.44
Range [microns]		328.69	84.85	282.09
Mean [microns]		314.84	323.84	334.41
Standard Deviation		49.34	13.98	40.03
Sum		42428.41	36043.51	38823.00
Samples		134.89	111.33	116.78

Solvent and Ink Consumption Data

Cold ink				
Solvent consumption of magenta (Lts/hr):				1.50
Solvent consumption of cyan (Lts/hr):				1.67
1 Liter of solvent blend = 0.846 Kg				
Solvent consumption of magenta (lbs/hr):				2.79
Solvent consumption of cyan (lbs/hr):				3.10
Hot ink				
Solvent consumption of magenta (Lts/hr):				5.83
Solvent consumption of cyan (Lts/hr):				3.50
1 Liter of solvent blend = 0.846 Kg				
Solvent consumption of magenta (lbs/hr):				10.86
Solvent consumption of cyan (lbs/hr):				6.51
Normal ink				
Solvent consumption of magenta (Lts/hr):				2.08
Solvent consumption of cyan (Lts/hr):				2.00
1 Liter of solvent blend = 0.846 Kg				
Solvent consumption of magenta (lbs/hr):				3.88
Solvent consumption of cyan (lbs/hr):				3.72
Solvent consumed:		Cold	Normal	Hot
Magenta (lbs/hr)		2.79	3.88	10.86
Cyan (lbs/hr)		3.10	3.72	6.51
Ink consumed:		Cold	Normal	Hot
Magenta (lbs)		7.98	7.44	10.34
Cyan (lbs)		11.70	11.1672	16.92

Cold ink	
Solvent consumption of magenta (Lts/hr):	1.50
Solvent consumption of cyan (Lts/hr):	1.67
1 Liter of solvent blend = 0.846 Kg	
Solvent consumption of magenta (lbs/hr):	2.79
Solvent consumption of cyan (lbs/hr):	3.10

Hot ink	
Solvent consumption of magenta (Lts/hr):	5.83
Solvent consumption of cyan (Lts/hr):	3.50
1 Liter of solvent blend = 0.846 Kg	
Solvent consumption of magenta (lbs/hr):	10.86
Solvent consumption of cyan (lbs/hr):	6.51

Normal ink	
Solvent consumption of magenta (Lts/hr):	2.08
Solvent consumption of cyan (Lts/hr):	2.00
1 Liter of solvent blend = 0.846 Kg	
Solvent consumption of magenta (lbs/hr):	3.88
Solvent consumption of cyan (lbs/hr):	3.72

Solvent consumed during trial :	65	72	95
Magenta (lbs/hr)	2.79	3.88	10.86
Cyan (lbs/hr)	3.10	3.72	6.51
Ink consumed during trial:	65	72	95
Magenta (lbs)	6.72	9.41	14.78
Cyan (lbs)	14.78	14.1134	21.384
Ink beginning weight:	65	72	95
Magenta (lbs)	73.91	77.27	83.32
Cyan (lbs)	72.57	73.24	78.62
Ink ending weight	65	72	95
Magenta (lbs)	67.19	67.87	68.54
Cyan (lbs)	59.80	58.46	57.79
Solvent consumed during trial in tons/year:	65	72	95
Cyan (tons/year)	11.17	13.392	23.44
Magenta (tons/year)	10.05	13.968	39.09
Cost of solvent consumed per year	65	72	95
Magenta $ in (tons/year)	10050.48	13968	39085.20
Cyan $ in (tons/year)	11167.20	13392	23436.00

Cost of ink consumed per year	65	72	95
Magenta $ in (tons/year)	193521.52	270930.13	425747.35
Cyan $ in (tons/year)	367680.00	425760.00	599916.73

Cost of solvent = $0.5/lbs = $500/ton
cost of ink = $4 /lbs = $8000/ton

Ink consumed during trial in tons/year:	65	72	95
Magenta (tons/year)	24.19	33.87	53.22
Cyan (tons/year)	45.96	53.22	74.99
Ink consumed during trial in [lbs]:	65	72	95
Magenta	6.72	9.41	14.78
Cyan	12.77	14.78	20.83

Cyan [tons]				Total mass consumption
Cold				35.08
Normal				38.48
Hot				60.57
Magenta [Tons]				Total mass consumption
Cold				20.28
Normal				28.29
Hot				63.66
Cyan [lbs]				Total mass consumption
65				26.10
72				28.63
95				45.06
Magenta [lbs]				Total mass consumption
65				15.09
72				21.05
95				47.36

Appendix B

Tabular Tables for Preliminary Experiment

Cooling Preliminary experiment

Date:				Inlet water temp: 51F			
Sequence:		11/5/98		Outlet water temp: 54F			
Color		Yellow			Water flow: 4gal/min		
Value		Yellow			Ink flow: 8gal/min		
Value	**Visco [s]**	**Temp [F]**	**Amount solvent added [L]**				
Time [min]				Coil length: 50ft			
0	20.37	68	2				
2	20.5	67	0				
4	20.7	66	0				
6	21.6	65	0.25				
8	21	64	0				
10	21.25	63	0.125				
12	20.53	62	0				
14	21.88	62	0.25				
16	20.97	61	0				
18	21.44	61	0.25				
20	21.2	60	0				
22	21.5	60	0.125				
24	20.97	60	0				
26	21.2	60	0				
28	21.44	59	0.125				
30	21.24	59	0				
32	21.12	59	0				
34	20.93	59	0				
36	21.34	59	0.125				
38	21.12	59	0				
40	21.5	59	0.125				
Ave.	21.13	61.52	3.375				

Heating Preliminary experiment

				Inlet water temp: 113F			
Date:	11/24/98			Outlet water temp: 108F			
Sequence	yellow				Water flow: 4gal/min		
Color	Yellow				Ink flow: 8gal/min		
Value	**Visco [s]**	**Temp [F]**	**%Solids [%]**	**Amount solvent added [L]**	Coil length: 50ft		
Time [min]							
0	33	70	31.2	0			
2	27	75		0			
4	24.59	88		0			
6	24	91		0.5			
8	20.87	93		0			
10	23.12	95	33.15	0.5			
12	19.97	98		0			
14	20.88	101	32.32	0			
16	21.01	102		0			
18	20.69	101		0			
20	21.97	99		0			
22	22.1	98		0.25			
24	21.31	98		0.4			
26	22	98		0.4			
28	20.31	98		0			
30	20.35	100	36.98	0			
32	20.56	102		0			
34	20.5	103		0			
36	20.82	102	35.21	0			
38	20.47	101		0			
40	20.34	101	33.91	0			
Ave.	22.18	95.90	33.80	2.05			

Preliminary Solvent Evaporation Data

Preliminary test: 400gr of ink + 115 gr of Blend

Time [Minutes]	Weight [gr]
0	515
5	514.6
10	514.5
15	513.8
20	513.5
25	513
30	512
35	511.5

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