Effects of Temperature Control on Gravure Packaging Inks

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Abstract

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.

Introduction

It is well known that variations in ink temperature cause a variation in color density and viscosity (Celio, 1998). The viscosity of inks changes about 3 to 4% per degree Fahrenheit change (GATF, 1995). 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

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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); gravure inks contain about 60 to 75% of VOC's such as toluene or ethyl acetate. The VOC's are emitted from cleanup and printing operations; however, little information is available which quantifies these emissions. Usually, VOC emissions are calculated based on raw material consumption (Blaszczak, 1998). Changes in print quality can be quantified by measuring visual parameters, such as density, 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% growth rate and the value of the shipments were 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 a lower cost per unit of package. The majority of these products are categorized as flexible packaging because they are used in the food industry. For example, 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 VOC's produced by gravure companies, the Environmental Protection Agency (EPA) created regulations. These emissions are thought to be precursors of organic compounds which may destroy the ozone layer (Neal, 1989).

Objective

This study provides 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.

Experimental Design

The experimental design consisted of applying a cooling/heating method to two gravure packaging inks (magenta and cyan) to determine the effect of different ink temperatures on ink viscosity, print density, gloss, rub resistance, solvent consumption, and ink consumption. To cool or heat the printing ink, two small heat exchangers were constructed, one for each printing color. Cold/hot water was pumped through a 50 feet, 5/8" OD copper coil.

The experimental design project was divided into three conditions. Condition I of the project consisted of an ink printability study of packaging ink at a cold temperature (60°F). Condition II of the project consisted of an ink printability study of packaging ink at a normal temperature (72°F). Condition III of the project consisted of an ink printability study of packaging ink at a warm temperature (95°F).

The engraved cylinder selected for cyan has a screen angle of 30° and 175 lines per inch (lpi); the engraved cylinder selected for magenta has a screen angle of 60° and 175 lpi.

A standard packaging nitrocellulose ink with 50% normal propyl acetate and 50% normal propyl alcohol as solvent base was used. The substrate used was clear polyethylene with a surface tension of 36 dynes/cm.

During the test runs, added solvent, viscosity, temperature, and time were recorded every 5 minutes to determine solvent consumption at the given temperature. To control viscosity, a Zahn cup #2 was used. Also during the test run, the printed roll was flagged every twenty minutes. At the end of the run, five signatures were collected from each flag. Printability analysis was performed at each set of the printed samples.

After the test runs, signatures were collected and analyzed using the previously described printability methods. Two hundred and twenty five measurements of density and specular gloss per color per temperature were performed, a total of 2250 measurements. A total of 108 measurements using image analysis were done.

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

Condition I: Cold Temperature

The experimental design in Condition I of the project consisted of running a test on a four-color gravure press (Cerutti, Model 118, 24 inches wide) for three hours. The test was conducted in two colors: magenta and cyan. Solvent consumption and ink consumption will be presented in both cyan and magenta. However, to simplify the results for this project, the printability data will be presented in one color only, cyan. The ink temperature selected for Condition I of the project was 60°F. The ambient temperature for all the conditions of the project was 84°F. The room was heated in order simulate an actual printing environment. The relative humidity for all of the conditions ranged between 30 and 38%. For Condition I, cold tap water (50-52°F) was pumped through the 50 feet copper coil.

Table 1 shows the different running parameters selected for Condition I, II, and III:

Table 1. Temperature and running parameters for Condition I, II, III.

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

Condition II: Normal Temperature

The ink temperature selected for Condition II of the project was 72°F maintaining the same ambient temperature (84°F), running parameters (Table 1), and substrate as for Condition I.

Condition III: Hot Temperature

The ink temperature selected for Condition III of the project was 95°F maintaining the same ambient temperature (84°F), running parameters (Table 1), and substrate as for Condition I. For Condition III, hot tap water (110-115°F) was pumped through the 50 feet copper coil.

Results and Discussion

Variation in Ink Viscosity as a Function of Temperature

Throughout the experiment, viscosity readings were made every 5 minutes for each of the experimental conditions. The average efflux time for magenta and cyan are presented in the Table 2. The error reading on a Zahn cup is about 0.5 seconds (Ciucci, 1999). As can be seen, all efflux times were kept under target and no major errors were involved in the viscosity readings.

Table 2. Viscosity measured as efflux time.

CYAN	Efflux time [sec]	Standar Deviation	MAGENTA	Efflux time [sec]	Standar Deviation
Cold	22.8	0.54	Cold	22.7	0.33
Normal	22.5	0.66	Normal	22.6	0.56
Hot	22.2	0.63	Hot	22.7	0.84

Solvent Consumption as a Function of Temperature

Throughout the three conditions of the project, the amount of solvent added to the systems to maintain viscosity was recorded after the ink reached equilibrium temperature.

Figure 1 shows the magenta solvent consumption throughout the entire project as a function of ink temperature on a lb/hr basis. Shown in Figure 1, the consumption of solvent increases with increasing temperature. 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 temperature were kept constant and the only changing variable was the partial pressure of the inner layer between the air and the ink. As the temperature of one of the variables increases, the partial pressure of such variable increases as well. This means that at a higher partial pressure value, the inner layer of gases can sustain more VOC's, thus evaporating more solvent from the ink. Based on Figure 1, the equation for magenta solvent consumption as a function of temperature was determined as follows:

$$Solvent_{magenta} = 0.0049 * T^2 - 0.5199 * T + 15.758 \quad (1)$$

Where T represents the ink temperature and $solvent_{magenta}$ represents solvent consumption on a lb/hr basis. Figure 1 also represents the amount of cyan solvent consumed during the print trials on a lb/hr basis. As can be seen, solvent consumption increases with increasing temperature and both cyan and magenta follow the same increasing curve. As mentioned before, solvent consumption is a function of solvent evaporation. At the highest temperature, there is 45.8% more solvent consumption for magenta and 64.1% more solvent consumption for cyan than at normal ink temperature. The increase in solvent consumption is even higher compared to the cold ink 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).

Based on Figure 1, the equation for cyan solvent consumption as a function of temperature was determined as follows:

$$Solvent_{cyan} = 0.0011 * T^2 - 0.0633 * T + 2.5428 \quad (2)$$

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 its cost is about 4 times the cost of solvent (Ciucci, 1999).

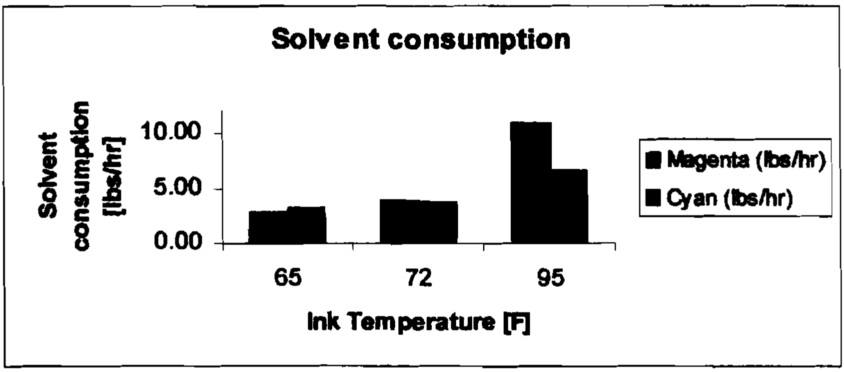


Figure 1. Magenta and cyan solvent consumption during trial

Printers like to use as little ink as possible because it reduces the 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 pollution problems for the environment, and less hazardous contact for the people working around the ink. By reducing the amount of ink consumed, not only will the printing plant benefit from reducing costs and safety precautions with workers, but it will also benefit the environment by creating less pollution.

The total ink consumption during the trial was determined. Figure 2 represents the ink consumption for cyan and magenta. It can be gather from Figure 2 that the biggest effect on ink consumption comes from the hot 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 cyan is 28% and for magenta is 13.7%. The equation for ink consumption was determined as follows:

Ink consumption for cyan:

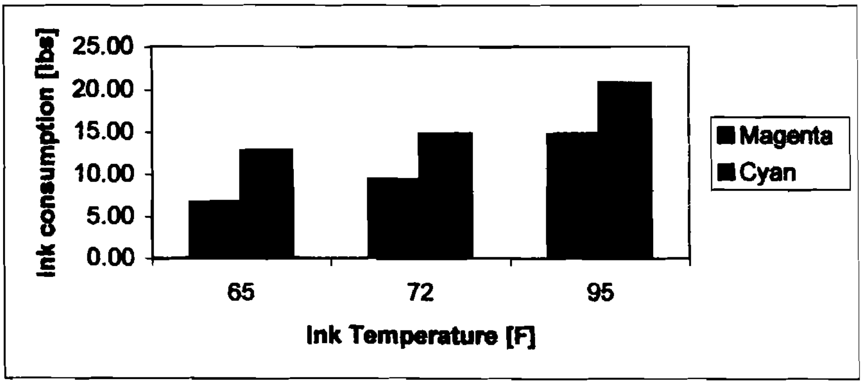


Figure 2. Cyan and magenta ink consumption

$$Ink_{cyan} = -0.003 * T^2 + 1.4484 * T - 35.5 \quad (3)$$

Table 3 represents the total solvent and ink consumption throughout the research trial. Shown in Tables 3, 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 refers to the previously discussed solvent consumption. The fourth column 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 six and 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 3 is another representation of the last column in Table 3. Figure 3 indicates, the total mass consumption for the two colors is almost the same at cold and normal temperature, but it 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, thus printing 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. This contrasts the percentage needed for hotter temperature, which is only 13.3% for magenta and 6.9% for cyan.

Table 3. Consumption of ink and solvent for magenta and 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)
Magenta						
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
Cyan						
Cold ink temperature	59.66	14.26	9.30	23.56	57.12	26.10
Normal ink temperature	73.71	3.58	11.16	14.72	59.80	28.63
Hot ink temperature	76.19	7.13	19.53	26.66	57.79	45.06

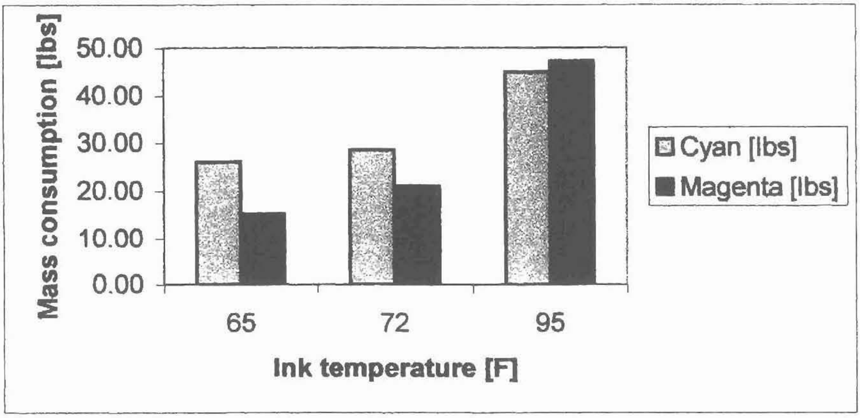


Figure 3. Total mass consumption for cyan and magenta ink (ink + solvent)

Reflection Density as a Function of Temperature

For this project, an X-Rite densitometer (Model #408) was used to measured reflection density. The sensitivity of the densitometer was 0.02% of reflection density. This means that any variation less than 0.02% was not 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 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 4 represents the total variation in cyan reflection density throughout the entire experiment. As gather from the graph, there is no major variation between the colder and normal temperature, but as the temperature gets warmer, the reflection density decreases. 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, 1999). 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. Consequently, 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 is defined as the period of time the web is in physical contact with the engraved cylinder (GAA, 1991). This drying causes a wettability problem of the ink on the substrate. In other words, 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. This is usually caused by high ink viscosity or ink that dries too fast (GAA, 1991). With screening, the shape of the cylinder cells shows up in the print. This results in a mix of white and dark areas, which compose most of the printed solids. As a result, the overall printed solid area is reduced and the reflection density decreases.

From Figure 4, the polynomial equation of the curve was calculated:

$$D = -0.0002 * T^2 + 0.0257 * T + 1.361 \tag{4}$$

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

Figure 4 indicates, the cyan density can be predicted as a function of temperature. Figure 4 demonstrates that the reflection density varies 0.09% of reflected light from the cold temperature to the normal temperature, but it 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. On average, the reflection density varies 0.055% of reflected light every 5°F. This result is somewhat different from Celios' result (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. It was concluded that the biggest effect of reflection density comes from a variation on ink temperature as it goes from normal temperature to a warmer temperature.

Specular Gloss as a Function of Temperature

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 was not registered. Figure 5 is a representation of the effects of ink temperature on specular gloss. As demonstrated in Figure 5, a higher portion of light is reflected from the thinner ink film, 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 was higher than the specular gloss of the image areas. As seen in Figure 5, 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 hot temperatures. Reflected light is a function of ink film thickness. As the ink becomes colder, it lays a thinner layer of ink film because there is a higher solvent to pigment concentration load. At the colder temperature, the specular gloss of the film approaches the gloss of the non-printed image, which is a higher value. From this graph 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 was less than 6%.

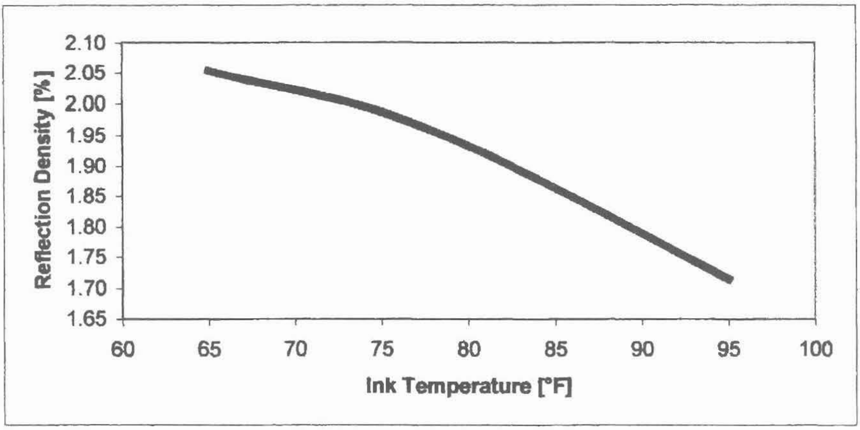


Figure 4. Cyan reflection density as a function of temperature

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 efflux time of the ink at the hotter temperature, although reduction in efflux time means more solvent consumption.

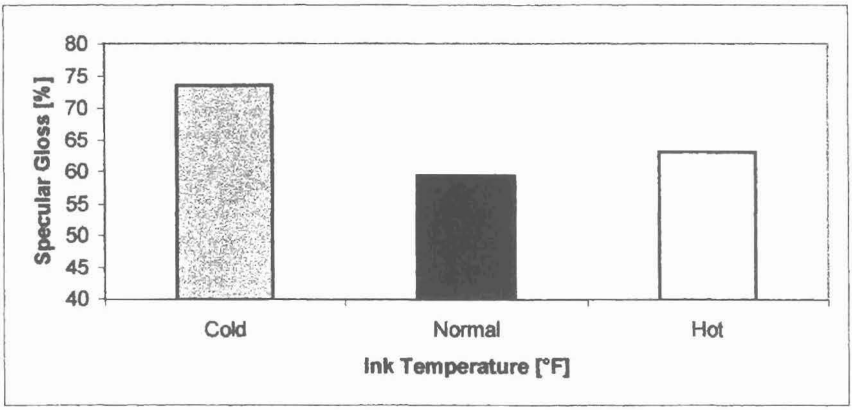


Figure 5. Variation of specular gloss as a function of ink temperature.

Tone Step Curve as a Function of Temperature

To compare the effects of ink temperature control on tone steps, the tone step values of every 20 minutes were averaged for a particular ink temperature. The total average of a particular ink temperature was compared to the total average of another ink temperature. Figure 6 shows the variation in reflection density for the tone steps in relation to the different ink temperatures. As shown in Figure 6, 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. From cold ink to normal ink, 50% of the tone steps (5 out of 10) were not affected. In other words, the reflection density was equal to or less than the accuracy of the instrument (0.02%). On the other hand, the changes from cold and/or normal ink to hot ink were significant. All of the tone steps (10 of them) changed 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. With lower tone steps 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.

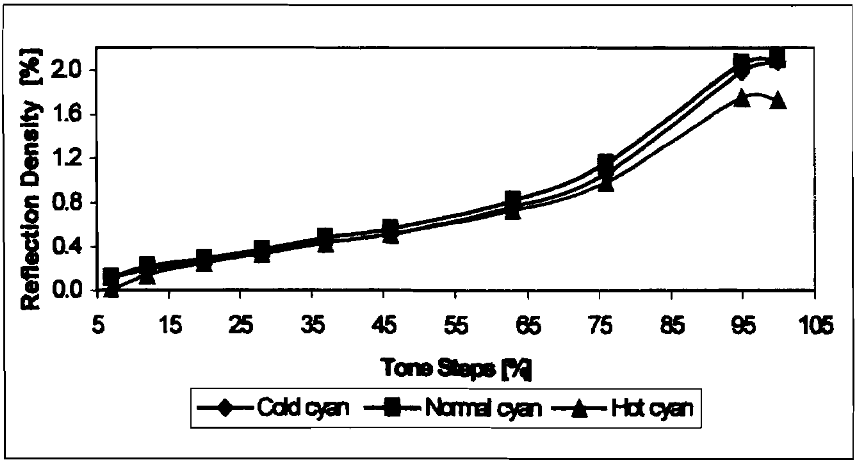


Figure 6. Cyan tone step curve for all ink temperatures.

Dot Structure as a Function of Temperature

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 trapped between the ink and the substrate. The air prevents the ink from being transferred to the middle of the printed dot; it forces the ink to be spread outward. As the ink gets warmer, it becomes less viscous and more fluid. A less viscous ink will produce a bigger concave meniscus shape on the cell, thus allowing more air to be trapped between the ink and the substrate (Ciucci, 1999). With more air trapped, the donut becomes bigger.

The air trapped between the meniscus and the substrate forces the ink outward creating another common printing problem in gravure known as bleeding (Ciucci, 1999). Bleeding can be defined as fine, hair-like lines that appear dragged from solid dot areas into non-printed areas. It was found that the bigger the donut effect, the bigger the bleeding effect on the dots. Figure 7 shows pictures taken at the 37% tone.

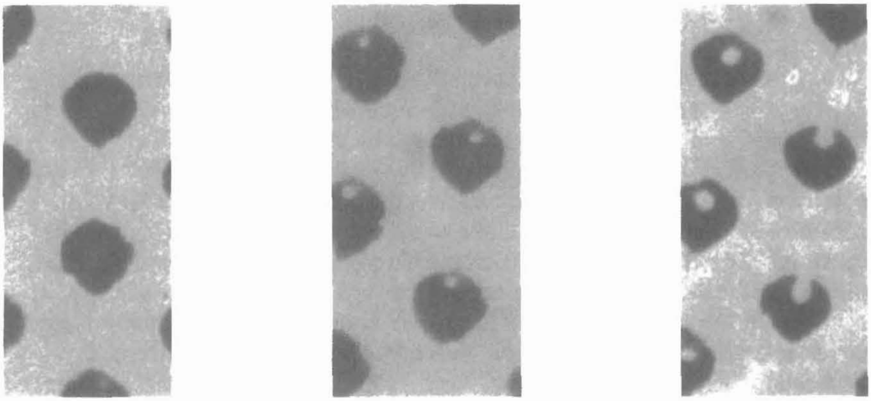
The image analyzer was also used to prove the effects of ink temperature control on wettability, which consequently affects reflection density. Figure 8 shows pictures taken on solid areas. As can be seen, the white, non-printed areas of the solids increase with increasing ink temperature. The white areas are portions of the substrate not covered by the ink film; indeed, they represent the cell shape of the printing cylinder. At the hottest 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, known as screening. This phenomenon reduces the overall reflection density of the color.

Figures 8 also show that the print at colder temperature results in lighter colors. On the other hand, the color at normal and hot temperature looks darker. 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.

Cost Analysis

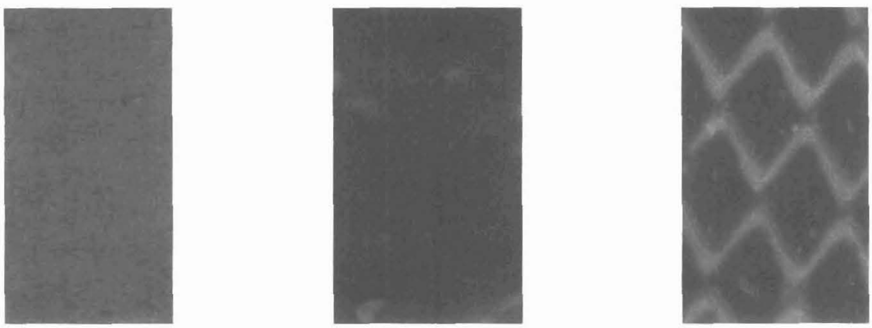
Solvent Cost

It is assumed that a production model consists of the following variables:
Size: 23 inches wide
Number of units: 6 colors
Production hours per year (EPA, 1998): 7200 hours/year



Cold Dot Normal Dot Hot Dot

Figure 7. Dot structure at different ink temperatures.



Cold Solid Normal Solid Hot Solid

Figure 8. Picture of cyan cold solids

Production rate: 300 fpm
Liner foot of production: 13,333 feet/hour or 96,000,000 feet/year

With this model, cost of solvent and ink consumption was calculated on a yearly basis. Figure 9 shows the cost of tons of solvent per year used in magenta, assuming a cost of $0.50/lb of solvent (Ciucci, 1999). As shown in Figure 9, 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.

The same calculations were considered for the cyan color. Figure 9 shows the cost of solvent consumption per year for cyan, assuming a cost of $0.50/lb of solvent (Ciucci, 1999). As seen in Figure 9, the cost increases with increasing temperature. Note that at the highest temperature, an extra $15,000/year per cyan color is spent. 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.

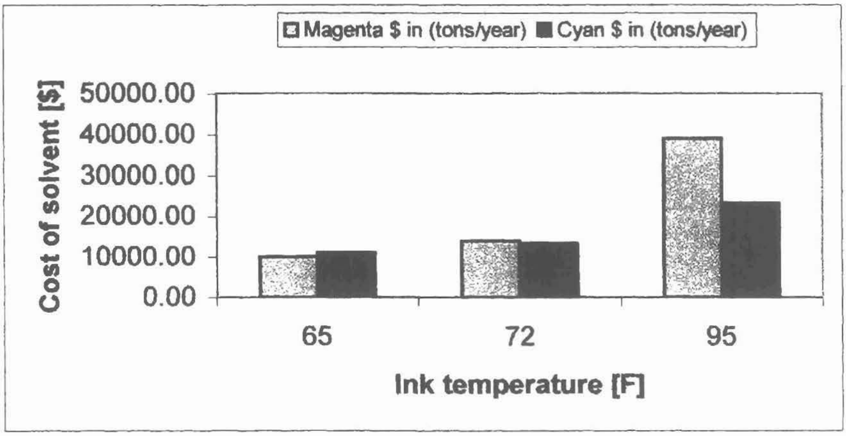


Figure 9. Cost of solvent used in magenta and cyan in a ton/year basis.

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 10 shows the cost of cyan and magenta on a ton/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 as compared to the cost at a 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 could 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, however 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 colors and $35,000 of solvent per 6 colors).

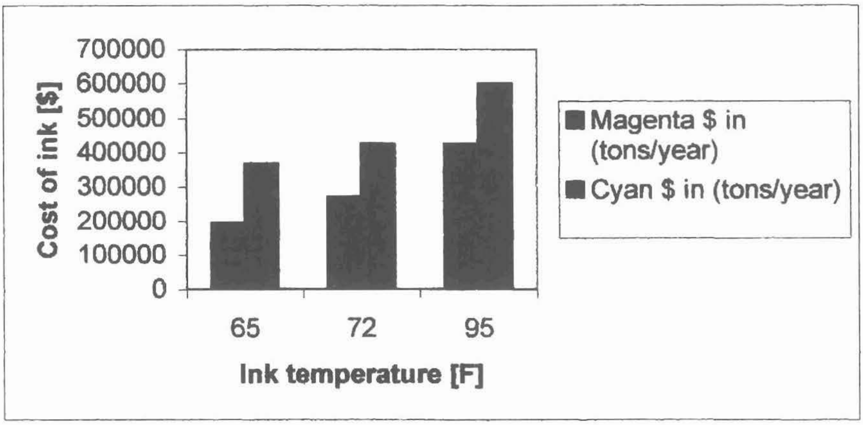


Figure 10. Cost of cyan and magenta ink

Conclusions

Based on this research project, the following conclusions were made:

1. 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 an ambient temperature of 72°F.
2. 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% by reducing the ink temperature from 95°F to an ambient temperature of 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 hotter temperatures demands more pigment and ink components, thus printing with a higher ink film thickness.
3. From the printability analysis, it was concluded that the biggest effect comes from wettability. At higher temperature, the ink dries faster preventing it from spreading outward on the substrate. Wettability causes reduction in reflection density due to screening. Reflection density decreases 0.055% of reflected light every 5°F.
4. Wettability also causes reduction 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.

5. Specular gloss was also affected by wettability. Screening changes the reflection of light from the instrument, thus it reduces the specular gloss. Specular gloss decreased 20% from cold to normal ink temperature.
6. One of the biggest effects of temperature control was on dot structure. It was found that higher ink temperature increases dot deformation. Higher temperature causes the ink to form a bigger meniscus on the engraved cell. With higher meniscus, there is more air trapped 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.
7. It was estimated that the model company would save approximately $250,000 a year in solvent consumption per press from reducing its temperature to a range close to ambient temperature.
8. It was estimated that the same model company would save approximately $60,000 to $70,000 a year on 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.

The wettability problems could be fixed by adjusting the viscosity of the ink at different temperatures. For example, this could be achieved by reducing the efflux time at the hottest temperature. Although a reduction in efflux time means more solvent consumption and more solvent evaporation, cost savings may become insignificant. An important conclusion from this part of the research is that temperature control measurements help control print quality because there are fewer viscosity fluctuations in the ink. At the range of temperature control selected, performing fingerprinting on the press can maximize the pigment to solvent ratio. This optimization of pigment/solvent ratios in addition to temperature control measurements can increase print quality dramatically.

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