INK CONSUMPTION IN ROTOGRAVURE - DETERMINING INK MILEAGE ON GRAVURE PUBLICATION PAPERS

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Keywords: Ink Mileage, Density, Wettability, Absorptivity, Porosity

Abstract: Gravure publication paper grades with different physical and chemical properties (porosity, contact angle) accept at the same printing conditions (ink viscosity, press speed, impression pressure, ESA- electrostatic-assisted ink transfer, etc.) different amounts of ink. Ink mileage for SCA grades is higher than that of LWC grades, while the printout reflection density of SCA is lower. The transfer of ink is further affected by press speed and ink viscosity. Ink transfer decreases with increasing press speed. It is difficult to predict the ink mileage by measuring optical properties alone, (reflection optical density, CIE L*a*b* values) - because of non-uniform absorption of the ink and ink hold-out. Parker Print Surf porosity of the substrate was found to be an excellent predictor of ink mileage. Absorptivity of the paper substrate was found to be linearly correlated with ink mileage and was determined to be the best parameter for predicting ink mileage.

INTRODUCTION

Ink transfer in rotogravure is a function of cylinder cell geometry. Publication gravure cylinders are engraved electro-mechanically. The process of electro-mechanical engraving, whereby an angled diamond stylus is dug into the rotating cylinder, gives rise to an inverted pyramid cell configuration (Smith, 1994).

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Cell shape is affected by the angular configuration of the cutting stylus. Screen resolution and screen angles are both independently controlled on the engraver. Horizontal screen and vertical screen controls adjust both screen resolution and screen angle. With the two screen controls set to be equal, the screen angle is 45°. The screen angle is controlled by modifying the vertical and horizontal spacing of the cell separately. Screen angles from 30 ° to 60 ° are common in electro-mechanical engraving (Fraser, 1993). However, the influence of cutting and screen angles on ink transfer and mileage is not yet clearly understood and needs further investigation.

Studies on ink mileage in gravure were done using various analytical methods such as colorimetry (Joyce and Fuchs, 1966), fluorescence (Takahashi, 1968), x-ray fluorescence (Birkett, 1973; Elsayad, 1975), neutron activation (Fernandez et al., 1970),and atomic absorbtion (George and Welch, 1978). However, these studies used unrealistic ink systems and were done at printing speeds less than 1.5 $m.s^{-1}$, which is much slower than commercial printing speeds. One study used higher speed of 3.5-8.5 $m.s^{-1}$, but it was done on an impulse press simulator, not a rotary gravure press (Jeske, 1990). Commercial publication rotogravure printing presses run in excess of 13 $m.s^{-1}$ (2500 ft/min). Speeds of state of the art commercial presses now exceed 15 $m.s^{-1}$ (3000 ft/min). For this reason, there is a need to study ink mileage at more realistic speeds and to do so at real gravure presses.

An ink mileage curve was defined as a plot of the printed optical density of an ink on a given substrate as a function of the ink film thickness (Chou and Harbin, 1991). Optical density initially increases with ink film thickness and eventually levels off. The maximum optical density achievable by an ink is termed saturation density. However, ink mileage is generally defined as the area which may be printed with one gram of ink yielding a solid print with the target optical density (Kornerup et al., 1969). The ink mileage definition needs to be completed and corrected because of different behaviors of ink on varying paper substrates.

The objective of this work was to focus on ink transfer at changing press speed, to study the effect of physico-chemical properties of paper substrates on ink transfer and mileage, and to develop a predictive model of ink consumption by simply measuring selected paper characteristics.

EXPERIMENTAL

Paper substrates

The following five paper substrates were used in this study:

Supercalendered	SCA	4.55 $g.m^{-3}$
Matte Coated #4	MC	7.23 $g.m^{-3}$
Light Weight Coated	LWC-A #5	4.50 $g.m^{-3}$
Light Weight Coated	LWC-B #5	4.59 $g.m^{-3}$
Light Weight Coated	LWC-C #5	5.92 $g.m^{-3}$

Printing procedure

A Cerutti pilot rotogravure web printing press (Cerutti Model 118, Casalmonferrato, Italy) was used to print test samples at press speed of 5 $m.s^{-1}$ (1000 ft/min) to 2 $m.s^{-1}$ (400 ft/min). Two electromechanical engraved gravure cylinders with various volumetric and cell configurations were used. Oven dryers were set to 60 °C at 9000 cfm nozzle velocity. All experiments were run without electrostatic assist. Impression roll dynamics were set at 125 pli at 3/8 nip flat with an 85 Durometer (Shore A) roller. Group VI toluene ink was selected. Efflux time ("printing viscosity") was in the range of 37 seconds to 17 seconds on a Shell #2 efflux cup for black ink. The solids content of the ink was 41.4 - 31.3 % due to changing viscosity.

Gravimetric evaluation of coating weight

The exact size of shadow printed and unprinted areas were cut and weighted with 1.10^{-4} grams accuracy using analytical balances. Printed and unprinted areas were measured and coating weight was expressed in $g.m^{-2}$.

Porosity, roughness and compressibility

A Parker Print-Surf Model ME 90 (Messmer Instruments Ltd., U.K) was used for both porosity and roughness measurements. An EMVECO stylus profilometer was also used for smoothness determination. Porosity was measured using a clamping pressure 500 kPa; roughness was measured at 500 and 1000 kPa. The compressibility was calculated as the ratio of the roughness at 500 kPa and 1000 kPa clamping pressure.

Contact angle

The contact angle of paper samples was measured using a Fibro 1121/1122 DAT Dynamic Contact Angle and Absorption Tester (FIBRO System AB, Stockholm, Sweden). Contact angles of toluene solution with resin varnish at 5 % w/w (Resinol R-127) were measured at 0.1, 0.25, and 0.5 second.

CIE L*a*b* spectral values

CIE L*a*b* values were measured using a Datacolor International colorimeter, equipped with large aperture. Calibration was done with specular gloss included. Each reported value was the average of 10 measurements.

RESULTS AND DISCUSSION

Substrates and Engravings

The main purpose of this study was to find paper properties or parameters useful for predicting ink mileage or ink coating weight. Three LWC #5, one SCA, and one Matte coated #4 gravure publication papers were used in this study. Some of their physico-chemical properties are described in the **Table 1**.

Table 1: Paper grades used in ink mileage determination (Compr. = Compressibility, CA = contact angle, measured at 0.1 s)

SAMPLE	Porosity at 500kPa [ml/min]	Roughness at 500 kPa [μ]	Roughness at 1000 kPa [μ]	Compr. R_{500}/R_{1000}	CA 0.1 s [deg]
(SCA)	42.36	1.44	1.17	1.23	20.9
(MC)	14.2	2.10	1.24	1.69	15.6
(LWC-A)	8.64	1.34	0.95	1.41	19.2
(LWC-B)	10.06	1.55	1.12	1.38	18.0
(LWC-C)	6.84	1.17	0.88	1.31	20.3

The data in **Table 1**. show porosity as being the most significant difference between paper grades. The gravure cylinder geometry specifications are listed in **Table 2**. The cell volumes were calculated to be between 1.5×10^5 μ^3 and 3×10^5 μ^3, with screen angles of 30^0, 40^0, and 60^0. The image on the cylinder was comprised of solid shadow areas only.

Table 2: Characteristic of gravure cells used for mileage determination.
* Estimated angle. (LPI= Lines per square inch)

Engraving	LPI	Compression Angle [deg]	Volume [μ^3]
I	175	40	$2.938.10^5$
II	175	60	$3.003.10^5$
III	200	30	$1.683.10^5$
IV	175	40*	$2.773.10^5$
V	200	40*	$1.496.10^5$

Theoretical coating weights were calculated for all engravings used and are listed in **Table 3**. Actual coating weights were determined using a gravimetric method. The transfer efficiency was determined as the ratio of actual to theoretical coat weight. The efficiency was determined at one paper substrate for engravings I-III and at different paper substrate for IV-V engravings. Also, ink solids were constant for I-III engraving and different for IV and V. Therefore, only preliminary evaluation of ink transfer due to cell geometry is possible and it shows that the elongated cells produce the best ink transfer. However, these preliminary results also indicate that the ink viscosity, press speed, and gravure cell geometry play an important role in the ink transfer.

Table 3: The comparison of theoretical and real coating weight for engraving I-III at press speed of 800 $ft.min^{-1}$ and for engraving IV and V at 1000 $ft.min^{-1}$. Engravings I-III were tested on the same paper substrate (LWC-C). Engravings IV-V were tested on various paper substrates. (Eng. = Engraving, LPI= Lines per square inch).

Eng.	LPI	Theoretical coat "volume" [$cm^3.cm^{-2}$]	Theoretical coat weight [$g.cm^{-2}$]	Actual coat weight [$g.cm^{-2}$]	Efficiency [%]
I	175	$1.395.10^{-3}$	$5.774.10^{-4}$	$3.90.10^{-4}$	67.54
II	175	$1.425.10^{-3}$	$5.898.10^{-4}$	$4.66.10^{-4}$	79.01
III	200	$1.043.10^{-3}$	$4.317.10^{-4}$	$2.97.10^{-4}$	68.79
IV	175	$1.317.10^{-3}$	$4.820.10^{-4}$	$1.59.10^{-4}$	32.98
V	200	$0.927.10^{-3}$	$3.393.10^{-4}$	$1.13.10^{-4}$	33.30

Specific gravity of solvent based ink approx. = 1 $g.cm^{-3}$. Solids content on engravings: I-III = 41.39 %, and IV-V = 36.60 %. Theoretical coating volume is volume of solids and solvents (toluene). Theoretical coating weight excludes toluene, and it was calculated at the ink solids of 41.4%.

Mileage and Optical Density

Ink mileage is generally defined as the area which may be printed with one gram of ink yielding a solid print with the target optical density (Kornerup et al., 1969). However, we found that at different paper substrates at the same or very similar ink mileage different printout density will be achieved (**Fig. 1**). As can be seen from **Fig. 1**, substantial differences in printout density occur between different paper grades: light weight coated grades achieve higher optical density at lower ink mileage than supercalendered. However, standard densitometry did not measure accurately enough differences in coating weight.

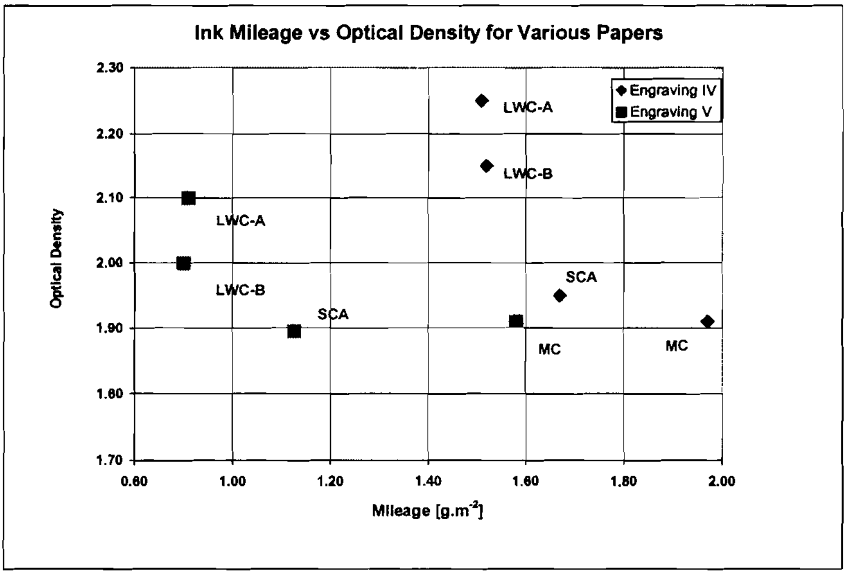

Figure 1: Influence of ink mileage (coat weight) on optical density for various paper grades: supercalendered SCA, matte coated MC, and light weight coated LWC-A, and LWC-B. Two different engravings, IV and V, were studied.

Mileage and Press Speed

First, the effect of press speed on ink coat weight, or ink mileage, at one paper grade (LWC-C) was tested (**Fig. 2** and **Fig. 3**). **Fig. 2** shows decreasing ink mileage (measured by gravimetry) with increasing press speed from 200 $ft.min^{-1}$ to 800 $ft.min^{-1}$ for four different types of engraving. Also CIE L* value decreases with increasing press speed (**Fig. 3**) which shows that there exists some relationship between L* value and coat weight or ink mileage.

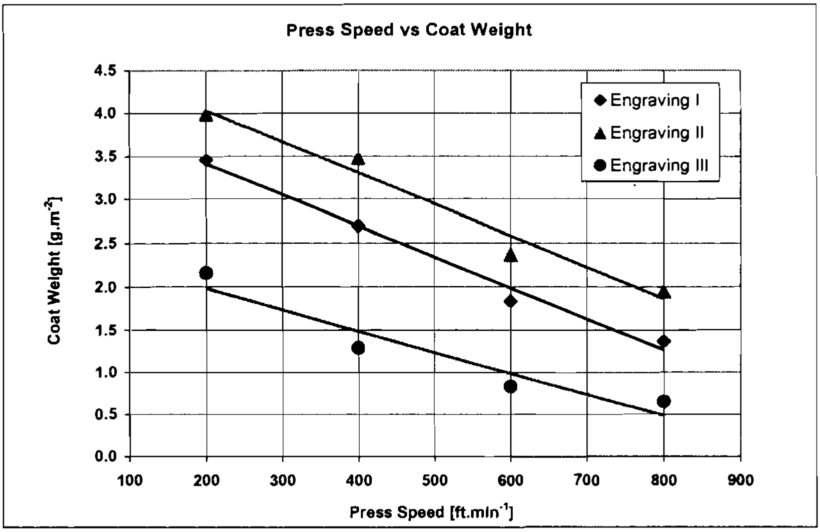

Figure 2: Gravure press speed versus ink mileage (coat weight) for three different engravings, I, II, and III. Experiments were done on a LWC-C paper grade. Ink solids were 31.3%.

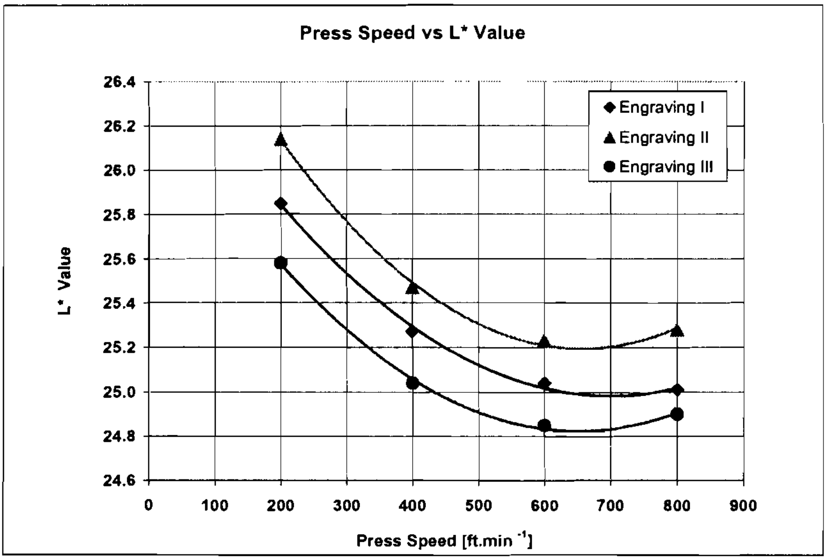

Figure 3: Gravure press speed versus CIE L* value for three different engravings, I, II, and III. Experiments were done on a LWC-C paper grade. Ink solids were 31.3%.

All coat weights were plotted against their L* values (**Fig. 4**). A linear correlation was found between L* and coat weight with a correlation coefficient of R = 0.87.

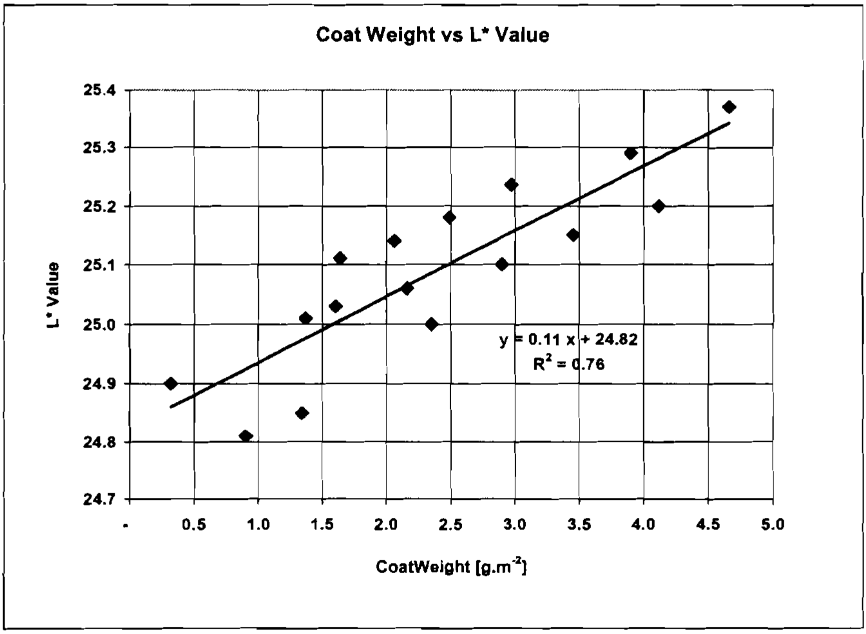

Figure 4: Correlation between ink mileage (coat weight) and CIE L* value for engravings I-III. Experiments were done on LWC-C paper grade. Ink solids were 31.3%.

Different paper grades (SCA, MC and LWC) were tested for correlation between ink mileage and L* value (**Fig. 5**). The correlation between L* values and coat weight was lower in the case of different paper substrates (**Fig. 5**) than with only one paper substrate (**Fig. 4**), where a correlation coefficient R=0.68 was found. In this case, CIE L*a*b* does not have sufficient resolution between paper substrates, most likely because of paper porosity differences.
As paper porosity increases, ink penetration increases resulting in fiber (or coating) visible on the surface significantly altering L* values. Primarily for these reasons, it was decided not to use optical properties (density and CIE L*a*b*), but to develop useful methods which can predict more reliably ink mileage.

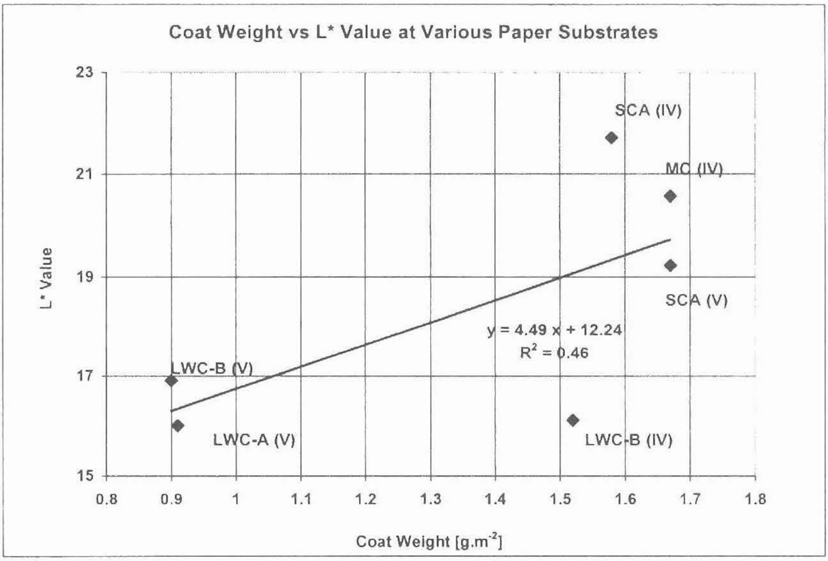

Figure 5: Correlation between ink mileage (coat weight) and CIE L* value for engravings IV and V and four different paper substrates SCA, MC, LWC-A, and LWC-B. Ink solids were 36.6 %.

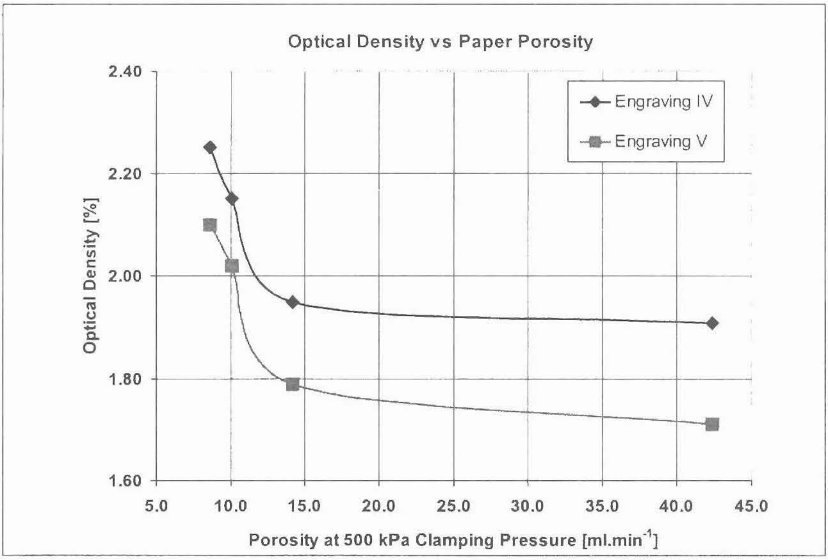

Figure 6: Optical reflection density for engravings IV and V and four paper substrates SCA, MC, LWC-A, and LWC-B. Ink solids were 36.6%.

Mileage , Porosity, and Absorptivity

It was determined that optical density decreases with increasing paper porosity if all other parameters (press speed, ESA, cylinder engravings, ink solids) stay constant (**Fig. 6**). However, ink transfer is increased with increasing porosity, which is indicated by higher ink coat weight (or ink mileage) of the supercalendered and matte coated substrate (**Fig. 7**). Therefore, the porosity of unprinted substrates can be used for quick prediction of ink mileage. Compressibility was found not to correlate well with the ink transfer (data not

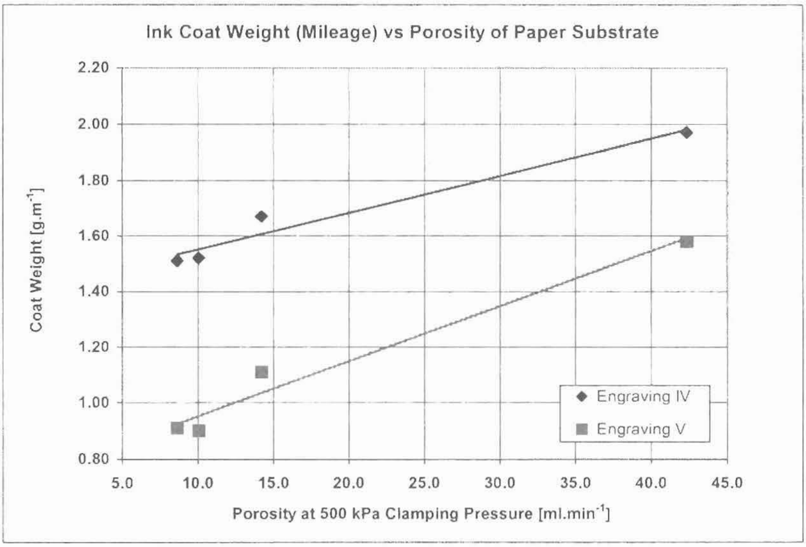

Figure 7: Ink mileage (coat weight) versus porosity of paper substrates. Four different paper substrates SCA, MC, LWC-A, and LWC-B were tested. Ink solids were 36.6 %.

shown). Also, the contact angle with toluene varnish at a constant, specified time (0.1 s) did not to correlate with ink transfer or mileage (data not shown). However, further investigation found that the linear regression as plotted through the function of contact angle versus time (**Fig. 8**) was a reliable predictor of ink mileage for all paper substrates.

The slope of the wetting curve was then used to determine absorptivity. The steeper the slope, a ($y=ax+b$), the faster the decrease in contact angle, which shows that absorptivity is greater. It was found that significant differences in absorptivity of paper substrates with toluene varnish (**Fig. 8**) occur.

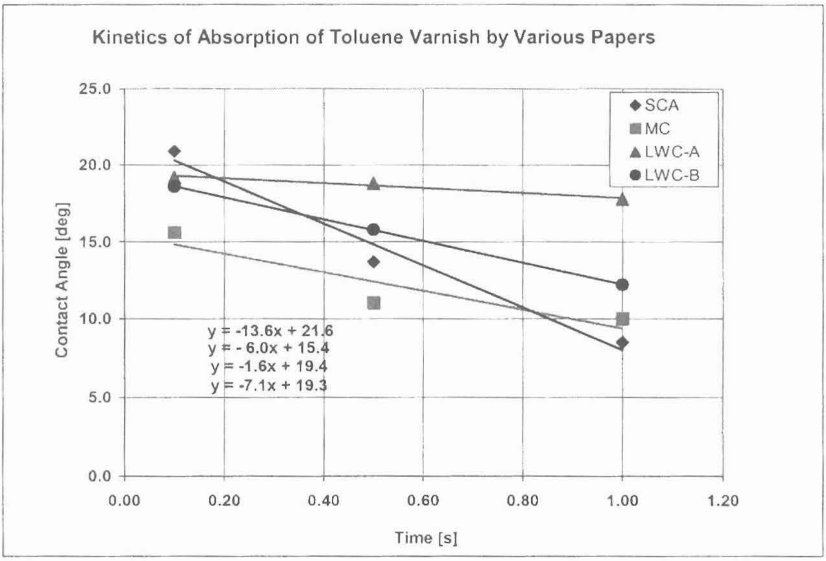

Figure 8: Kinetics of absorption of toluene varnish on four different paper substrates SCA, MC, LWC-A, and LWC-B. (Contact angles of toluene varnish containing 5 % w/w resin Resinol R-127 were gathered at 0.1, 0.25, and 0.5 seconds.)

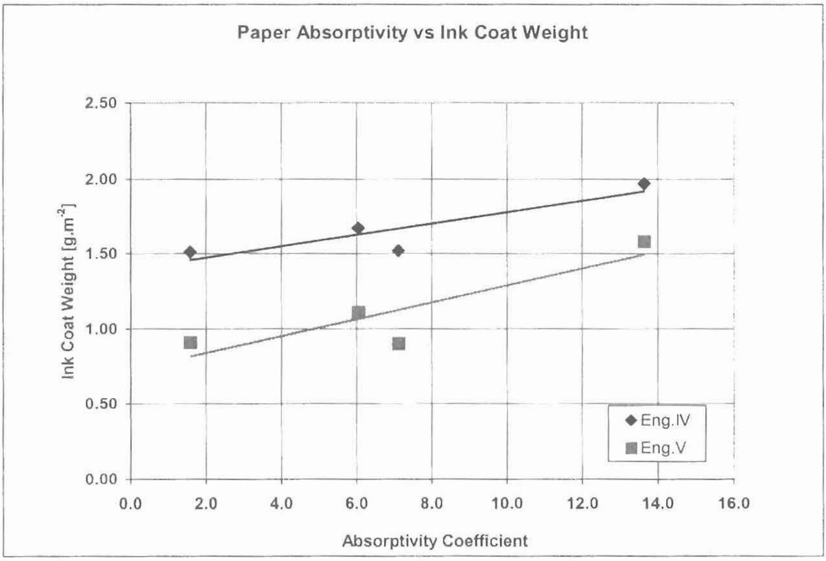

Figure 9: Correlation between paper absorptivity and ink mileage for engravings IV and V and on four different paper substrates SCA, MC, LWC-A, and LWC-B.

The absolute value of the slope, **a,** was defined as the absorptivity coefficient (***a***). The absorptivity coefficient was plotted against ink coating weight for two types of engraving, IV and V (**Fig. 9**). It was found that ***a*** is linearly, positively correlated to ink coat weight, or mileage. Therefore, the ***a*** can be used for predicting the ink mileage.

CONCLUSION

This study shows that conventional reflection densitometry is not adequate to evaluate ink mileage. When conditions remain constant (cylinder engraving, ESA, impression pressure, press speed, ink viscosity), density decreases with increasing substrate porosity. CIE L*a*b* colorimetry is linearly correlated with coat weight or ink mileage only if one substrate type is used for comparison. CIE L*a*b* does not have sufficient resolution when more than one substrate is used. Ink mileage increases with increasing paper porosity. Therefore, paper porosity can be a useful measure for predicting ink mileage. Contact angles of toluene varnish with paper substrates were determined. The decrease of contact angle with the time (if occurs) caused by paper absorptivity was determined for each paper substrate as a slope of regression function of contact angle versus time. This absorptivity coefficient is linearly correlated with ink mileage and was shown to be a useful tool for ink mileage prediction. Our future work in this area will investigate in more detail the relationship between gravure cell geometry and ink transfer.

ACKNOWLEDGEMENT

Financial support for this work from the GenCorp Co., Akron, OH, is gratefully appreciated.

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