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An analysis of wet-on-wet trapping using the Walker and Fetsko ink transfer equation

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MASTER'S THESIS

This is to certify that the Master's Thesis of

Sam J. Powell

With a major in Printing Technology
has been approved by the Thesis Committee as
satisfactory for the thesis requirement for the
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September, 1987

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AN ANALYSIS OF WET-ON-WET TRAPPING USING THE WALKER AND FETSKO INK TRANSFER EQUATION

by

Sam J. Powell

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
School of Printing Management and Sciences in the
College of Graphic Arts and Photography
of the Rochester Institute of Technology.

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Thesis Advisors:

Dr. Julius L. Silver

and

Professor Joseph E. Brown

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October 12, 1987

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ABSTRACT

In this thesis the Walker and Fetsko ink transfer equation was used as an analytic tool to determine how the physical properties of the transfer surface change from printing on unprinted paper to overprinting on another wet ink film. The equation has three parameters, b, k, and f, which indicate what is happening in the nip of the press during the moment of impression. Parameter b represents the maximum absorptive capacity of the paper, parameter k is highly reflective of printing smoothness, and parameter f represents the fraction of free ink film which splits to the paper surface. The I.G.T. Printability Tester was used to simulate the wet-on-wet trapping which occurs on a lithographic press. Heatset inks and uncoated paper were used to conduct the testing.

Application of the equation to the experimental data showed that the surface in wet-on-wet trapping is less absorbent, smoother, and increases the fraction of free ink film which splits to the paper in comparison to the surface of the unprinted paper. The first two observations are explained simply by considering that in wet-on-wet trapping the paper porosity and the low spots on the paper surface are filled by the first-down ink film. The third observation regarding parameter f is explained by considering a model in which the ink film cavities expand and the ink film ruptures more readily in areas of high vehicle concentration and low viscosity. In printing to the unprinted paper the vehicle drains more quickly into the paper than the pigment particles due to its lower viscosity and lower molecular weight. Thus

there is a higher concentration of vehicle nearer the paper surface, causing the split to occur here. On the other hand, the surface in wet-on-wet trapping at the moment the second ink film is transferred is not very absorbent. Therefore, the vehicle does not drain that quickly into the surface, causing the viscosity of the ink film to be the same throughout, which tends to create a fifty percent split.

CHAPTER 1

INTRODUCTION AND STATEMENT OF THE PROBLEM

Traditionally, the topic called 'ink trapping' concerns how much ink overprints to another ink film relative to the unprinted paper. This is evidenced by considering the Frank Preucil percent trap formula, which is based on the assumption that the densities of transparent ink films are additive.

D1= density of first down ink film read through the complimentary color filter of D2.

D2= density of second down ink film read through its complimentary color filter.

D3= density of the overprint of D2 and D1, read through the complimentary color filter of D2.

Figure 1. Model for Frank Preucil percent trap formula.

Based on the model given in figure 1, percent trap is given by the equation:

$$\% \text{ Trap} = \frac{D2}{D3-D1} \times 100$$

This equation is commonly used by the lithographic industry to evaluate what Frank Preucil called 'apparent trap.'[1] The trap is usually evaluated in this way, though the computations rarely correlate with the actual amount of ink trapped by weight due to the failure of the ink layer densities to be additive.[2] The apparent trap, however, is critical to process color reproduction. The additivity failure of the ink layer densities has been examined in detail by Clapper and Yule.[3] However, little attention has been paid to the physical differences between ink transfer to unprinted paper as opposed to overprinting the ink on another wet ink film, which is commonly called wet-on-wet trapping.

Wet-on-wet trapping in offset lithography depends on there being a tack difference between the first and second inks down. Tack is a measurement which reflects the amount of force required to split an ink film. If less force is required to split the second-down ink film as compared to the first, then trapping will be achieved. The fact that trapping has been achieved does not reflect the amount of ink which has been overprinted relative to the unprinted paper. Tack differences do not reflect how the ink receptivity characteristics of the paper, at the moment of impression, change from unprinted paper to printing on another wet ink film.

Statement of the Problem

The problem undertaken by this thesis research will bring some insight into how the ink transfer characteristics change, at the moment of impression, from printing on white paper to printing on another wet ink film. The influence which adding a solvent to reduce the ink viscosity has on the transfer characteristics at the moment of impression was also examined. The Walker and Fetsko ink transfer equation was used as an analytic tool to determine how the characteristics change from printing on white paper to printing on another wet ink film. The equation has been shown to be applicable to heat-set inks which are used in web offset printing in a thesis study completed in the School of Printing Management and Sciences.[4] The full Walker and Fetsko ink transfer equation is presented below:

$$y=(1-e^{-kx})\{b(1-e^{-x/b})+f[x-b(1-e^{-x/b})]\}$$

where:

y= ink film thickness transferred to paper.

x= initial ink film thickness available on the plate.

b= immobilization parameter, maximum absorptive capacity of the paper.

k= paper smoothness parameter.

f= ink film splitting parameter.

e= base of the natural logarithms, approximately 2.718.

With a set of experimental values for x and y, the parameters b, k, and f are adjusted so that the equation accurately predicts y values which correlate with the experimental y values. The three parameters b, k, and f are then indicative of what is happening in the nip of the press during the moment of impression.[5]

Footnotes for Chapter 1

[1] Frank Preucil, "Color and Tone Errors in Multicolor Presses," Technical Association of the Graphic Arts Proceedings (1958): 176.

[2] J. A. C. Yule and F. R. Clapper, "Additivity of Ink Densities in Multicolor Halftone Printing," Technical Association of the Graphic Arts Proceedings (1956): 153.

[3] Yule, "Additivity of Ink Densities," 153.

[4] Dein Wang, "An Investigation of the Applicability of the Walker and Fetsko Ink Transfer Equation on and the Influence of Ink Viscosity on the Heat Set Inks Used in the Web Offset Process," (Master's Degree Thesis, Rochester Institute of Technology, 1987), 57.

[5] William C. Walker and Jacqueline M. Fetsko, "A Concept of Ink Transfer in Printing," Technical Association of the Graphic Arts Proceedings (1955): 141.

CHAPTER 2

BACKGROUND THEORY

When William Walker and Jacqueline Fetsko studied ink transfer in relationship to print quality, they found that a characteristic curve shape resulted when percent ink transfer was plotted as a function of initial ink film thickness available on the printing plate. At low levels of available ink film thicknesses the percent transfer is low due to an incomplete contact between the paper and the ink film, but quickly rises to a maximum. After maximum percentage transfer is reached, the curve decreases and asymptotically approaches a limiting value which is determined by the ink film splitting behavior at the moment of impression.[1] These findings generally agree with those of other investigations done in this area, including work with newsprint at the Institute of Paper Chemistry.[2] The typical percent transfer curve shape is sketched in figure 2.

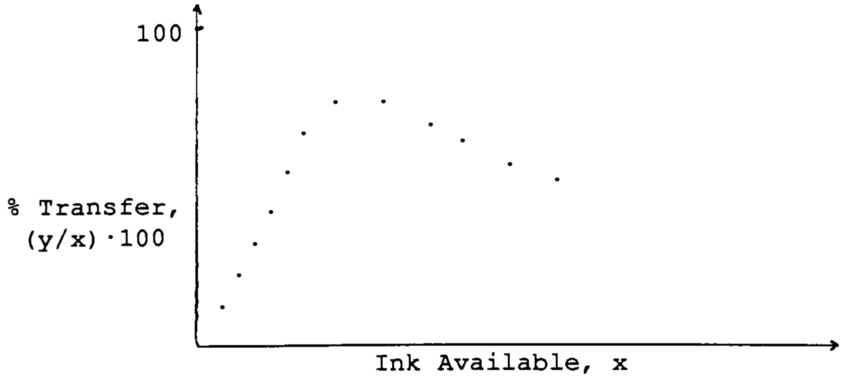


Figure 2. Typical percent transfer curve shape.

Through analysis of the data and the resulting curve shapes, Walker and Fetsko formed a physical picture of what happens in the nip of the press during the moment of impression. During this brief moment the paper absorbs part of the ink film. The portion of the ink film which is not absorbed splits between the printing plate and the paper surface. The amount of ink absorbed by the paper reaches a maximum value at high x values, at which point the curve of y (ink transferred) plotted as a function of x (ink available) becomes linear. From this physical picture Walker and Fetsko derived their ink transfer equation.

Deriving the Equation

The starting point for deriving the final ink transfer equation is the following simple equation:

$$y=F\cdot Y$$

y= ink film thickness transferred to paper.

F= fractional contact area between the ink film and the paper surface.

Y= ink film thickness transferred in the area of contact.

A. Expression for F.

Fractional contact area is dictated by the smoothness of the printing paper. Walker and Fetsko found that the function $(1-e^{-kx})$, illustrated in figure 3, represented the fractional contact area quite well. Parameter k increases with smoothness[3].

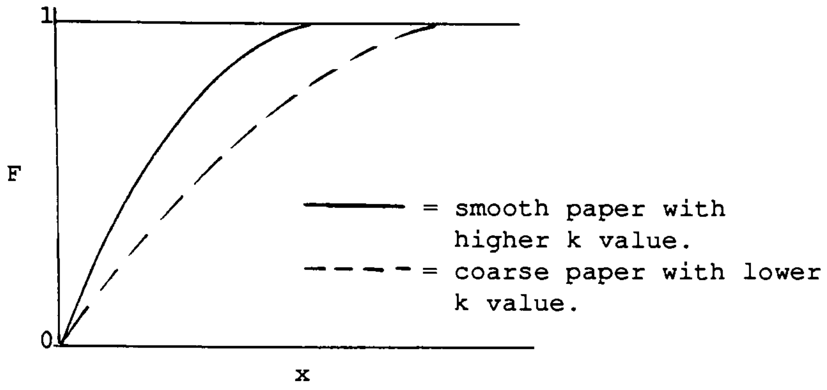


Figure 3. Fractional contact area as a function of available ink film thickness.

B. Expression for Y.

William Walker explains the derivation of the expression for Y based on the physical picture of the ink film split where the ink film contacts the paper. William Walker is quoted directly in explaining the derivation of an expression for Y, where he is referring to figure 4, which was copied from his paper:

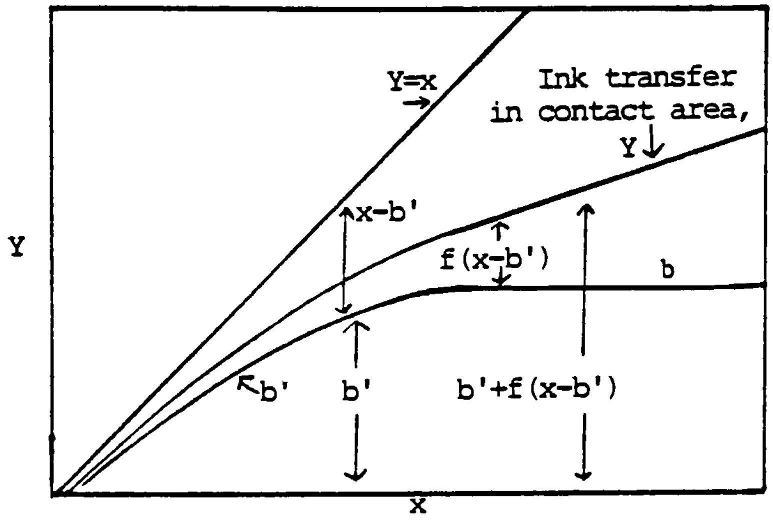


Figure 4. Visualized ink transferred per unit of contact area as a function of ink film thickness.

First, the line Y=x in this graph would represent the situation if all of the ink in the contact area were transferred to the paper. Certainly no more ink than this can ever be transferred. Second, the line marked "b" represents the capacity of the paper surface to immobilize the ink. When ample ink is available, less may be effectively immobilized. Thus, the amount of ink immobilized as the ink film thickness on the plate increases follows a curve such as the one marked b' (function of b) in figure 4. As the amount of ink on the plate increases, b' increases until it reaches its maximum value, b.

To complete "Y", the total ink transferred in the contact areas, it is necessary to consider the split of the excess or free ink which is not immobilized at the paper surface. The excess ink of the free ink is transferred, of f(x-b'). Thus, the total ink transferred is the sum of the two quantities: the ink immobilized plus a constant percentage of the free ink. When this picture is expressed mathematically, the following equation is obtained:

$$Y=b'+f(x-b') \qquad \text{Equation 1}$$

The function which has been found to represent b' most adequately to date is:

$$b' = b(1-e^{-x/b}) \qquad \text{Equation 2}$$

Substituting Equation 2 into Equation 1 gives:

$$Y = b(1-e^{-x/b}) + f[x-b(1-e^{-x/b})]$$

Substituting the derived expressions for F and Y gives the final ink transfer equation:

$$y = (1-e^{-kx})\{b(1-e^{-x/b}) + f[x-b(1-e^{-x/b})]\} \qquad 4$$

Solving for the Transfer Parameters

A. Parameters b and f.

At high values of x the logarithmic expressions for F and b' become very close to one, thus for all practical purposes reducing the equation to the linear form:

$$y = b + f(x-b)$$

Rearranging gives:

$$y = b(1-f) + fx$$

Using this form of the equation, parameters b and f can be solved from the experimental data at high levels of available ink film thickness. To achieve this it is best to plot the experimental data in the form of y as a function of x, as in figure 5.

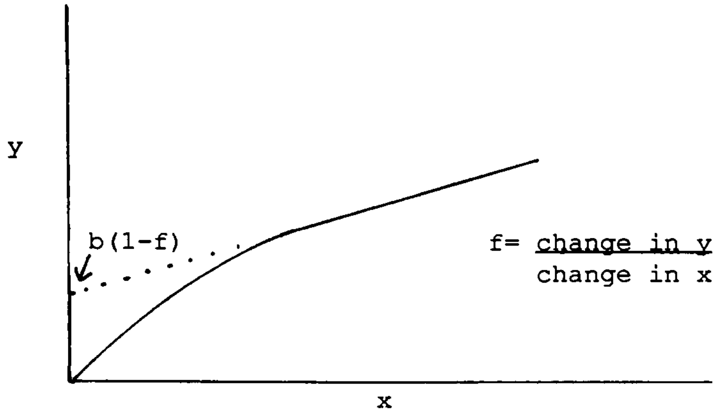


Figure 5. Using the linear model at high x values to solve for parameters b and f.

The y-intercept is interpolated from the straight line portion of the curve in figure 5, while the slope of this line is used as parameter f.[5]

B. Parameter k.

Once values have been obtained for the b and f parameters, parameter k can be obtained using the experimental data at low x values. Rearranging the full ink transfer equation to solve for k gives:

$$k=\frac{-\ln(1-y/Y)}{x}$$

The technique employed by Walker and Fetsko was to solve for k at a number of ink film thicknesses, then to use the average as the k value for the final calculations.[6]

Applications of the Parameters

The parameters b, k and f obtained for the Walker and Fetsko ink transfer equation for a set of experimental data indicate what is happening in the nip of the press during the moment of impression. Parameter k is indicative of the substrate smoothness and was found to correlate well with other tests of smoothness. Parameter b is the maximum absorptive capacity of the paper under the specific printing conditions. The development of this equation allowed investigators, for the first time, to determine how much ink is being absorbed by the paper at the moment of impression. Parameter f represents the splitting action of the free ink film. Walker and Fetsko investigated the effects of varying the printing conditions on the tranfer parameters. The variables they investigated were: printing speed, pressure, and ink viscosity. Their results are outlined below.[7]

A. Influence of printing variables on parameter k.

    1. Increased printing pressure was found to increase k in a given stock due to the paper being compressed and made effectively smoother at the moment of impression.[8]

    2. Decreased printing speed was found to increase k slightly because with a longer dwell time in the nip the paper has more time to flatten out.[9]

B. Influence of printing variables on parameter b.

    1. Parameter b is highly dependent on the paper stock, with uncoated stocks giving high b values and coated stocks giving low b values.[10]

2. Ink viscosity has a greater effect on b than any other printing variable. Parameter b decreases sharply with increased viscosity.[11]
3. Increased dwell time in the nip (decreased printing speed) was found to increase parameter b.[12]
4. Increased printing pressure was found to increase parameter b.[13]

C. Factors influencing parameter f.

At the time Walker and Fetsko conducted this investigation parameter f was the least understood. Parameter f was found to increase slightly with printing pressure and increase slightly with decreasing ink viscosity. The most significant variable influencing parameter f is some property related to the paper which at the time was not clearly understood.[14]

Discussion of Viscosity

The ink viscosity was found to be an important variable regarding parameter b.[15] Viscosity is a property which can be discussed in relationship to all fluids, since they possess a resistance to change in form with force, as governed by internal structural properties such as the attraction the particles have for each other. The unit of measurement for viscosity is defined by the equation:

$$\text{viscosity} = \frac{fd}{va}$$

The expression fd represents work, or force multiplied by distance, given by the unit $(\text{gm})(\text{cm}^2)/\text{sec}^2$. The expression va represents volume (centimeters per second) multiplied by area (square centimeters), in combination giving the expression cm^3/sec. When the expressions for *fd* and *va* are substituted into the equation, it reduces to gm/(cm)(sec), or one poise, the common unit for measuring viscosity.[16]

Viscosity of Lithographic Inks

Lithographic inks are non-Newtonian in nature, meaning that the relationship betweeen *fd* and *fa* is non-linear, however the relationship becomes linear at higher *fa* values.

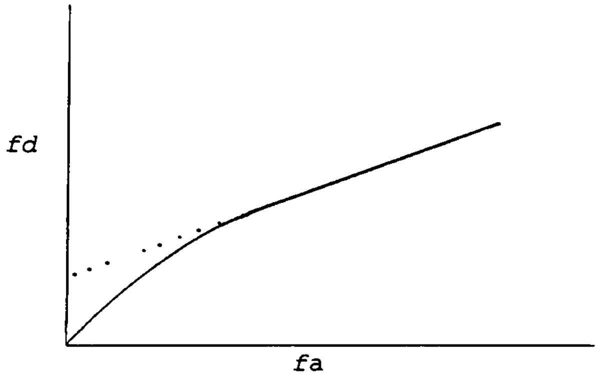


Figure 6. Flow curve for lithographic inks.

The viscosity is defined as the slope of the straight-line portion of this curve, and the theoretical yield value is the y-intercept interpolated from the straight-line portion.[17]

Footnotes for Chapter 2

[1] Jacqueline M. Fetsko and William C. Walker, "Measurements of Ink Transfer in the Printing of Coated Papers," Technical Association of the Graphic Arts Proceedings (1955): 130.

[2] G. R. Sears, N. J. Beckman, J. O. Thompson, and I.L. Yurkowitz, "A Study of some Ink-Paper Relationships," Technical Association of the Graphic Arts Proceedings (1952): 62.

[3] William C. Walker and Jacqueline M. Fetsko, "A Concept of Ink Transfer in Printing," Technical Association of the Graphic Arts Proceedings (1955): 141.

[4] Walker, "A Concept of Ink Transfer," 142.

[5] Walker, "A Concept of Ink Transfer," 143.

[6] Walker, "A Concept of Ink Transfer," 143.

[7] Walker, "A Concept of Ink Transfer," 145.

[8] Walker, "A Concept of Ink Transfer," 145.

[9] Walker, "A Concept of Ink Transfer," 145.

[10] Walker, "A Concept of Ink Transfer," 146.

[11] Walker, "A Concept of Ink Transfer," 146.

[12] Walker, "A Concept of Ink Transfer," 146.

[13] Walker, "A Concept of Ink Transfer," 146.

[14] Walker, "A Concept of Ink Transfer," 147.

[15] Walker, "A Concept of Ink Transfer," 146.

[16] Isaac Asimov, Understanding Physics, Volume I (New York: Walker and Company, 1966), 132.

[17] A. C. Zettlemoyer, R. F. Scarr, and W. D. Schaeffer, "Influence of Ink Properties on Transfer During Printing," International Bulletin for the Printing and Allied Trades 13 (June 1958): 89.

CHAPTER 3

LITERATURE REVIEW

The most important paper relevant to this thesis, which has already been cited numerous times, is A Concept of Ink Transfer in Printing by William C. Walker and Jacqueline M. Fetsko.[1] Another work which led to the development of this thesis topic is Dein Wang's Master's Thesis entitled An Investigation of the Applicability of the Walker and Fetsko Ink Transfer Equation on and the Influence of Ink Viscosity on the Heatset Inks Used in the Web Offset Process. In this thesis Wang used the equipment available in the School of Printing to collect a set of transfer data using heatset inks, then applied the equation to the experimental data. He obtained a good correlation between the percentage transfer values obtained from the equation and his experimental data.[2]

Another work showing the usefulness and versatility of the Walker and Fetsko equation is an article entitled Influence of Ink Properties on Transfer During Printing.[3] In this investigation the f parameter from the equation was studied in relationship to the viscosity and yield value of the inks. However, no papers were found in which the equation was applied to ink transfer in wet-on-wet trapping.

Footnotes for Chapter 3

[1] William C. Walker and Jacqueline M. Fetsko, "A Concept of Ink Transfer in Printing," Technical Association of the Graphic Arts Proceedings (1955): 141.

[2] Dein Wang, "An Investigation of the Applicability of the Walker and Fetsko Ink Transfer Equation on and the Influence of Ink Viscosity on the Heat Set Inks Used in the Web Offset Process," (Master's Degree Thesis, Rochester Institute of Technology, 1987), 57.

[3] A. C. Zettlemoyer, R. F. Scarr, and W. D. Schaeffer, "Influence of Ink Properties on Transfer During Printing," International Bulletin for the Printing and Allied Trades 13 (June 1958): 91.

CHAPTER 4

METHODOLOGY

Hypothesis

The following hypothesis was examined by this thesis:

A. Using heat-set inks, the Walker and Fetsko ink transfer equation can be used to generate a curve shape which will reflect the relationship between available ink film thickness and percent transfer in the following situations:

1. Ink transfer to unprinted (white) paper.
2. Ink transfer in wet-on-wet trapping, in which case the ink film is printed on another wet ink film.

B. The Walker-Fetsko parameters b, k, and f can be used to determine how the transfer characteristics differ in situations A.1 and A.2. The transfer surface in situation A.2 will be less absorbent and smoother, as reflected in the b and k parameters respectively. Parameter b in situation A.2 will be reduced due to the paper pores being filled by the first down ink film. The smoothness will be increased due to the low spots in the paper being filled up by the first down ink film.

C. When a solvent is added to the ink to reduce the viscosity, the percent transfer curves in situations A.1 and A.2 will run closer together, indicating that better physical trapping has occured. Better physical trapping is defined as the amount of ink transferring to the wet ink film (A.2), more closely matching the amount of ink transferring to the white paper (A.1).

Experimental Objective

The objective of this experiment was to run two ink transfer curves simultaneously under the same conditions. One curve represents transfer to unprinted paper (Hypothesis A.1), and one curve represents transfer to a wet ink film (Hypothesis A.2). The experiment was repeated after the ink viscosity was adjusted by the addition of a solvent.

Instrumentation

The instruments used to conduct this experiment were an I.G.T. Printability Tester and a Mettler analytic balance. The I.G.T. Printability Tester is a small mechanical abstraction of a rotary printing press consisting of two parts: an inking device and a printing device. The inking device makes provisions for the inking of two small printing disks, with two different inks, to varying degrees of ink film thickness as controlled by the operator. The disks are then mounted on the printing device, where both print in quick succession onto the same area of a thin strip of paper (see appendix). This action of the printing device simulates the wet-on-wet trapping which occurs on a multi-color press. Single color printing can be simulated by mounting only one printing disk on the printing device. The analytic balance was used to determine the available ink and the amount of ink which transfered to paper.

Discussion of Experimental Procedure

The experimental procedure, which will be described in the following section, was repeated a number of times to generate data for this experiment. Following the procedural outline once generated two pieces of data:

A. One point on the percent transfer curve representing ink transfer to the unprinted paper (Hypothesis A.1).

B. One point on the percent transfer curve representing ink transfer in wet-on-wet trapping (Hypothesis A.2).

A heat-set magenta ink was used to run all curves. The available ink film thickness was varied by applying different amounts of ink to the rollers of the I.G.T. inking device.

A heat-set yellow ink was used as the first ink down in the wet-on-wet trapping curves. A yellow ink film thickness was selected which appeared to give good coverage, and the ink film thickness was kept as constant as possible by applying the same amount of yellow ink to the I.G.T. inking device rollers throughout the experiment.

Before the experiment began, all testing instruments were placed on a counter within close proximity for easy access. The paper was cut into strips suitable for mounting on the I.G.T. printing device and marked, so that the same side of the paper (felt or wire) was used throughout the experiment. The I.G.T. printing device was set at a pressure setting of 40 Kg. All disk mounts were placed in impression mode and ready for testing. The weight of the clean printing disks was recorded so that the amounts of available and transferred ink could be determined. The surface area of the disks was also measured and recorded.

Experimental Procedure

I. Apply the inks to the I.G.T. inking device.

   A. Apply the yellow ink to the left-side inking rollers.

   B. Apply the magenta ink to the right-side inking rollers.

   C. Allow the device to work the inks on their respective rollers long enough to obtain the most even and consistent coverage as possible throughout the surface of all the rollers.

II. Determine a datum point for the percent transfer curve which represents ink transfer to the unprinted paper (Hypothesis A.1).

   A. Ink the disk with the magenta ink.

   B. Determine the mass of the inked disk with the analytic balance and record.

   C. Print the ink to the paper with the I.G.T. printing device.

   D. Determine the mass of the inked disk after printing and record.

III. Determine a datum point for the percent transfer curve which represents ink transfer in wet-on-wet trapping (Hypothesis A.2).

   A. Ink a disk with yellow ink.

   B. Ink a disk with magenta ink. This disk must be narrower than the yellow disk to insure that the magenta ink will print to the yellow ink film.

   C. Mount the yellow disk on the I.G.T. printing device in position to be the first-down ink.

   D. Determine the mass of the inked magenta disk and record.

E. Mount the magenta disk on the printing device and print the yellow and magenta inks on the paper.

F. Determine the mass of the magenta disk after printing and record.

IV. Clean the I.G.T. inking device with appropriate solvents and prepare to repeat this procedural outline.

Test for Solvent Evaporation From The Ink

The ink which had solvent added to it was tested for weight changes over time due to solvent evaporation. The I.G.T. printing disk was inked with a thin ink film and the mass recorded. The mass was determined and recorded three times at one-minute intervals to see if weight changes due to solvent evaporation would be confounding the experimental results.

CHAPTER 5

DATA ANALYSIS AND CONCLUSIONS

Categories of Experimental Data

There were four categories of experimental data which were analyzed in this research:

A. Unadjusted ink, printed on white paper (Hypothesis A.1).

B. Unadjusted ink, printed on, or trapped over, a wet yellow ink film (Hypothesis A.2).

C. Adjusted ink, printed on white paper (Hypothesis C and A.1).

D. Adjusted ink, trapped over yellow (Hypothesis C and A.2).

The adjusted ink has four percent solvent added by weight. Ink film thickness is expressed as milligrams per square centimeter for all categories of data so they can be meaningfully compared to each other.

Use of Computer

The Apple IIe computer and the Visicalc spreadsheet software were used to perform all calculations for data analysis. Each category of data was analyzed individually on its own spreadsheet, which was then stored as a spreadsheet file on floppy disk. The spreadsheet was set up to automatically calculate available ink film thickness, ink transferred, and percent transfer for each datum point collected. After each set of data was plotted on graph paper, each spreadsheet was expanded to do transfer calculations based on the Walker and Fetsko ink transfer equation. The spreadsheet was set up so that values could be entered for the Walker-Fetsko parameters and a new curve shape recalculated based on the chosen values. This allowed the operator to experiment with different parameter values and see the effects on the resulting Walker-Fetsko curve shape. By plotting the Walker-Fetsko curve on the same graph as the experimental values, it could be seen how well the Walker-Fetsko curve matched the data. Then decisions could be made on how to alter the parameter entries to change the Walker-Fetsko curve shape to better fit the data.

Outline of Data Analysis

There are two objectives to be met in analyzing the data obtained from the experiment:

A. Plot each set of experimental values in two ways:

1. Percent transfer, $(y/x)\cdot 100$, as a function of available ink film thickness, x.
2. Ink film thickness transferred, y, as a function of available ink film thickness, x.

B. For each data category, manipulate the parameters b, k, and f in the Walker and Fetsko ink transfer equation so it produces the best possible curve fit to the data as plotted in A.1.

1. Based on the linear model at high ink film thicknesses, use the data as plotted in A.2 to derive parameters b and f.
    a. Interpolate the y intercept, which will be entered as $b(1-f)$ and used to solve for parameter b.
    b. Calculate the slope of the linear portion of the curve and enter as parameter f.

2. Calculate parameter k from the experimental data at low ink film thicknesses. Use the average k as the value for the final transfer calculations.

Deriving the Parameters for Data Analysis

Manipulating the Walker-Fetsko parameters b, k, and f to alter the curve fit to the experimental data was achieved through the use of a computer, as described previously. Parameters b and f are derived from a linear model of ink transfer, which Walker and Fetsko encountered at high ink film thicknesses. The parameter f is the slope of the line in which y is plotted as a function of x and represents the fraction of free ink film which splits to the paper. Parameter f can also be interpreted as the limiting value of the percentage transfer curve at high ink film thicknesses, and decreasing f lowers this part of the curve. The y intercept of the linear model, represented by the expression b(1-f), is used to solve for b, the maximum absorptive capacity of the paper. Under the Walker and Fetsko model, a greater parameter b increases the maximum percentage transfer and slows down the rate at which this curve approaches f at high ink film thicknesses.

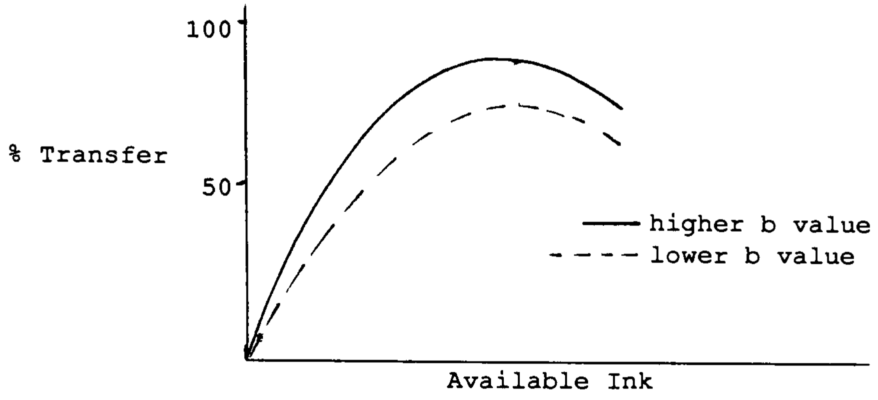


Figure 7. Effects of adjusting parameter b on the Walker-Fetsko percent transfer curve.

The Walker and Fetsko equation is solved for k at low ink film thicknesses and averaged to obtain a final value for use in the equation. The term F in the equation, represented by the function $(1-e^{-kx})$, will approach full contact more quickly for a smoother substrate. In analyzing the data it was found that the average k for all experimental values in the thin ink film region did not yield the best possible curve fit. The curve fit as related to the F term could be judged by considering the F value at different points on the curve. The F value should be quite high by the time maximum percentage transfer is reached. If this is not the case then the k value is too low, in which case data points which yield a lower k value can be eliminated from the average to increase it. This procedure of averaging different k values was repeated on a trial and error basis until the best possible curve fit was achieved in the thin ink film region of the percent transfer curve.

It was noted that a low k value, which in turn causes the F terms in the equation to be low, will not allow a good curve fit to be achieved at higher ink film thicknesses and causes the b and f parameters to be overestimated. Before being aware that a k value was too low, this researcher attempted to raise the b and f parameters to achieve good curve fit in the region of maximum percentage transfer. In this situation it was observed that excessively high b and f parameters could not raise the curve to where it should be.

Result of the Test for Solvent Evaporation from the Ink

The test for solvent evaporation from the ink indicated that no significant loss in weight of the ink film occured due to this factor. It is therefore concluded that solvent evaporation has not significantly confounded the experimental results.

Materials Used in the Experiment

The paper used for the experiment was an uncoated, 70lb. Opaque Vellum. The inks used were manufactured by the Flint Ink Company and were a heatset type commonly used in commercial web printing. To test part C of the hypothesis four percent solvent was added to the ink by weight. The solvent used was a liquid type used to reduce ink tack, however, no information was available on its chemical composition. All materials were obtained from the laboratory of the Technical and Education Center for the Graphic Arts at the Rochester Institute of Technology through Mr. William Eisner.

Presentation of Data

The experimental data and the Walker-Fetsko calculations are presented in table form for each data category with the ink transfer parameters listed at the bottom. The data and the accompanying graphs are divided into two sections: unadjusted ink (data categories A and B) and adjusted ink (data categories C and D). Within each section, the experimental data for the ink printed on white paper and trapped over yellow are presented on the same set of Cartesian coordinates for comparison (figures 8 and 14). The Walker-Fetsko percent transfer curves are presented in the same way (figures 11 and 17).

What follows is an explanation of the contents for each data table. The contents of the body of each table will be explained in the first outline, then the parameters listed at the foot of each table will be explained in the second outline.

Outline of Table Body Contents

A. Ink Avail.- The amount of ink available on the printing disk, expressed as milligrams/cm^2. This value is used as x in the Walker-Fetsko calculations.

B. Ink Trans.- The amount of ink transferred to the paper, expressed as milligrams/ cm^2. This value is used as y in solving the equation for parameter k at low ink film thicknesses.

C. Perc. Trans.- Percentage transfer calculated from the experimental values.

D. b'- The expression $b(1-e^{-x/b})$ solved for the given x value.

E. b(1-f) - This expression is evaluated from the b' value at the given x value. This expression is being evaluated so it can be determined if the equation has reached linearity at a given x value. The equation has reached linearity if this expression matches the b(1-f) value obtained from the linear plot of y as a function of x.

F. Y- The amount of ink transferred in the area of contact, which is the expression:

$$Y=b(1-e^{-x/b})+f[x-b(1-e^{-x/b})]$$

G. K- The Walker and Fetsko equation solved for k using the x and y values from the experimental data, which is evaluated as the expression:

$$k=\frac{-\ln(1-y/Y)}{x}$$

The only k values which are listed are the ones which were averaged as the k value for the final calculations.

H. F- The Walker and Fetsko equation solved for fractional contact area, which is evaluated from the expression:

$$F=(1-e^{-kx})$$

I. Calc. Trans.- The calculated ink transfer from the equation, evaluated as F·Y.

J. Calc. Perc.- Calculated percentage transfer from the equation.

Outline of Table Foot Contents

A. b(1-f)- The value entered as the y intercept of the linear model.

B. b- The parameter b, as solved from b(1-f).

C. f- The slope of the linear model.

D. average k- The average of the k values given in the body of the table which was used for final calculations.

E. Correlation Coefficient between Ink Trans. and Calc. Trans.- The statistical correlation coefficient between the experimental values for y and the y values computed from the equation at the given x.

Table 1.

EXPERIMENTAL DATA AND WALKER-FETSKO CALCULATIONS FOR UNADJUSTED INK PRINTED ON WHITE PAPER

Ink Avail. Mg/sq. cm	Ink Trans. Mg/sq. cm	Perc. Trans.	b'	b(1-f)	Y	K	F	Calc. Trans.	Calc. Perc.
.0231	.0077	33.33	.0209	.0136	.0217	.....	.3726	.0081	34.99
.0274	.0101	36.69	.0244	.0159	.0255	.....	.4252	.0108	39.48
.0381	.0166	43.52	.0324	.0211	.0344	.....	.5363	.0185	48.48
.0454	.0207	45.65	.0375	.0244	.0403	.....	.6000	.0242	53.25
.0483	.0225	46.53	.0395	.0257	.0426	.....	.6232	.0265	54.91
.0602	.0343	57.05	.0469	.0305	.0515	.....	.7033	.0362	60.24
.0738	.0464	62.83	.0545	.0354	.0612	19.17	.7746	.0474	64.31
.0781	.0497	63.64	.0567	.0369	.0642	19.04	.7935	.0510	65.25
.0976	.0657	67.27	.0659	.0428	.0770	19.64	.8608	.0663	67.88
.1207	.0852	70.59	.0749	.0487	.0909	22.95	.9127	.0830	68.73
.1211	.0882	72.80	.0750	.0487	.0911	.....	.9134	.0832	68.73
.1229	.0888	72.23	.0756	.0491	.0922	.....	.9164	.0845	68.73
.1323	.0878	66.32	.0787	.0512	.0975	.....	.9310	.0908	68.59
.1442	.0990	68.67	.0823	.0535	.1040	.....	.9457	.0983	68.19
.1501	.1039	69.25	.0840	.0546	.1071	.....	.9518	.1019	67.92
.1505	.1006	66.84	.0841	.0546	.1073	.....	.9522	.1022	67.90
.1604	.1128	70.36	.0866	.0563	.1124	.....	.9608	.1080	67.37
.1905	.1266	66.46	.0933	.0606	.1273	.....	.9787	.1246	65.39
.2071	.1310	63.24	.0962	.0625	.1350	.....	.9848	.1330	64.20
.2239	.1375	61.41	.0988	.0642	.1426	.....	.9891	.1410	63.00

b(1-f)	b	f	average k
.075	.1154	.35	20.20

Correlation Coefficient between Ink Trans. and Calc. Trans. = .998

Table 2.

EXPERIMENTAL DATA AND WALKER-FETSKO CALCULATIONS FOR UNADJUSTED INK TRAPPED OVER YELLOW

Ink Avail. Mg/sq. cm	Ink Trans. Mg/sq. cm	Perc. Trans.	b'	b(1-f)	Y	K	F	Calc. Trans.	Calc. Perc
.0255	.0073	28.57	.0146	.0071	.0201	.....	.5122	.0103	40.45
.0304	.0126	41.33	.0158	.0077	.0232	25.60	.5745	.0133	43.95
.0352	.0166	47.13	.0168	.0082	.0262	28.53	.6289	.0165	46.75
.0538	.0296	54.89	.0189	.0093	.0367	30.29	.7803	.0287	53.25
.0623	.0308	49.35	.0194	.0095	.0413	.....	.8270	.0342	54.82
.0709	.0385	54.29	.0198	.0097	.0458	.....	.8638	.0396	55.87
.0741	.0466	62.84	.0199	.0097	.0475	.....	.8757	.0416	56.17
.0777	.0470	60.42	.0200	.0098	.0494	.....	.8878	.0439	56.45
.0826	.0425	51.47	.0201	.0098	.0519	.....	.9021	.0469	56.74
.0874	.0449	51.39	.0201	.0099	.0545	.....	.9146	.0498	56.96
.0883	.0474	53.67	.0201	.0099	.0549	.....	.9166	.0503	56.99
.1012	.0591	58.40	.0203	.0099	.0615	.....	.9421	.0580	57.29
.1130	.0704	62.37	.0203	.0100	.0676	.....	.9584	.0648	57.33
.1490	.0838	56.25	.0204	.0100	.0860	.....	.9849	.0847	56.84
.1518	.0838	55.20	.0204	.0100	.0874	.....	.9861	.0862	56.78
.1664	.0907	54.50	.0204	.0100	.0949	.....	.9907	.0940	56.48
.1725	.0960	55.63	.0204	.0100	.0980	.....	.9922	.0972	56.35
.1753	.1032	58.89	.0204	.0100	.0994	.....	.9928	.0987	56.29
.1919	.1126	58.65	.0204	.0100	.1079	.....	.9955	.1074	55.96
.2073	.1166	56.25	.0204	.0100	.1157	.....	.9971	.1154	55.66

b(1-f)	b	f	average k
.01	.0204	.51	28.14

Correlation Coefficient between Ink Trans. and Calc. Trans. = .995

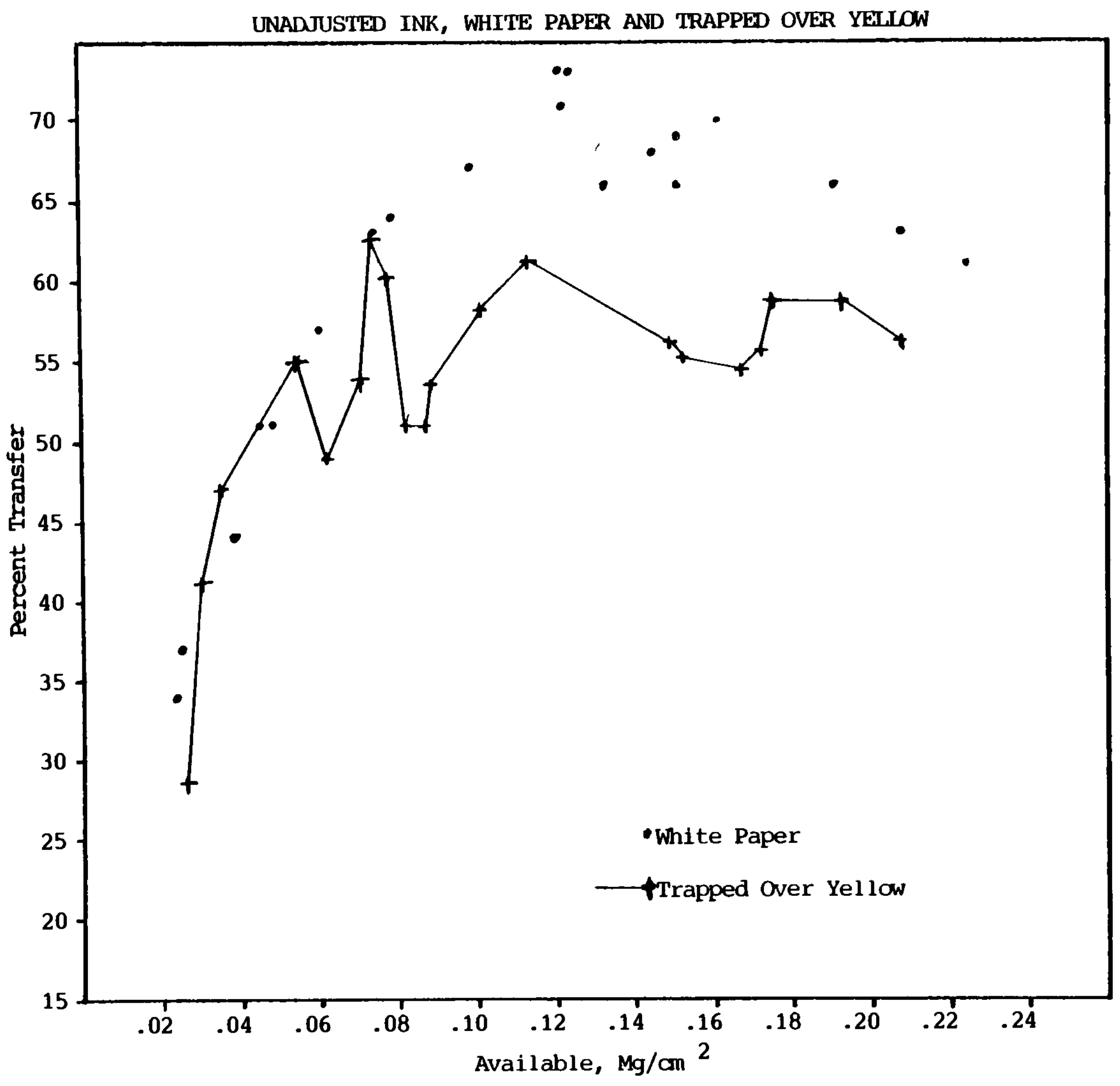


Figure 8. Percent transfer plots of experimental values.

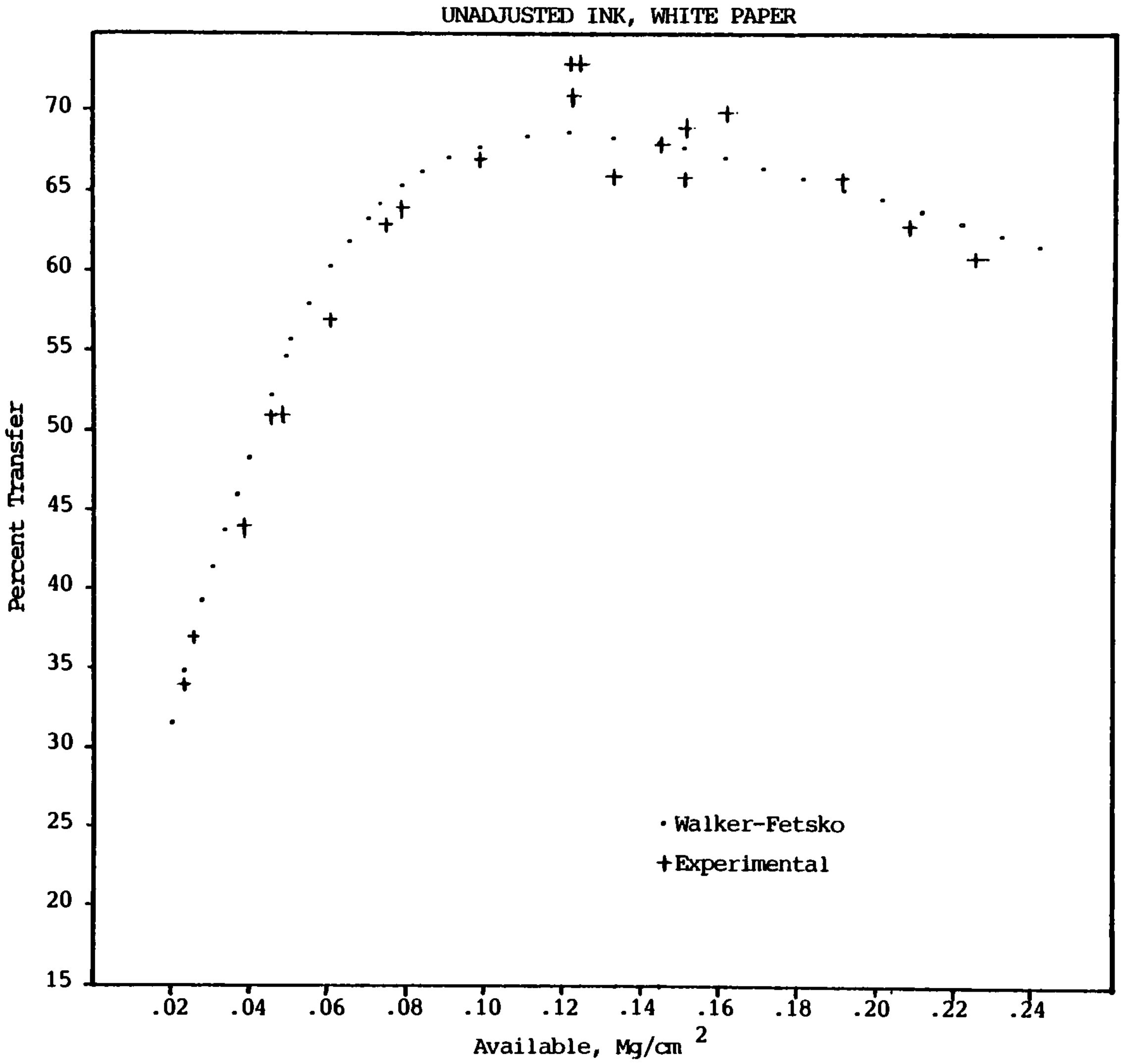


Figure 9. Walker-Fetsko percent transfer curve and experimental values.

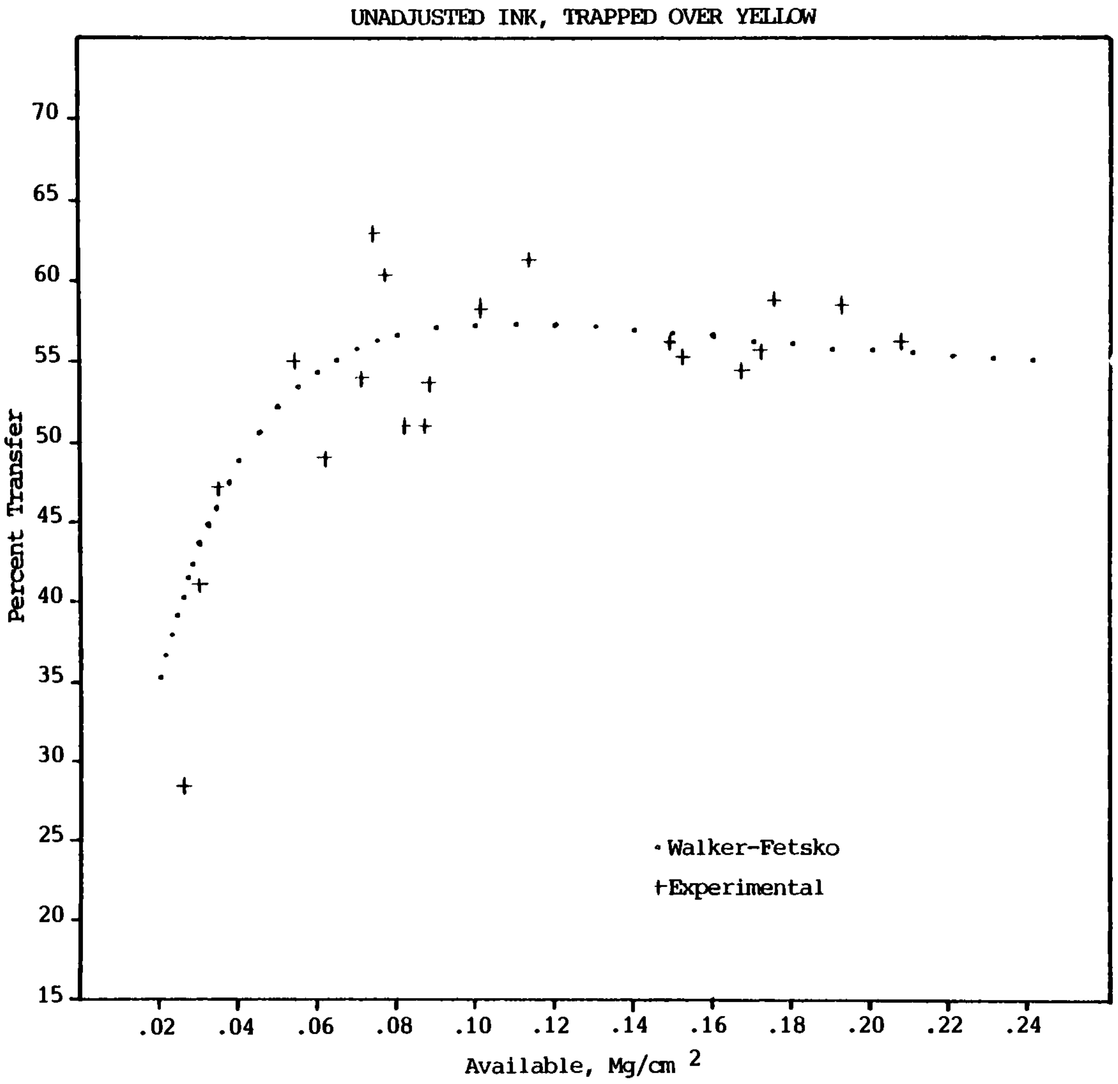


Figure 10. Walker-Fetsko percent transfer curve and experimental values.

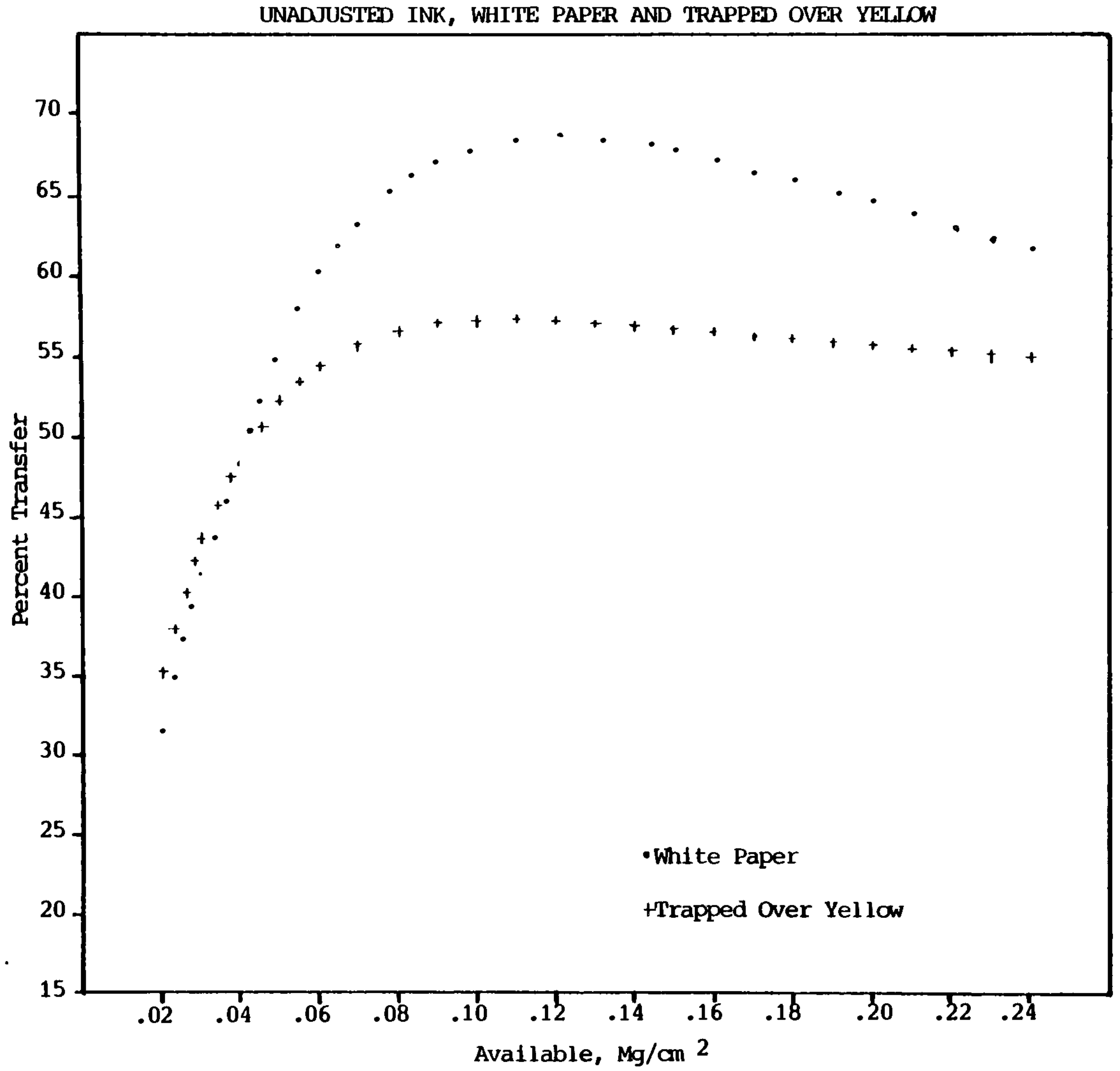


Figure 11. Walker-Fetsko percent transfer curves.

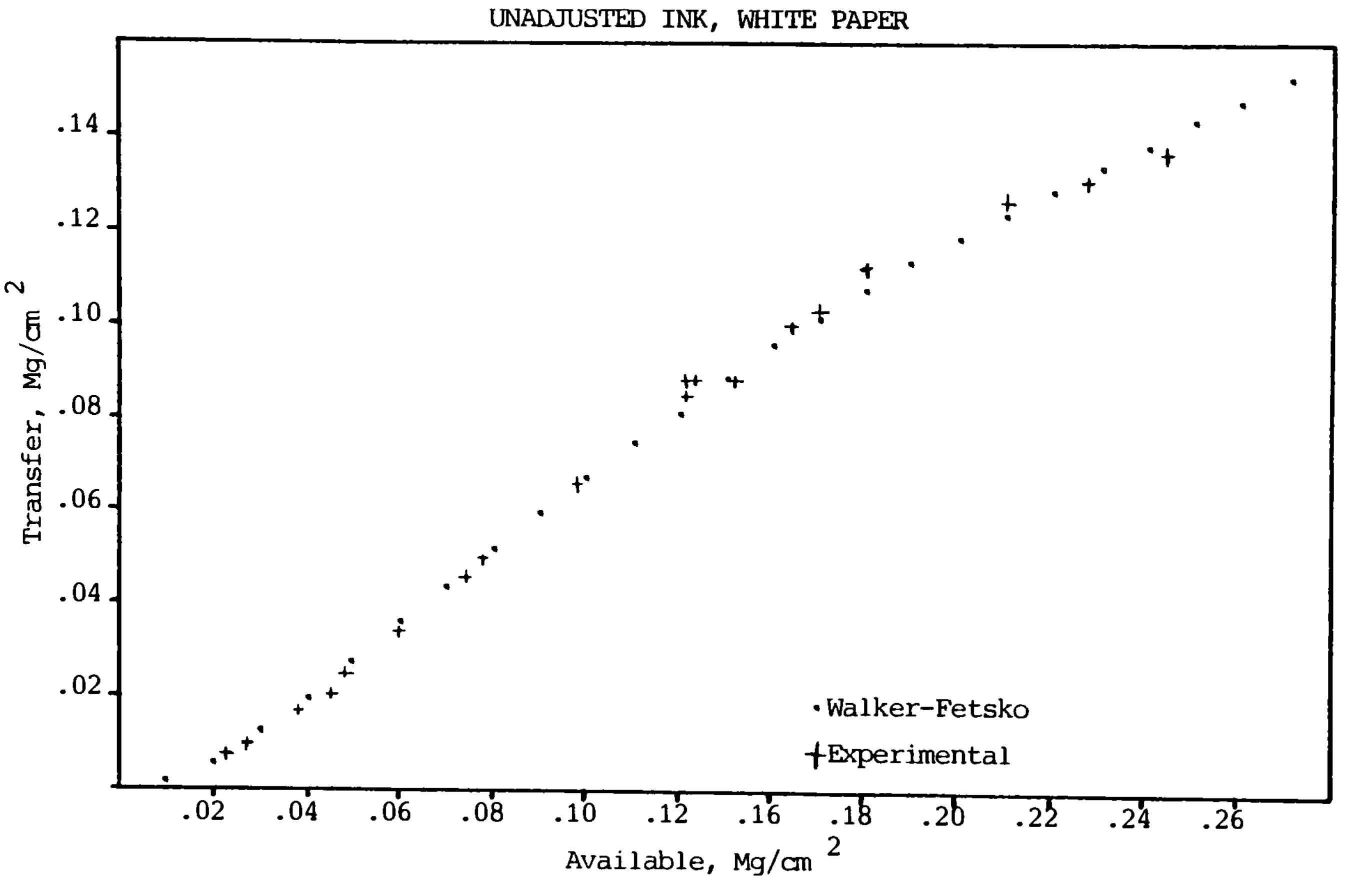


Figure 12. Walker-Fetsko transfer plots and experimental values.

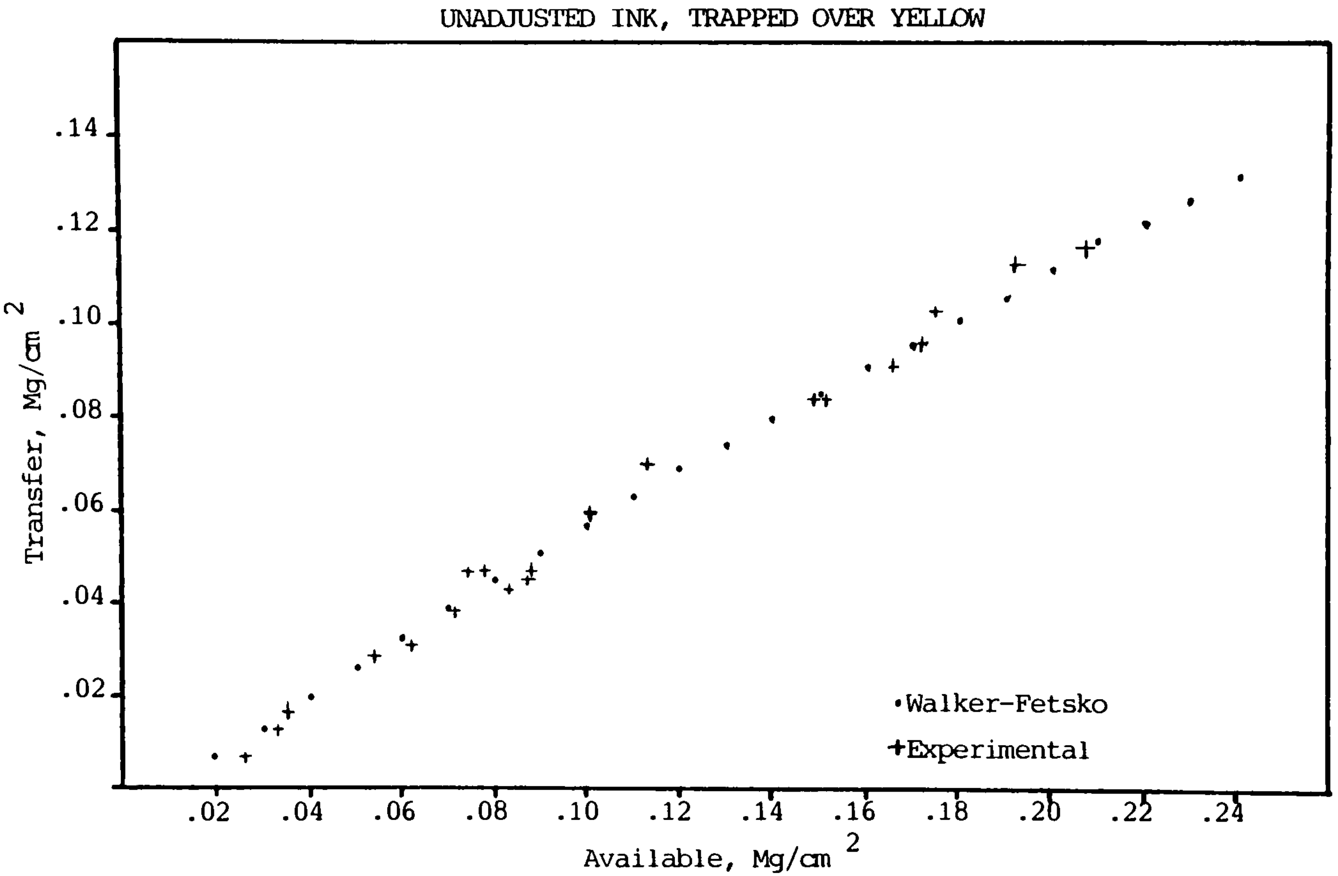


Figure 13. Walker-Fetsko transfer plots and experimental values.

Table 3.

EXPERIMENTAL VALUES AND WALKER-FETSKO CALCULATIONS FOR ADJUSTED INK PRINTED ON WHITE PAPER

Ink Avail. Mg/sq. cm	Ink Trans. Mg/sq. cm	Perc. Trans.	b'	b(1-f)	Y	K	F	Calc. Trans.	Calc. Perc.
.0187	.0049	26.32	.0174	.0119	.0179	.....	.2931	.0052	27.93
.0280	.0093	33.10	.0252	.0171	.0261	.....	.4045	.0106	37.68
.0351	.0144	41.01	.0307	.0209	.0321	.....	.4778	.0154	43.75
.0363	.0136	37.50	.0316	.0215	.0331	.....	.4892	.0162	44.66
.0418	.0183	43.87	.0357	.0243	.0377	.....	.5388	.0203	48.55
.0436	.0215	49.32	.0370	.0252	.0391	18.30	.5537	.0217	49.68
.0517	.0278	53.82	.0426	.0290	.0455	18.28	.6157	.0280	54.22
.0519	.0264	50.95	.0427	.0291	.0457	16.67	.6171	.0282	54.32
.0570	.0323	56.75	.0461	.0314	.0496	18.53	.6518	.0323	56.71
.0789	.0487	61.75	.0591	.0402	.0654	17.31	.7678	.0502	63.66
.0793	.0531	66.92	.0593	.0403	.0657	20.80	.7695	.0505	63.75
.0815	.0536	65.86	.0605	.0411	.0672	19.68	.7786	.0523	64.20
.1051	.0722	68.67	.0720	.0489	.0826	.....	.8571	.0708	67.33
.1260	.0874	69.33	.0805	.0548	.0951	.....	.9030	.0859	68.13
.1387	.0998	71.98	.0851	.0579	.1022	.....	.9232	.0944	68.06
.1393	.0933	67.00	.0853	.0580	.1026	.....	.9240	.0948	68.05
.1501	.1026	68.33	.0888	.0604	.1084	.....	.9378	.1017	67.76
.1515	.1026	67.71	.0893	.0607	.1092	.....	.9394	.1026	67.71
.1708	.1213	71.02	.0948	.0645	.1191	.....	.9576	.1141	66.80
.1815	.1292	71.20	.0976	.0663	.1244	.....	.9652	.1201	66.18
.2049	.1327	64.77	.1029	.0699	.1355	.....	.9774	.1325	64.64
.2237	.1414	63.23	.1064	.0724	.1439	.....	.9841	.1417	63.33
.2383	.1479	62.09	.1089	.0740	.1503	.....	.9878	.1485	62.31
.2487	.1562	62.81	.1105	.0751	.1547	.....	.9900	.1532	61.58
.3428	.1809	52.76	.1203	.0818	.1915	.....	.9982	.1911	55.76

b(1-f)	b	f	average k
.088	.1294	.32	18.51

Correlation Coefficient between Ink Trans. and Calc. Trans. = .998

Table 4.

EXPERIMENTAL DATA AND WALKER-FETSKO CALCULATIONS FOR ADJUSTED INK TRAPPED OVER YELLOW

Ink Avail. Mg/sq. cm	Ink Trans. Mg/sq. cm	Perc. Trans.	b'	b(1-f)	Y	K	F	Calc. Trans.	Calc. Perc.
.0174	.0028	16.28	.0136	.0065	.0156	.....	.3828	.0060	34.30
.0251	.0101	40.32	.0177	.0084	.0216	25.22	.5013	.0108	43.11
.0417	.0227	54.37	.0239	.0114	.0333	27.46	.6852	.0228	54.64
.0445	.0259	58.18	.0247	.0117	.0351	30.07	.7090	.0249	55.90
.0644	.0397	61.64	.0287	.0136	.0474	28.14	.8321	.0395	61.31
.0656	.0433	66.05	.0289	.0137	.0482	.....	.8376	.0403	61.50
.0769	.0453	58.95	.0303	.0144	.0548	.....	.8814	.0483	62.74
.0777	.0490	63.02	.0303	.0144	.0552	.....	.8841	.0488	62.80
.0858	.0543	63.21	.0310	.0147	.0598	.....	.9074	.0543	63.23
.0883	.0559	63.30	.0312	.0148	.0612	.....	.9134	.0559	63.31
.0919	.0579	63.00	.0315	.0150	.0632	.....	.9217	.0583	63.39
.1138	.0704	61.92	.0325	.0155	.0752	.....	.9573	.0720	63.26
.1243	.0704	56.68	.0328	.0156	.0809	.....	.9681	.0783	62.98
.1271	.0887	69.75	.0329	.0156	.0824	.....	.9705	.0799	62.89
.1279	.0725	56.65	.0329	.0156	.0828	.....	.9712	.0804	62.86
.1352	.0891	65.87	.0331	.0157	.0867	.....	.9764	.0847	62.61
.1457	.0874	60.00	.0332	.0158	.0923	.....	.9824	.0907	62.22
.1482	.0907	61.20	.0333	.0158	.0936	.....	.9835	.0921	62.13
.1514	.0988	65.24	.0333	.0158	.0953	.....	.9850	.0939	62.00
.1668	.0992	59.47	.0334	.0159	.1035	.....	.9902	.1024	61.42
.1854	.1202	64.85	.0335	.0159	.1132	.....	.9941	.1126	60.74
.1907	.1211	63.48	.0336	.0159	.1161	.....	.9949	.1155	60.55

b(1-f)	b	f	average k
.016	.0337	.525	27.72

Correlation Coefficient between Ink Trans. and Calc. Trans. = .992

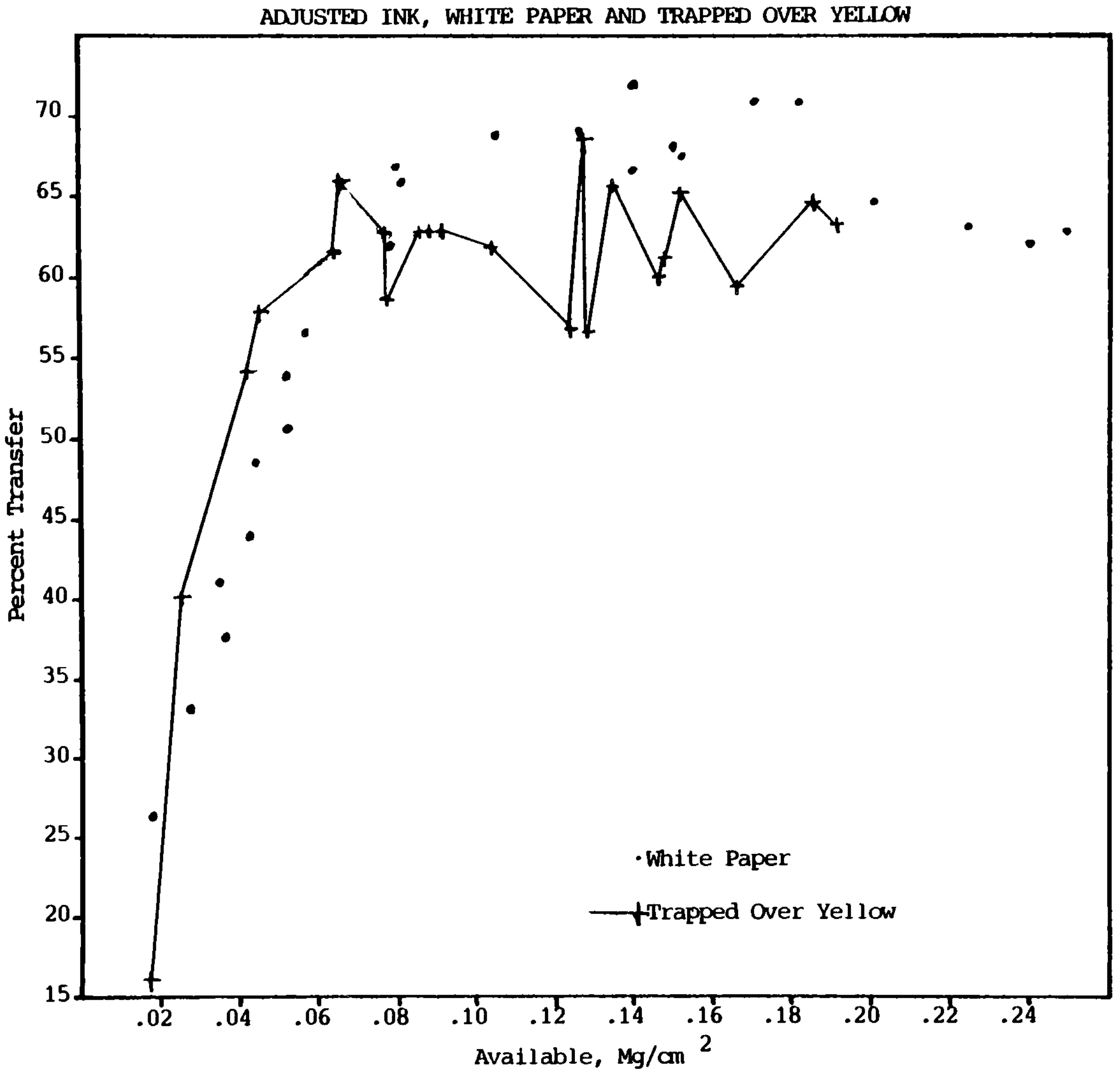


Figure 14. Percent transfer plots of experimental values.

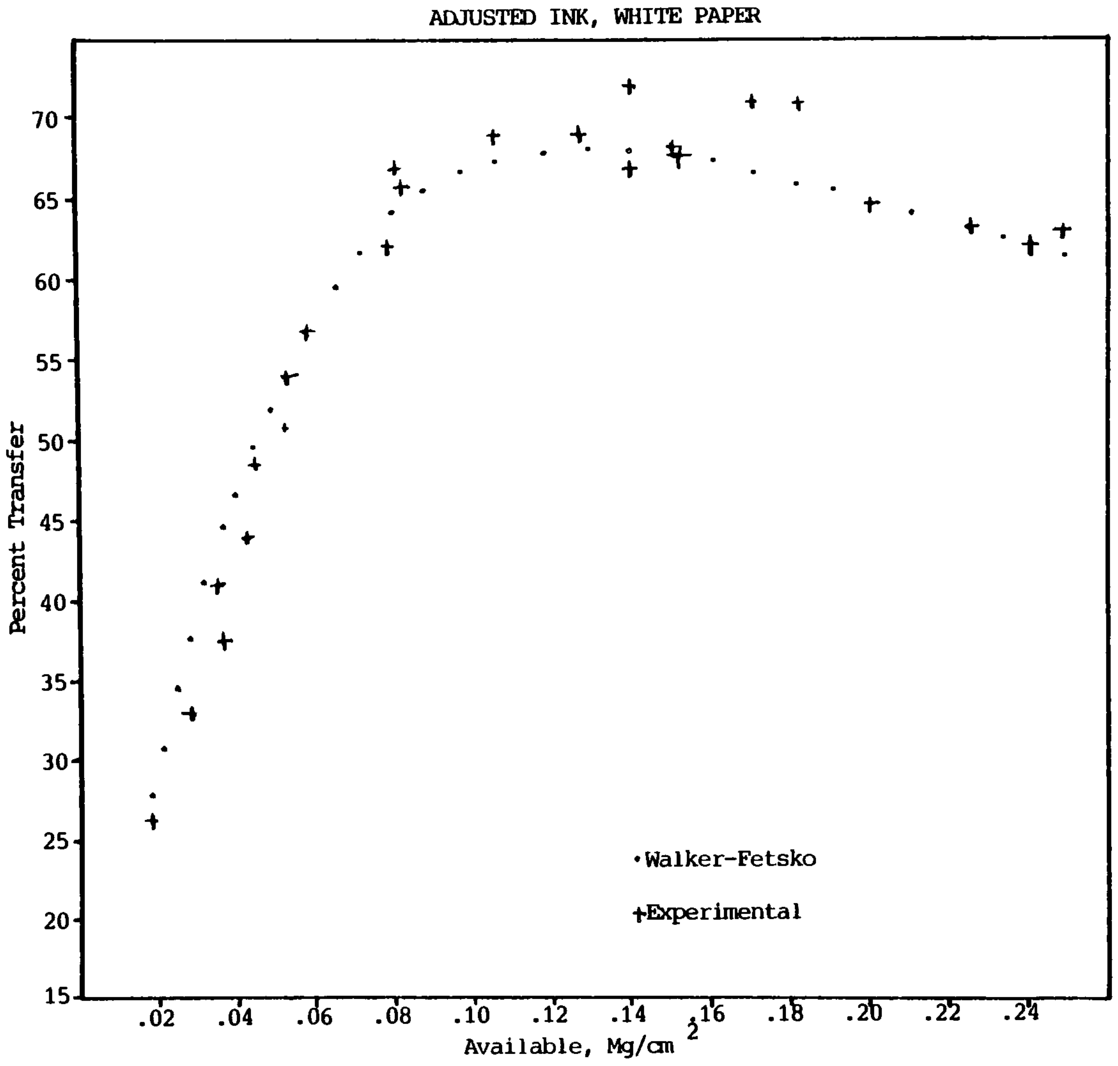


Figure 15. Walker-Fetsko percent transfer curve and experimental values.

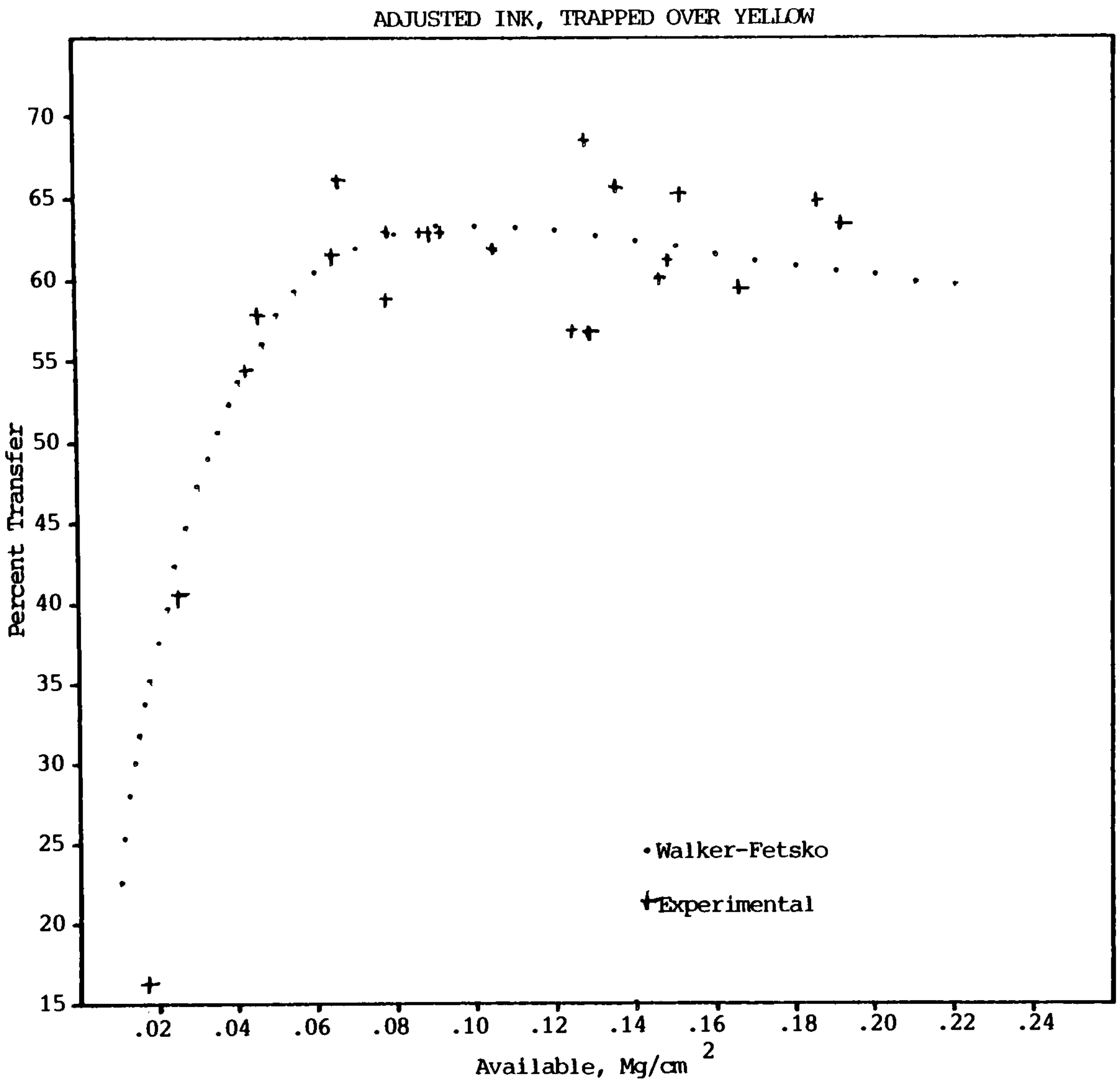


Figure 16. Walker-Fetsko percent transfer curve and experimental values.

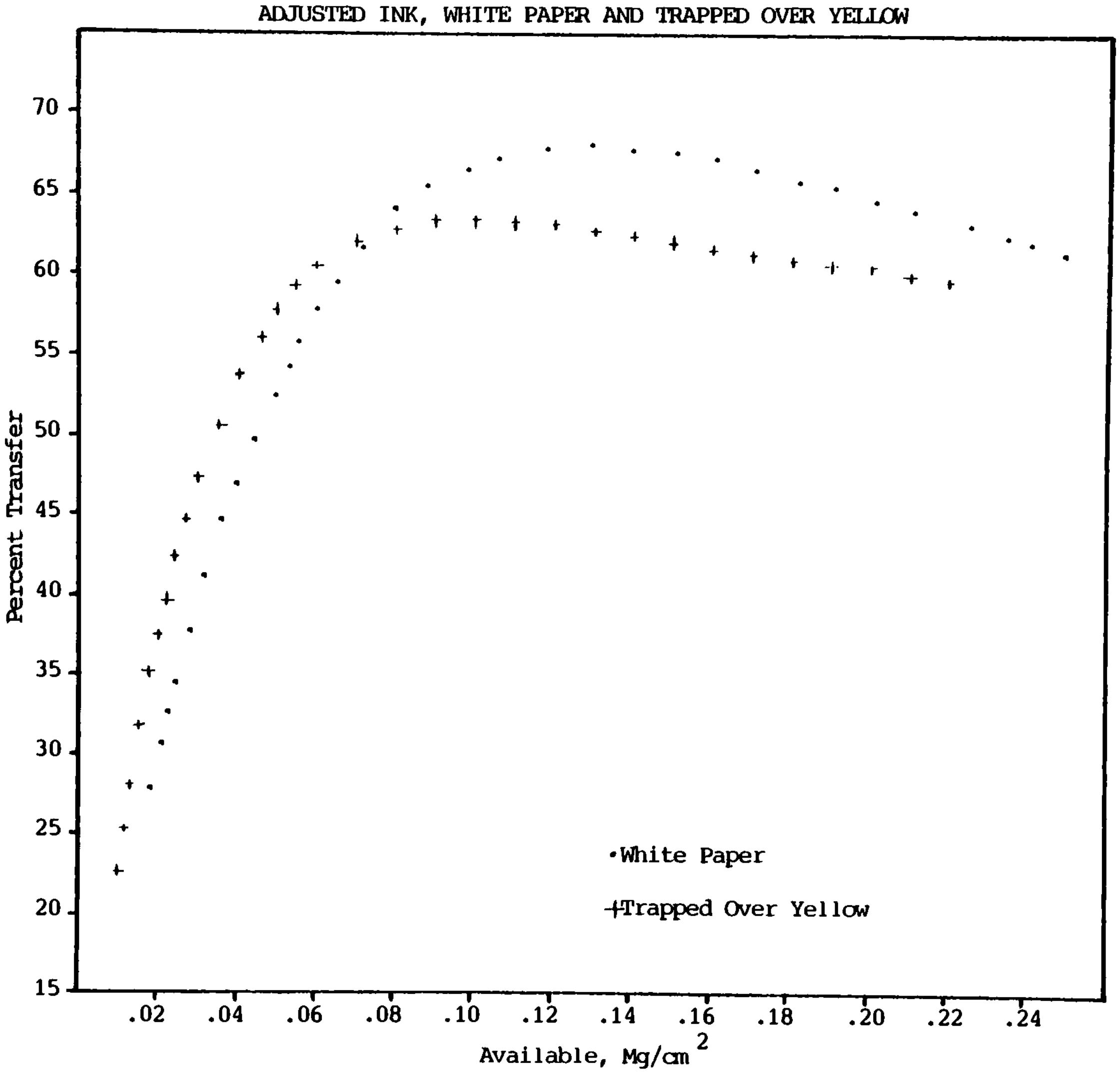


Figure 17. Walker-Fetsko percent transfer curves.

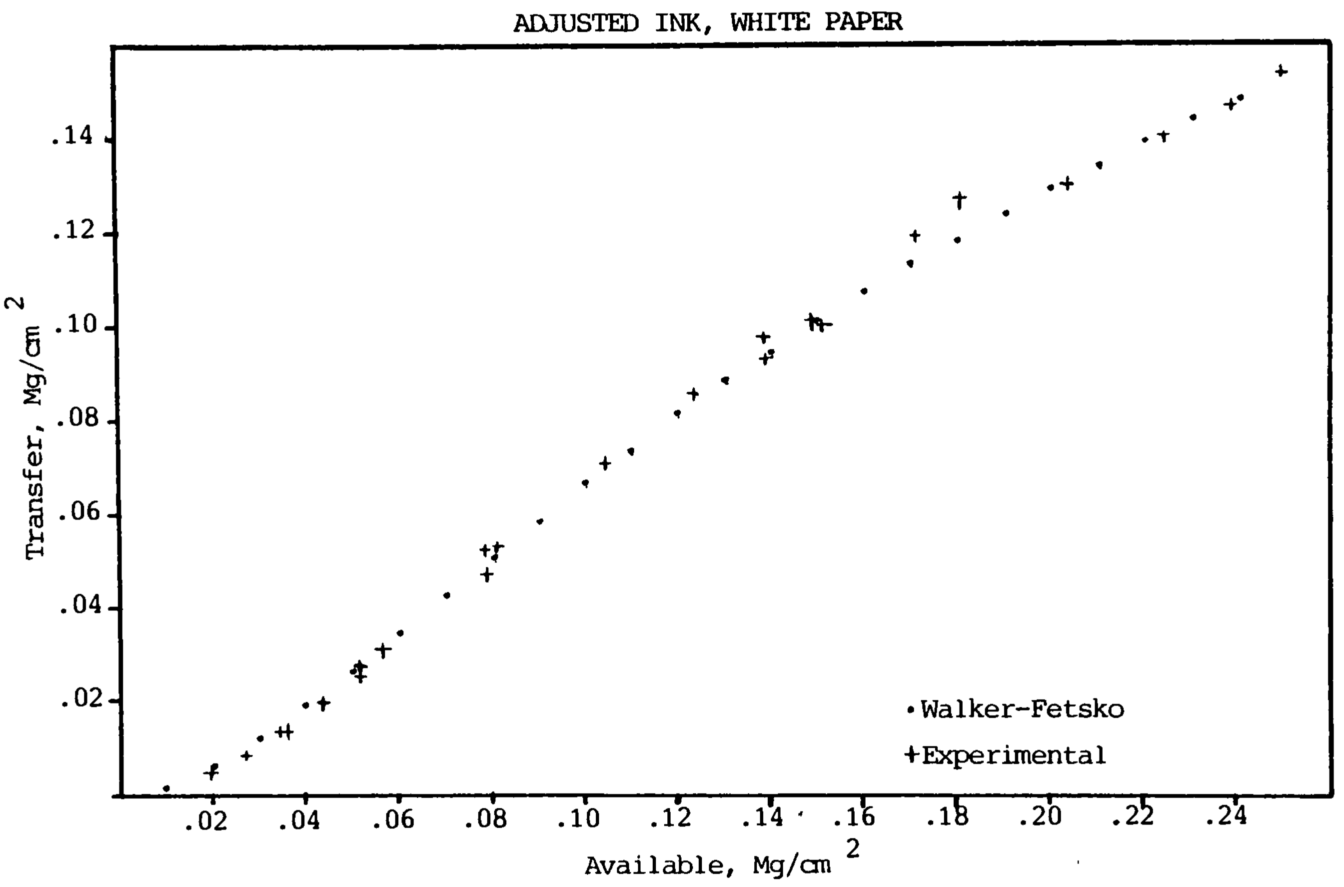


Figure 18. Walker-Fetsko transfer plots and experimental values.

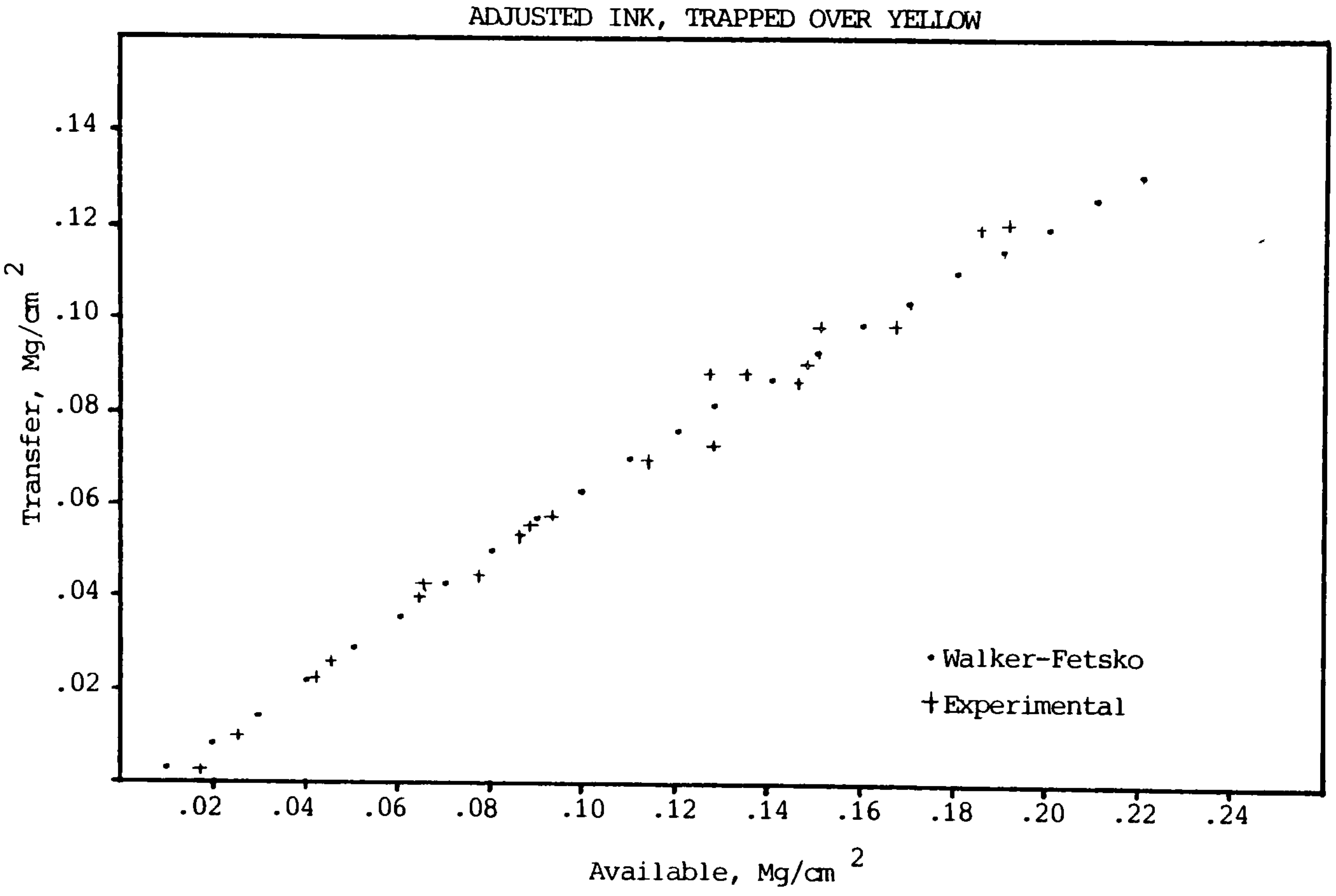


Figure 19. Walker-Fetsko transfer plots and experimental values.

Discussion of Results

The experimental data obtained for each data category did not plot as a perfectly smooth percent transfer curve. This is being attributed to experimental error inherent in the instrumentation and the testing conditions. In consultation with the thesis advisor, Dr. Julius Silver, it was decided that the best course of action was to form a curve which went through the middle of data points which were widely scattered. The greatest degree of scattering in the experimental data has been observed in the wet-on-wet trapping curves. This is being attributed to the introduction of another variable, the first down yellow ink film. The yellow ink film was kept as constant as possible. However, variation probably occured due to the nature of the I.G.T. inking device.

The Walker-Fetsko percent transfer curves seem to fit the experimental data quite well in the curves representing transfer to white paper. A particularly good fit is noticed in the percent transfer curve of adjusted ink printed on white paper (figure 15). The curve fit is not as good in the curves representing transfer in wet-on-wet trapping due to the scattering of data points. However, the Walker-Fetsko curves do seem to represent the data well. The correlation coefficients between the experimental values and the Walker-Fetsko calculations is close to one (perfect correlation) in every data category.

It is observed that in the two test groups representing printing on white paper (A and D) the plot of y as a function of x does not reach linearity. It can be determined if this curve has reached linearity by examining the expression b(1-f) as solved for the b' value at a given x. If the curve has reached linearity, b(1-f) solved at a given x will equal the b(1-f) value entered as the y-intercept as interpolated from the straight-line portion of the linear model. Experimental data could not be obtained at high enough ink film thicknesses for the curve to become linear in these two test groups due to limitations of the testing equipment. At high ink film thicknesses it was observed that the ink did not stay in the nip of the impression roller, but rather was forced out the sides of the printing disk. It was decided that the resulting data obtained under these conditions was not truly representational of what is happening in the nip at the moment of impression.

Due to the fact that the parameters were derived by adjustment to manipulate the final curve shape, it must be understood that the final ink transfer parameters were the result of this researcher's interpretation of the experimental data and are not to be interpreted as absolute truths regarding the ink transfer conditions. Slightly different parameter entries would have yielded just as good a correlation. Under the assumption that the resulting Walker-Fetsko curves are a good representation of the data, conclusions can be drawn regarding the ink transfer conditions and how they were changed from one data set to another.

Table 5.

COMPARISON OF INK TRANSFER PARAMETERS

Data Category	b	f	average k
A. Unadjusted Ink, White Paper	.1154	.35	20.20
B. Unadjusted Ink, Trapped Over Yellow	.0204	.51	28.14
C. Adjusted Ink, White Paper	.1294	.32	18.51
D. Adjusted Ink, Trapped Over Yellow	.0337	.525	27.72

Conclusions

A. The transfer surface in wet-on-wet trapping is smoother in comparison to printing on white paper due to the low spots of the paper surface in wet-on-wet trapping being filled by the first-down ink film. This claim is supported by the comparison of parameter k between the data categories A versus B, and C versus D. The k parameter is much higher in the wet-on-wet trapping groups, indicating a smoother transfer surface.

B. The absorptive capacity in wet-on-wet trapping, represented by parameter b, is much less than the absorptive capacity in printing on white paper. This is explained by the paper porosity in wet-on-wet trapping being filled by the first-down ink film, as evidenced by the comparison of parameter b between the data categories A versus B, and C versus D. Parameter b is much lower in the wet-on-wet trapping groups, indicating a much less absorptive surface during the brief moment of impression.

C. Comparison of figures 11 and 17, which are shown side by side in figure 20, shows that the percent transfer curves run closer together at the higher ink film thicknesses. This comparison proves that a

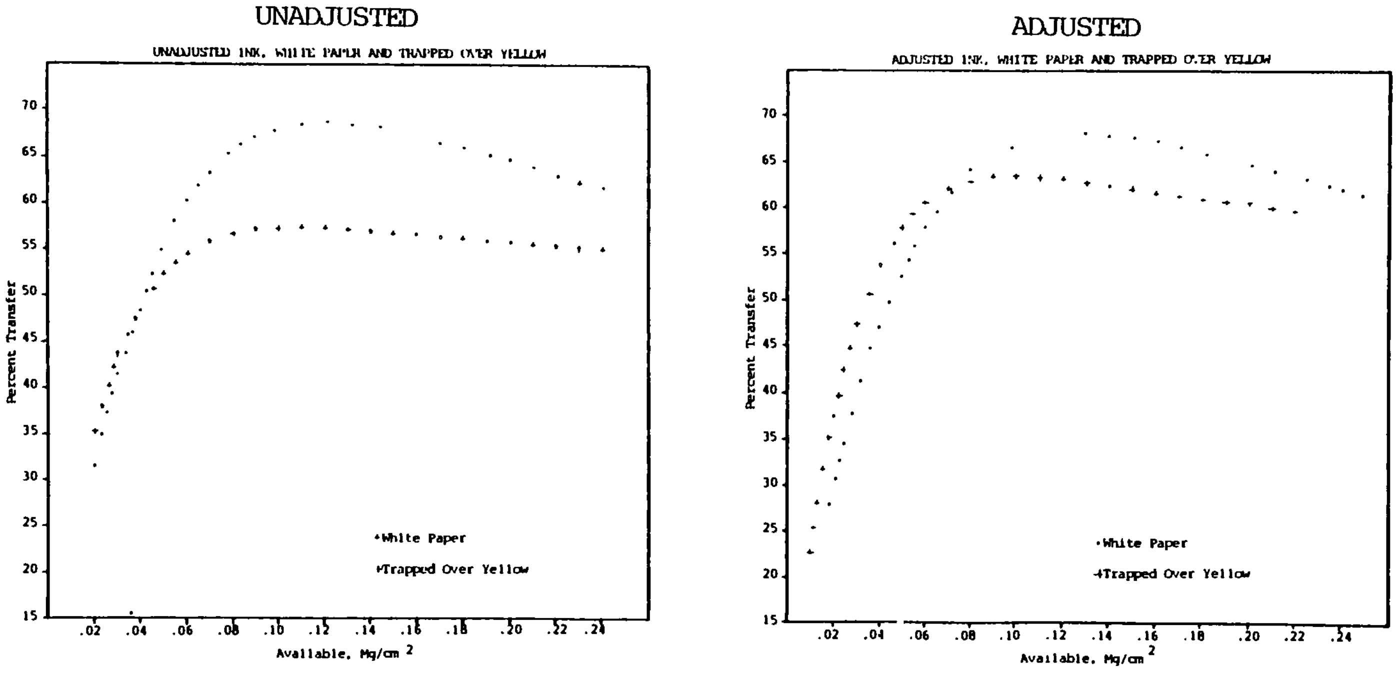


Figure 20. Comparison of Walker-Fetsko percent transfer curves for adjusted and unadjusted inks.

better physical trapping has occurred as a result of the addition of solvent.

It is assumed that the addition of solvent to the ink decreased the viscosity, causing parameter b to change between test groups A versus C, and B versus D. Comparison of the f parameter in these groups revealed that that f did not change much due to the additional solvent. This must mean that the improved physical trapping is explainable mainly by the b parameter, which rises at a faster rate with the addition of solvent in the wet-on-wet trapping groups (B versus D) as compared to the white paper groups (A versus C).

D. Developing a concept to explain the increase in parameter f in the wet-on-wet groups is a more difficult job. To do so it is necessary to consider a model of the film splitting mechanisms in the nip of the press, an issue explored in depth by Zettlemoyer, Scarr and Schaeffer of the National Printing Inks Research Institute.[1] They developed a model of the pressure profile and cavitational activity of the ink film in the nip of the press (figure 21).

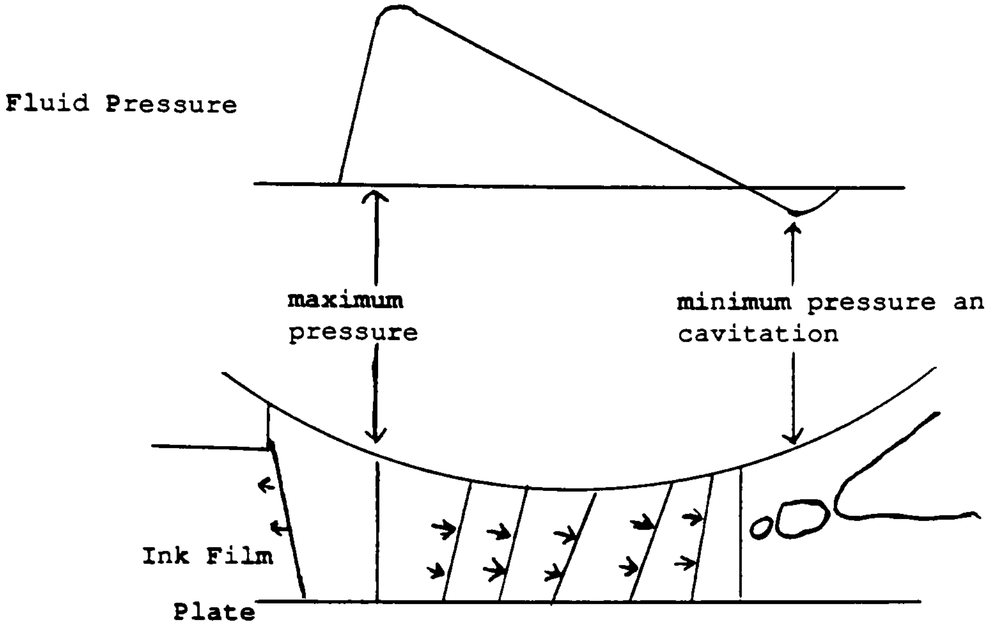


Figure 21. Pressure and stress profiles in the nip of the press.

In the region of negative pressure, cavities form which are the beginning of the ink film split. In the following passage Zettlemoyer, Scarr and Schaeffer describe the split of the ink film in relationship to the relative distribution of pigment particles and vehicle within the ink film:

> The level in the film at which ultimate rupture occurs must depend not only upon a preponderance in the number of incipient cavities present at that level, but must depend upon the growth of these cavities to macroscopic bubbles. Split will ultimately occur at that level with the minimum liquid cross-sectional area. Competition must occur among cavities at various levels within the film for growth, and unlike the nucleation step, the cavities can probably grow best in regions of lowest pigment loading or low viscosity. Thus, expansion of the bubbles from the upper to middle or lower half of the free ink film might be expected to occur

more readily in the lower viscosity vehicles, and lead to the higher average split observed.[2]

From this concept a theory can be developed to explain the higher f values in the wet-on-wet trapping groups. In printing on white paper, the low molecular weight vehicle drains into the absorbent paper more quickly than the pigment particles, causing a higher relative concentration of vehicle near the paper surface as compared to the rest of the ink film, thus causing growth of the cavities and film rupture to occur more readily in this region. However, in the wet-on-wet trapping groups, parameter b indicates that the substrate is not very absorbent, which has been explained by the paper porosity being filled by the first-down ink film. There will be less tendency for this surface to absorb the vehicle, leaving a more even distribution of pigment particles and vehicle throughout the ink film. The viscosity throughout the ink film will remain more constant in this situation, thus promoting more of a 50-50 split.

Footnotes for Chapter 5

[1] A. C. Zettlemoyer, R. F. Scarr, and W. D. Schaeffer, "Influence of Ink Properties on Transfer During Printing," International Bulletin for the Printing and Allied Trades 13 (June 1958): 94.

[2] Zettlemoyer, "Influence of Ink Properties," 94.

CHAPTER 6

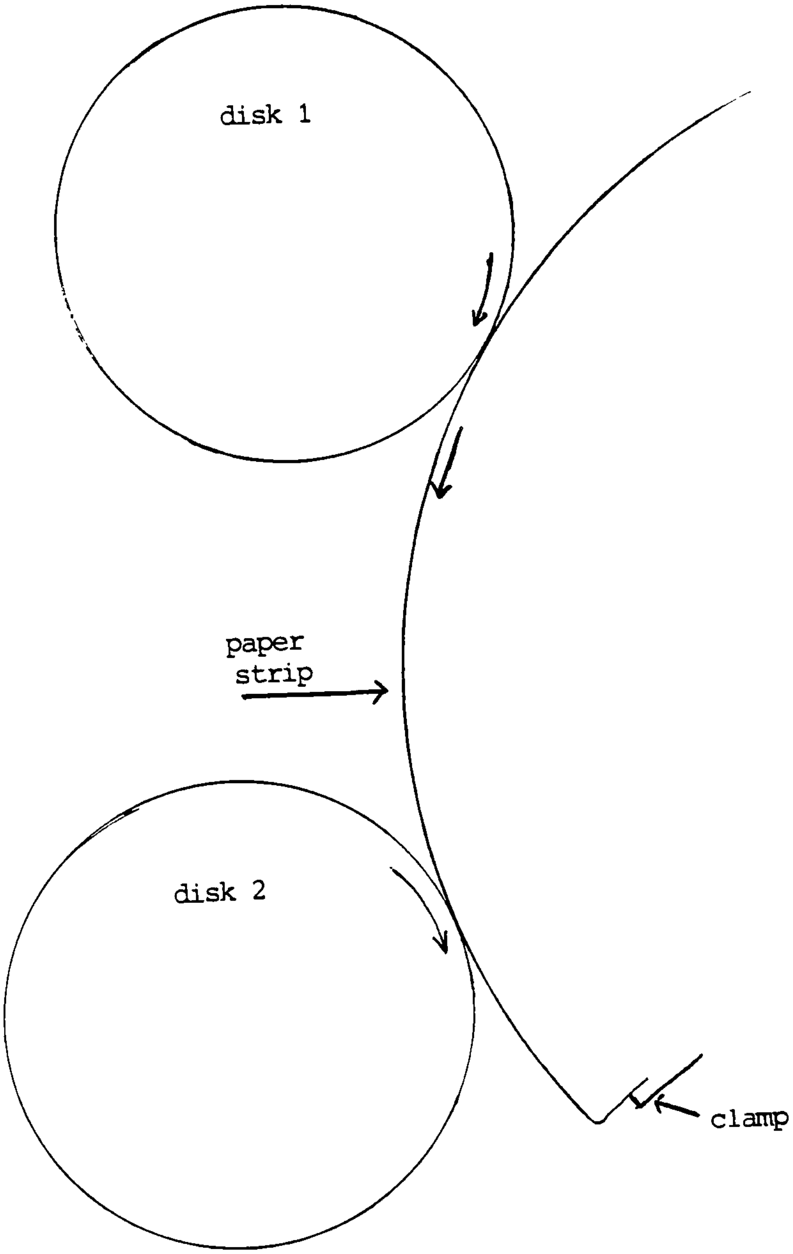
RECOMMENDATIONS FOR FURTHER STUDY

The Walker and Fetsko ink transfer equation is a versatile tool for determining what happens in the nip of the press during the moment of impression. Many variations on the study which has been presented in this thesis are possible. One example is to see the effects of changing the printing pressure on the transfer parameters in regards to wet-on-wet trapping.

One factor limiting the application of the equation in the School of Printing Management and Sciences is the experimental error encountered due to the testing equipment, specifically that printing speed cannot be precisely measured and controlled on the I.G.T. equipment. This author has noticed the existence of many Vandercook proofing presses in the School. This is the type of press which was used by Walker and Fetsko in their ink transfer studies, which are referenced throughout this paper. An interesting thesis would be to adapt one of these presses to conduct ink transfer studies, similar to the work of Walker and Fetsko, with more repeatable accuracy than is currently achieved in the use of the I.G.T equipment.

APPENDIX A

SCHEMATIC DRAWING OF I.G.T PRINTABILITY TESTER



The diameter of the disks is 6.5 cm.
The width of disk 1 is 2.5 cm.
The width of disk 2 is 1 cm.

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