A STUDY OF CONSTRUCTION EFFECTS ON THE COLOR OF CARPET

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SUMMARY

The purpose of this research was to investigate the effects of carpet construction on the carpet color measured by a spectrophotometric method and to examine the validity of the Kubelka Munk theory as applied to dyed carpet.

In this study, two nylon carpets of different constructions were employed, one being cut pile, the other loop pile. They were dyed with an acid dye Orange II at five different initial dyebath concentrations: 0.10 per cent, 0.25 per cent, 0.50 per cent, 1.00 per cent, and 2.00 per cent. The quantity of dye on the nylon fiber was determined by absorbance measurements, using ortho-chlorophenol as a solvent to dissolve the dye and the fiber. The reflectance of the specimens was measured by a reflectance spectrophotometer (large sphere Color-Eye). Carpet construction was varied in three ways: (1) loop pile was cut to form cut-pile; (2) the pile height was sheared in successive stages from a height of 0.32 inch to zero; and (3) pile density was decreased from 1.27 pounds/square yard to zero by pulling out the tufts in a random manner and in accordance with a selected pattern.

Compression of the specimen in the compression sample holder at pressure greater than 60 psi gave reproducible reflectance measurements. Variations of orientation of the specimen about an axis perpendicular to its surface had no appreciable effect on the measurements.

It was found that Kubelka Munk's equation held for Orange II at a wave length of 560 nm, but did not hold at either 400, 500, or 700 nm.

The minimum requirements of pile height and pile density, at which reflectance at 560 and 700 nm wave lengths was maintained at a maximum and essentially constant level, were 0.24 inch (at 0.476 pound/square yard pile density) and 0.635 pound/square yard (at 0.32 inch pile height), respectively, for a 16 denier nylon pile carpet. Under these conditions, variations in the scattering coefficient of the carpet and "grin through" of the carpet backing had negligible effect on the color of carpet.

CHAPTER I

INTRODUCTION

Purpose

The purpose of this research was to investigate the effects of carpet construction on the carpet color measured by a spectrophotometric method, and to examine the validity of the Kubelka Munk theory as applied to dyed carpets.

Statement of Problem

Color matching is the process of selection and compounding the mixtures of colorants to produce a desired color on a given substrate, and it is one of the oldest problems in the textile industry. The trial-and-error method is expensive, time-consuming and produces difficulty in achieving the high degree of accuracy and reproducibility required in industrial color control.[1] Many dye house laboratories have changed to some form of computer color matching in an effort to increase the quality and efficiency of their color matching.

The use of computers in color-matching of carpets has not been accepted as rapidly as computer color-matching of flat fabrics, yarns and fibers. In some instances this hesitancy may be attributed to non-technological problems. However, there are two major technological problems which have delayed progress. One of these is a growing use of multi-color effect fibers in blends. Such blends cannot be readily separated chemically, thus making separate spectrophotometric determination impossible. Second is the fact that most color-matching programs assume that scattering coefficient of the carpet and "grin through" of the backing are constants. Actually these are primarily functions of the carpet construction. In theory this requires that input data on every different construction be assorted. In practice this is an intolerable amount of input for carpet color matching since the style and construction of almost every carpet are different.

Method of Research

In this study, polyamide carpets were dyed by a standard reference acid dye - Orange II. The reflectance of the carpet was measured by using a reflectance spectrophotometer (large sphere Color-Eye). The deviation from Kubelka Munk's equation as carpet construction was varied was quantitatively investigated. The variation of carpet construction included pile forms, as cut pile or loop pile, different pile heights and different pile densities.

Literature Survey

Effect of Fabric Geometry on Color

The effect of construction on the color of carpet has not previously been reported. However some general comments about the relationship between color and textile construction have been made by Coats & Rigg.[2]

> When a beam of light strikes a solid, the nature of the radiation reflected from it will depend greatly upon the structure of the solid . . .
>
> Orientation of the particles in the surface layer (Figure 1) will give rise to some white specular reflection, in addition to the diffuse coloured light. For a woven fabric, the orientation of fibers

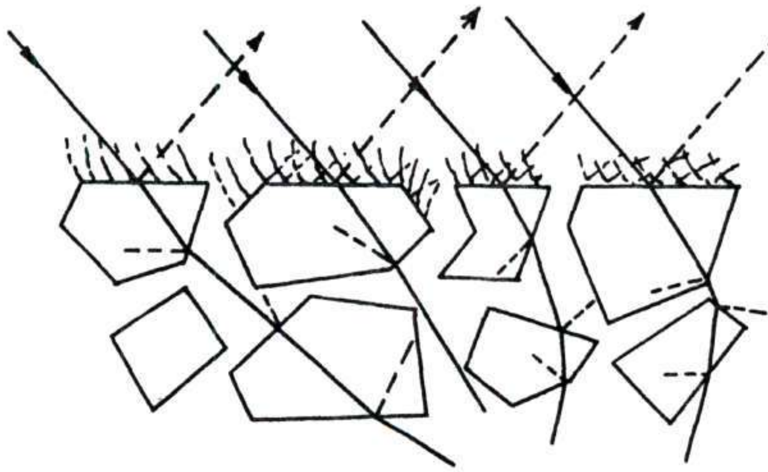


Figure 1. Surface Reflection Caused by Orientation of the Particles in the Surface Layer

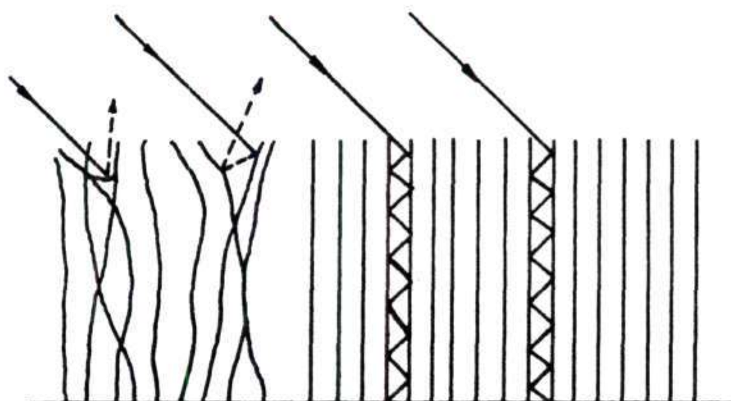


Figure 2. Orientation Effect on the Reflectance of Pile Fabric

> will have a marked effect on surface-reflection properties, and the relation between the directions of illumination and viewing will determine the color appearance . . . A pile fabric, absorbing strongly throughout the visible region of the spectrum and with the pile uniformly orientated in the direction of incidence, will approximate to this condition (Figure 2). It will be appreciated, however, that the appearance of such a fabric will depend critically on the fiber orientation.

Stearns[3] mentioned some of this in a discussion of surface reflectance:

> In order for light to come under the influence of the dye it is necessary for it to penetrate the fiber. There is some light that is reflected from the surface of the fiber and never has a chance to be absorbed. The effective surface reflectance from a fabric depends upon many factors, notably the type of weave. A pile fabric with erect pile has much less effective surface reflectance than a sateen weave fabric of the same fiber.
>
> Pile fabric gives the surface reflected light from one fiber more opportunity to strike and enter another fiber, before complete reversal of direction, than does sateen. The microscopically rough surface of wool compared to polyester gives the surface reflected light more opportunity to strike the same or another fiber before complete reversal of direction. Hence it is impossible to dye normal polyester to as dark a black as wool.
>
> The effect of surface reflectance is to give greater than expected reflectance with increased dye concentration because the surface reflected light does not come under the influence of the dye.

Computer Color Matching

Many workers have contributed to the development of the theory of optical characteristics of the turbid media model employed as a theoretical basis in computer color matching. Duntley has given an excellent review of previous work.[4] In order to increase the accuracy, a number of modified solutions of the differential equations of Kubelka and Munk have been derived.[5] However, only the solution of the differential equations for the case of infinite thickness and uniformity of the colorant layers is applied in the textile field. Infinite sample thickness may be defined in practice as a sample sufficiently thick that any further increase in thickness does not significantly change its reflectance. For the reflectance (R) of monochromatic light, the following solution can be obtained:

$$R = 1 + K/S - \left((K/S)^2 + 2\ K/S \right)^{\frac{1}{2}} \qquad (1)$$

The terms K and S are the absorption coefficient and the scattering coefficient respectively of the material forming the colorant layer.

If equation (1) is solved for K/S in terms of R, the following expression results:

$$\theta = K/S = (1-R)^2/2R \qquad (2)$$

The relationship between K/S and the concentration of dye or other absorbing material in the colorant layer was postulated by Nolan[6] and Foote[7] in work on dyed paper. The absorption coefficient K was assumed proportional to the concentration of the dye, and the light scattered and absorbed by the dye and fiber independently. This may be represented mathematically as follows:

$$\theta = (1-R)^2/2R = K/S \qquad (3)$$

$$\text{where } K/S = \frac{(K_F + K_{D1} + K_{D2} + K_{D3} + ---)}{(S_F + S_{D1} + S_{D2} + S_{D3} + ---)} \qquad (4)$$

If the scattering coefficient of each dye (S_{D1}, S_{D2}, S_{D3}, ---) is assumed to be very small or a constant for all dyes compared to the scattering coefficient of the substrate (S_F), then the equation (5) may be obtained.

$$\theta = \theta_F + \theta_{D1} + \theta_{D2} + \theta_{D3} + --- \tag{5}$$

$$\text{where } \theta_F = K_F/S_F,\ \theta_{D1} = K_{D1}/S_F \text{ etc.} \tag{6}$$

This indicates that θ is assumed an additive function.

Since the absorption coefficient (K) is assumed proportional to the concentration of the dye and scattering coefficient (S) is a constant, the following equation is obtained:

$$\theta = k\ C_D \tag{7}$$

where C_D is the concentration of a single dye and k is a constant. If k is known, C_D can be determined from the value θ_D since

$$C_D = \theta_D/k \tag{8}$$

The value of k can be determined by measuring θ_D at a known concentration of the dye. When the reflectance of a sample of dyed material θ is measured, the result obtained is $(\theta_D + \theta_F)$ and not (θ_D). The value (θ_F) can be determined by measuring undyed material similar to that on which the dyeing is to be made and (θ_D) can be obtained by subtracting θ_F from the measured value of (θ).

$$\theta_D = \theta - \theta_F = (\theta_D + \theta_F) - \theta_F \tag{9}$$

Then equation (5) may also be written as follows:

$$\theta_D = \theta - \theta_F = k_1C_{D1} + k_2C_{D2} + k_3C_{D3} + --- \tag{10}$$

There is similarity between θ_D and the absorbance (A) obtainable from transmittance data. Beer's law states that absorbance, which is the logarithm of the reciprocal of the transmittance, is a linear function of the concentrations of the various colorants in the solution:

$$A = \log_{10}(1/T) = c_1a_1 + c_2a_2 + c_3a_3 + \cdots \tag{11}$$

where A is the absorbance, T the transmittance, c_1, c_2, c_3 . . . and a_1, a_2, a_3 . . . are concentrations and absorbancy indexes of the components, respectively. Value of a_1, a_2, a_3 . . . are constants which can be calculated from the single colorants as in the case of k in reflectance measurement.

The science of computer color-matching is founded on linear equations (10) and (11). Details of some of the methods are given elsewhere.[2,8-14] Due to their high speed the computer allows a selection of matches, in terms of both metamerism and cost, to be economically carried out. Fastness and dyeing properties should be carefully screened before preparing input data to the computer and evaluating various combinations.

CHAPTER II

APPARATUS AND SPECIMENS

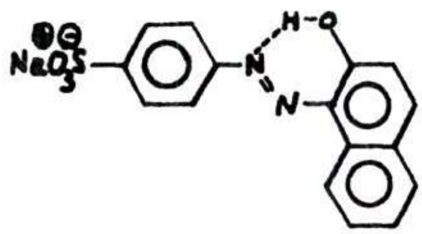
Carpet Specimens

This study was carried out utilizing polyamide carpets since polyamide fiber has been extensively used in the carpet industry and readily accepts dyes.

Two kinds of carpet specimens were studied. One was cut pile with one-half inch pile height, 1.27 pound/square yard density; the other was loop form pile with one and one-fourth inch loop length, 1.44 pound/square yard density. Both carpet specimens were made from a nylon 6,6 type fiber, semi-dull, 16 denier/filament; the fiber was spun into a 2/2 ply yarn and had subsequently been tufted into jute backing.

Dye Specimen

An acid leveling dye, Orange II (C. I. Acid Orange 7), manufactured by E. I. duPont de Nemours and Company, was chosen because its physical chemical properties have been studied in more detail[15] than any other dye suitable for the fiber used.



Orange II (C.I. Acid Orange 7) M.W. = 350.3

The commercial form of the dye was purified by means of recrystallization from saturated aqueous solutions until chromatographic and optical measurements methods showed no colored and/or uncolored impurities. The degree of efficiency of the purification process was checked by use of thin layer chromatography to separately show the colored isomers having different R_f values. UV studies of these chromatography plates also showed the degree of removal of inorganic uncolored materials. The spectrophotometric method was used to check the purity of the dye that resulted from each step in the purification process. The purified dye was dried over phosphorous pentoxide for three days at 1.0 mm mercury and $80^{o}C$.[16]

Apparatus

Shearing Board

A Shearing Board, designed and constructed by the staff of the A. French Textile School, Georgia Institute of Technology at the request of the Tufted Textile Manufacturers Association was used in this study to cut the pile height. The board has been approved by the Federal Housing Administration.

Figure (3) is a drawing of the Shearing Board. Since the carpet specimen with only jute backing was too soft and flexible to perform the normal shearing, a piece of uniformly thick cardboard was glued on the back of carpet specimen to obtain the stiffness required for the shearing operation. By decreasing the number of the height-shims,the cutting edge was lowered and the pile height after shearing was lowered. In general, the pile was combed before each shearing; the sample slide was moved

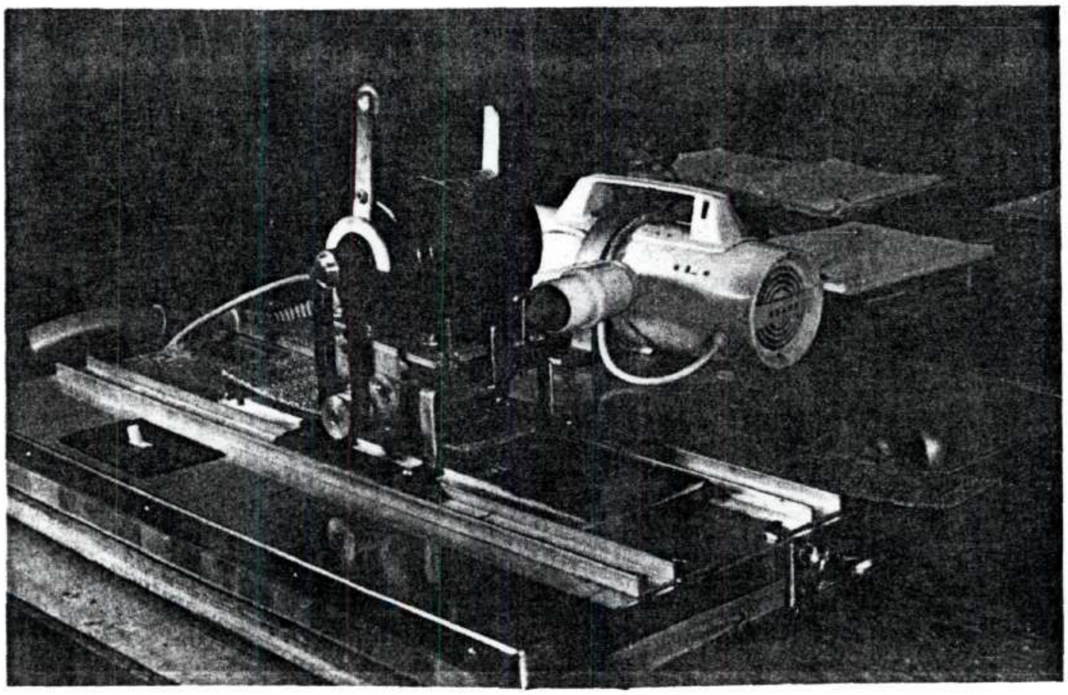


Figure 3. Shearing Board, Designed and Constructed by A. French Textile School, Georgia Institute of Technology

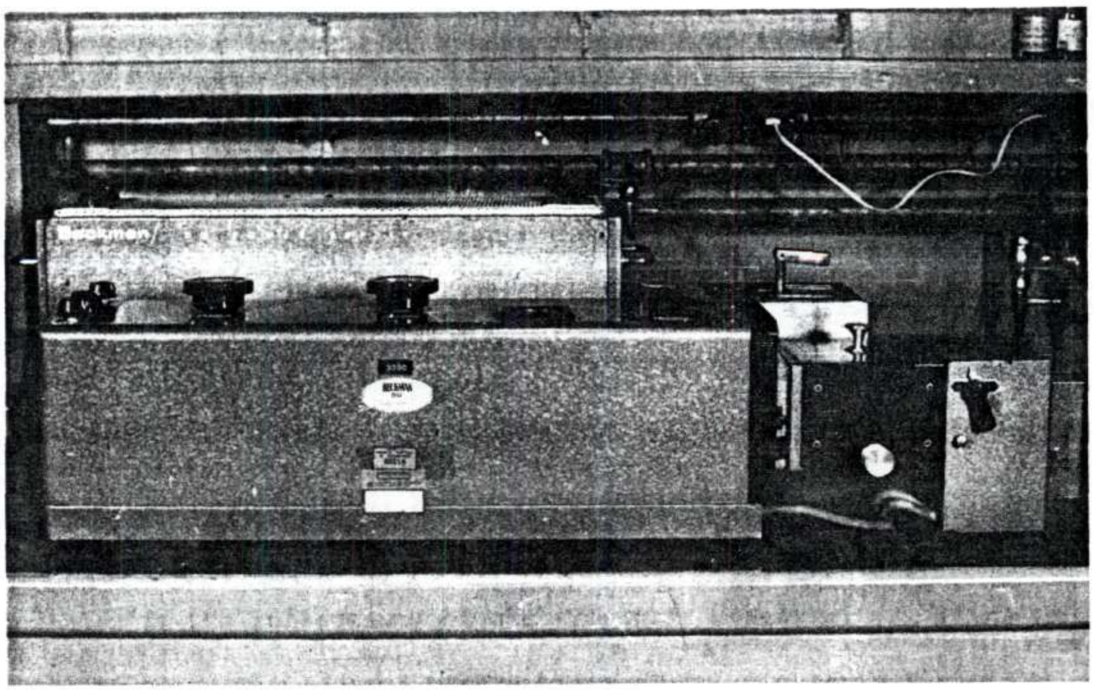


Figure 4. Beckman DU Spectrophotometer

slowly into the shearing position; and the direction of the sample with respect to shearing was changed several times and rerun at the same cutting height to obtain a uniform plane surface.

Beckman DU Spectrophotometer

A Beckman DU Spectrophotometer (Figure 4) was used to determine the actual quantity of dye absorbed by the dyed carpets. The fiber was dissolved in ortho-chlorophenol, and the absorbance was measured using 1.0 cm cells. Standard methods[17] were used to select the proper wave length to obtain precise and reproducible measurements.

Color-Eye

A large sphere Color-Eye, (Figure 5), manufactured by Instrument Development Laboratories, was used to measure reflectance. In this instrument, the sample and standard are diffusely illuminated within an 18 inch diameter integrating sphere and the 2.25 inches diameter sample is viewed at 8^{o} from normal. The instrument is specifically designed for measurement of materials with highly directional or irregular surface characteristics. The Monsanto compression sample holder for the Color-Eye provides a pneumatically-actuated sample presentation apparatus which presses the surface of the specimen against a glass plate for measurement; the specimen can be rapidly engaged and disengaged from the sample holder. The compression of the specimen can be adjusted to a value above a predetermined optimum pressure beyond which no significant variation in the reflectance of the sample is observed.[18] "A" White Vitrolite plate was covered with a glass plate matched to the one in the compression sample holder and was used as the reference plate.

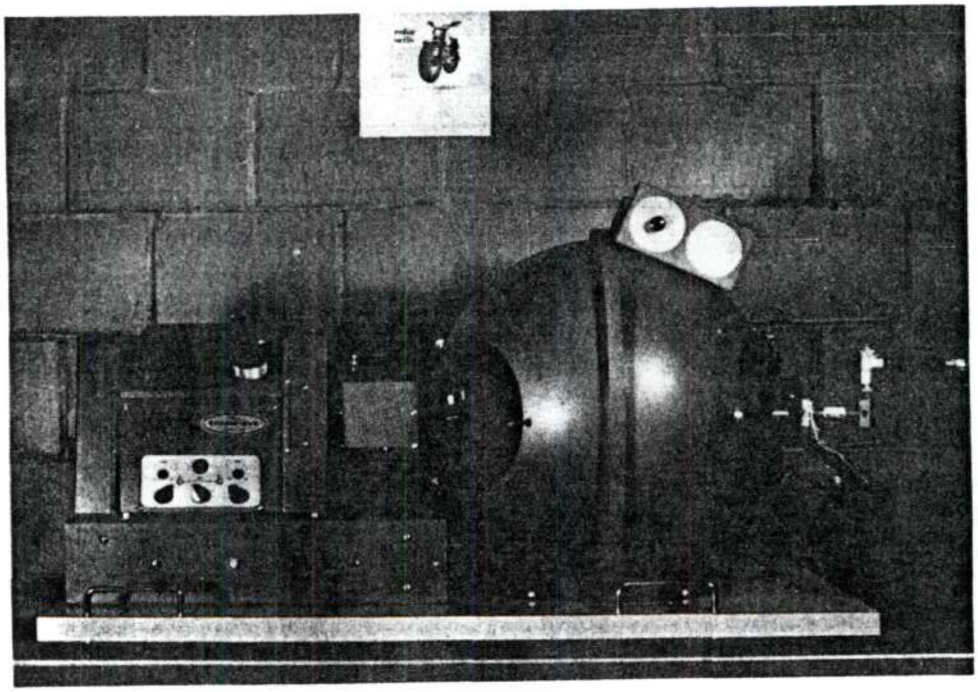


Figure 5. Model Large Sphere Color-Eye, by
Instrument Development Laboratories

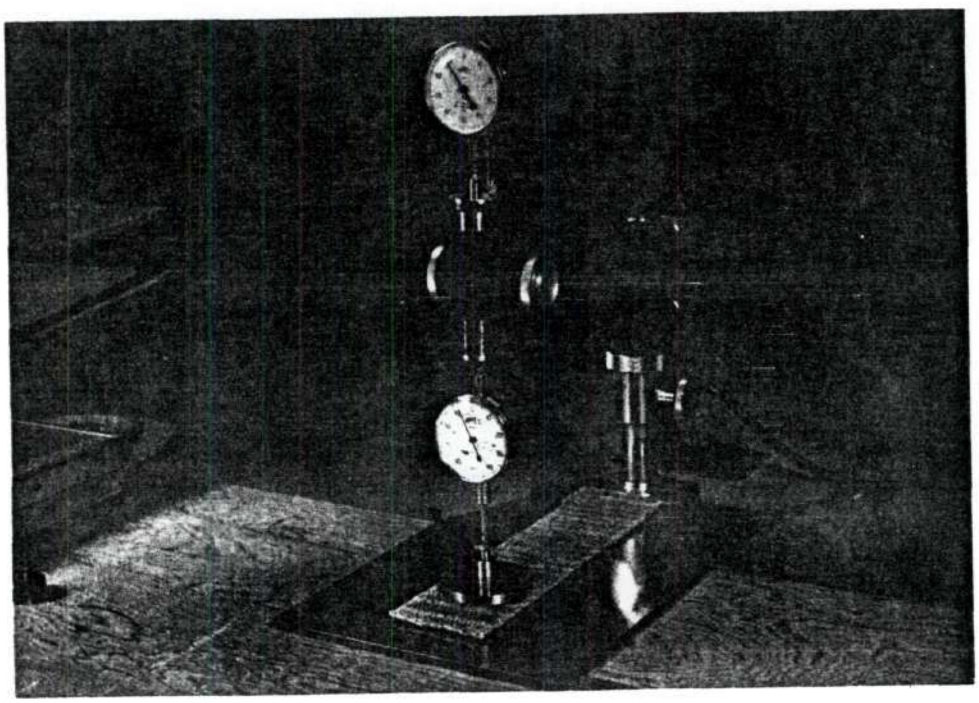


Figure 6. Compressometer, by Frazier
Precision Instrument Company

Compressometer

A compressometer (Figure 6) manufactured by Frazier Precision Instrument Company was applied to measure the pile height of each carpet specimen before and after cutting. All recorded data were the average of five readings.

Specimens were conditioned at 65 per cent relative humidity at a temperature of 70°F. which are the standard conditions for textile testing. The thickness of the specimen recorded is the distance between the foot and the anvil of the compressometer when pressure has been increased to a predetermined amount. The pressure which is applied to the specimen by the foot may be ascertained from the upper dial reading while the thickness of the specimen is indicated on the lower dial.

CHAPTER III

PROCEDURE

Preparation of Samples

Scouring

Carpet specimens were lightly scoured to remove any finishes applied during spinning, weaving, and tufting process. The following recipe was used for the scour:

1 g/1 Olate Flakes (Proctor & Gamble Company, Textile Specialties Section)

Liquor ratio 30:1 with distilled water

Boil for 30 minutes

The carpet was rinsed twice after scouring with 70°C. distilled water and then twice with 25°C. distilled water at a liquor ratio of 30:1. The scour removed most of the color from the jute backing. During scouring and rinsing, care was taken, to avoid damaging the carpet's structure or to pull the pile from backing.

The specimen was dried in the air and was ready for reflectance measurements and dyeing operations.

Dyeing

Dyebaths were prepared with distilled water and the following chemicals:

4.0% Na_2SO_4 (analytical reagent) on weight of carpet with backing

4.0% H_2SO_4 (analytical reagent) on weight of carpet with backing

Liquor ratio 30:1

Five different dye concentrations: 0.10 per cent, 0.25 per cent, 0.50 per cent, 1.00 per cent, and 2.00 per cent were used. All dyebaths were brought to the boil in 30 minutes, and boiled for 10 hours under reflux. With this procedure, the dye diffused into the fiber's cross-section and the dye in the fiber was apparently in equilibrium with the dye in the dyebath.

The carpet specimens after dyeing were again dried in the air. A small amount of dyed nylon fiber from each different dyebath concentration was used to determine the concentration of dye on the fiber, and the remainder of the sample was modified with respect to construction and their reflectance measurements were made on the Color-Eye.

Determination of the Concentration of Dyes on the Fiber

Orange II and nylon fiber from undyed carpet specimens were separately dissolved in ortho-chlorophenol then mixed and used to prepare a calibration curve from which determination of dye concentrations on dyed carpets could be subsequently made. Optical stability of the dye solutions was checked and shown to be sufficiently stable for the experimental period.[17]

In this determination, only the nylon fibers on the carpet specimens were studied. Care was taken to pick out any jute fibers in the sample using a pair of tweezers and a magnifying glass. It was found that the presence of jute fiber suspended in solutions resulted in erroneous spectral data.

Selection of Working Wave Length

The absorbancy spectrum of Orange II in the visible region was measured at three concentrations. The reference cell solution was prepared by weighing out 0.01 gram of undyed scoured nylon fiber, dissolving the fiber in ortho-chlorophenol in a volumetric flask, and diluting the liquid to 10 milliliters. The sample cell solutions were prepared as described previously using fibers from the dyed carpet specimens. Absorbancy readings were made each 20 nm from 400 nm to 700 nm.

Figure 7 shows the spectrum of Orange II from dyed carpet at 0.50 per cent initial dyebath concentration based on the weight of the conditioned carpet with backing. There were two peaks in the curve; however, the peak occurring at 500 nm wave length was the more stable and was chosen as the wave length to be examined.

Preparation for Calibration

A 2×10^{-4} gram per liter stock solution of Orange II was prepared. Reference cell solution was prepared by dissolving 0.01 gram of undyed nylon fiber in 25 ml. of ortho-chlorophenol. Each sample solution was prepared by weighing out 0.01 gram of undyed nylon fiber and adding various amounts of Orange II stock solution followed by addition of ortho-chlorophenol to make 25 ml. of solution.

Absorbancy measurements were made at a wave length of 500 nm on the DU Spectrophotometer for 15 sample solutions at various concentrations of Orange II. The concentration of dye in sample solution was expressed in terms of per cent Orange II on weight of nylon fiber. As

$$\frac{\text{X ml. of stock solution}}{\text{1,000 ml./l.}} \times \frac{2 \times 10^{-4} \text{ gms./l.Orange II}}{\text{0.01 gram of nylon}} \times 100 = \text{\% o.w.f.} \quad (13)$$

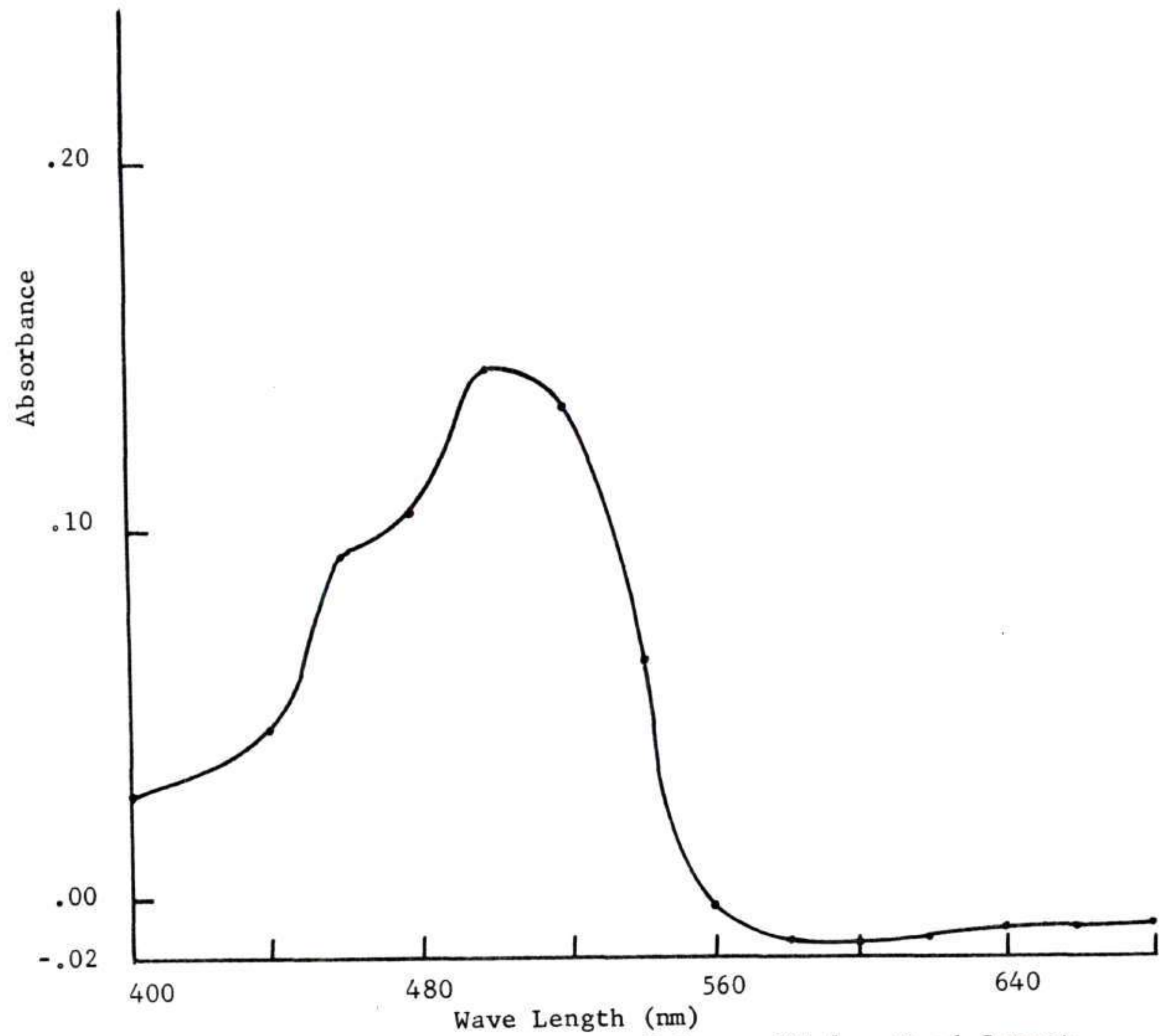


Figure 7. Absorbancy Spectrum of Orange II from Dyed Carpet at 0.50% Initial Dyebath Concentration

A plot of absorbance versus concentration (per cent o.w.f.) yielded a straight line (Figure 8) indicating that the dye solution obeyed Beer's law.[19] This calibration curve was used as a reference standard to determine the actual amount of dye on the nylon fiber of dyed carpets.

Measuring the Absorbance of Nylon Fiber on Dyed Carpets

The reference cell solution was prepared by weighing out 0.01 gram of undyed nylon fiber and dissolving in ortho-chlorophenol to make a 25 ml. solution.

The sample cell solutions were prepared by weighing out 0.01 gram of colored nylon fiber from each dyed carpet specimen and dissolving it in ortho-chlorophenol to make 25 ml. of solution. The absorbance of the solutions of the respective samples was measured at 500 nm wave length and their concentration obtained from the calibration curve depicted in Figure 8.

Measuring the Reflectance of Carpet Specimens

All the carpet specimens were picked free of jute fiber contaminants as previously described.

The Color-Eye was calibrated according to the manufacturer's recommended procedure. Light source C, high sensitivity and non-specular inserts were used for all measurements with "A" White Vitrolite plate as the reference standard. The digital dial was used for all measurements by nulling the potentiometer to 100 per cent and reading to four significant figures.

The carpet specimens were measured in two ways, both without the compression sample holder and with the compression sample holder. When

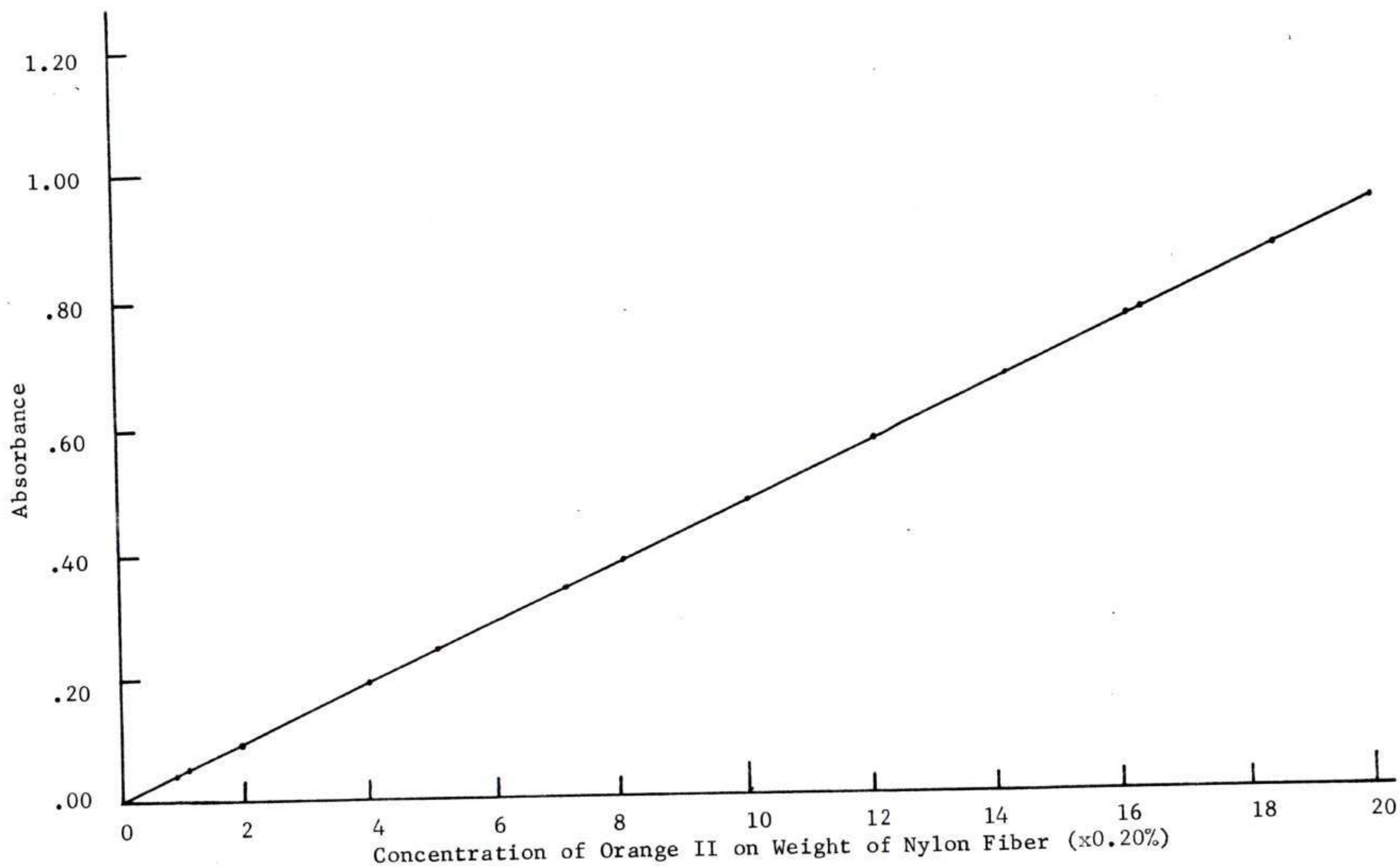


Figure 8. Calibration Curve of Orange II (at 500 nm) on Nylon Fiber

using the compression sample holder, a matched pair of glass plates supplied by the manufacturer was placed in front of the holder and the Vitrolite reference.

Changing the Pile Form, Height and Density of Carpet

Change of Pile Form

A pile form study was carried out on loop pile carpet. After completing the reflectance measurement of the loop carpet, all loops were cut individually at the top of the loop with a pair of scissors thus providing two tufts.

Change of Pile Height

Pile height was changing by going through the Shearing Board and decreasing the number of height-shims one at a time. Specimens of eight different heights were examined and measured with the Compressometer. The Compressometer was set with a three-inch pressure foot and the reading was taken from the lower dial ten seconds after the upper dial read 40. At this setting the upper dial reading was equal to 0.10 pound/square inch pressure using the calibration table supplied by the manufacturer. Each reading recorded was the average of five measurements.

Change of Pile Density

Pile density was varied on the full height cut-pile carpet specimens. The cut-pile carpet specimens, measured by use of the Compression Sample Holder, had a diameter of two and one-fourth inches and contained a total of 354 tufts uniformly distributed in 20 rows.

The density of pile was decreased by randomly pulling out 10 tufts at a time. Experiments showed that the pattern used in pulling the tufts had a negligible effect on the resulting reflectance. The order of pulling out the tufts from previously designated position was in accordance with numbers selected from a table of random numbers.[20] When a three-digit number was larger than 354 or indicated the position of a previously removed tuft, the first digit in the number was discarded and the second digit was considered as the first digit of the next three-digit number. If the number obtained was unsuitable, a digit was moved one more position until a suitable number was obtained.

When every tuft of the first specimen had been pulled out, the tufts in the specimens at other dye concentrations were pulled out according to this same number sequence. It was expected that this procedure would assist correlation among different dye concentrations.

During all reflectance measurements the specimens were oriented so that the row of tufts were vertical to the support clip of the Color-Eye unless otherwise specified.

CHAPTER IV

RESULTS AND DISCUSSION

Concentration of Dyes on Nylon Fiber

Ortho-chlorophenol solutions of the Orange II obey Beer's law, i.e., absorbances are proportional to the concentrations of Orange II as indicated in the calibration curve of Figure 8.

Table 1 shows quantity of dyes initially added to the bath as a per cent of solution and the concentration of Orange II on the nylon fiber as determined by solution analysis.

Reflectance Measurements

The reflectance measurements of a sample are modified by a change in compression and orientation of the warp direction of the sample with respect to a vertical axis when it is placed in the sample port of the Color-Eye.

Figure 9 shows the reflectance spectra of carpet specimens after scouring, blank dyeing and dyeing with Orange II. Blank dyeing reduced the reflectance of the carpet material, especially at the shorter wave lengths below 540 nm, indicating that the nylon fiber had been contaminated by extraction of impurities from the jute backing. Such staining of the nylon by the backing is known to occur in wet processing of carpet.

Table 2 indicates the reflectance average ($\bar{R}$), standard deviation (δ) and per cent coefficient variation (CV per cent) of the carpet specimens dyed by 0.50 per cent Orange II under different compression measured

Table 1. Absorbance and Reflectance Data of Dyed Carpets

Specimen No.	Dye Bath Concentration initially added to the bath based on weight of carpet with backing	Absorbance (at 500 nm)	Dye Concentration % obtained by solution measurements (on weight of nylon fiber)	Reflectance 560 nm R(%)	Reflectance 560 nm K/S	Reflectance 700 nm R(%)	Reflectance 700 nm K/S
1	0.10%	0.032	0.137	46.02	0.3166	84.78	0.01366
2	0.25%	0.090	0.385	33.57	0.6573	85.03	0.01318
3	0.50%	0.166	0.710	25.66	1.0768	86.44	0.01064
4	1.00%	0.344	1.472	16.19	2.1693	84.32	0.01458
5	2.00%	0.587	2.512	9.66	4.2243	78.66	0.02894

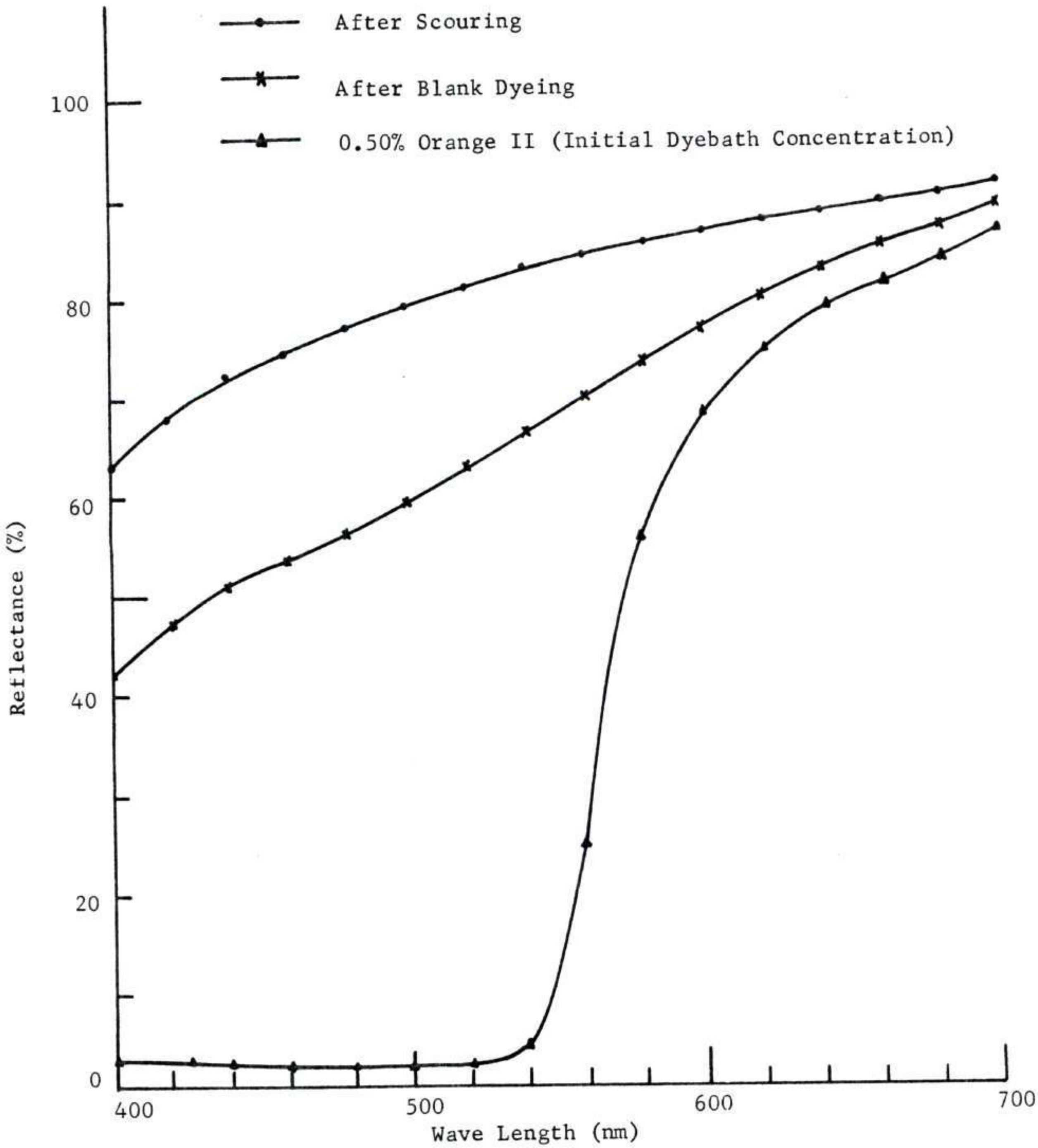


Figure 9. Reflectance Spectra of Compressed Carpet Specimens
(Pressure Inside Compress Sample Holder 80 psi)

Table 2. Reflectance (%) Variation of a Typical Carpet Specimen Under Different Pressures

Carpet Specimen Dyed by 0.50% Orange II (o.w.f.) Initial Dyebath Concentration

Reference: "A" White Vitrolite plate

Measured at 700 nm wave length

Measurement No.	Pressure (psi) 0	25	50	75	100
1	78.68	82.28	85.38	86.77	86.99
2	79.21	82.37	85.32	86.72	86.99
3	77.41	82.25	85.32	86.70	86.86
4	78.62	81.74	85.48	86.56	86.81
5	79.10	81.79	85.70	86.59	86.81
6	79.41	81.57	85.52	86.64	86.81
7	77.02	82.14	85.27	86.56	86.81
8	77.59	81.65	85.27	86.47	86.81
9	78.66	82.32	85.52	86.51	86.81
10	77.59	81.51	85.88	86.45	86.83
Average Reflection $\bar{R}$	78.329	81.962	85.466	86.597	86.853
Standard Deviation δ	0.807	0.323	0.189	0.103	0.070
Per Cent Coefficient CV% Variation	1.030	0.394	0.222	0.119	0.081

at 700 nm. The higher the pressure, the higher the reflectance and the smaller the standard deviation (δ) and the per cent coefficient of variation (CV per cent).

Figure 10 shows the effect of rotating the carpet specimen to several positions about a horizontal axis normal to the surface on the respective reflectance measurements of the specimen. The vertical position of the warp is the standard (0 per cent), the percentage of the variation of reflectance (R) when the warp direction is rotated to a 45^{o} or 90^{o} position from the vertical are indicated in the figure. The distribution of data is quite random and under $\pm$ 4 per cent. This indicates that the positioning of the sample is not critical in the measurement because of the diffuse illumination and large integrating sphere characteristics of the instrument.

Application of Kubelka Munk's Equation

In Figure 11, data for reflectance versus dye concentration on the fiber are exhibited for a range of light wave lengths. From the figure, it appears that no linear equation can be found in the relation between reflectance and the dye concentration on the fiber.

In Figure 12, K/S at various wave lengths versus the dye concentrations are plotted. Kubelka Munk's equation states that K/S is proportional to dye concentration on the fiber if a monochromatic light is used and if K/S is plotted versus dye concentration, a straight line should result at most wave lengths. However, in the experiments, a straight line was obtained only at wave length 560 nm.

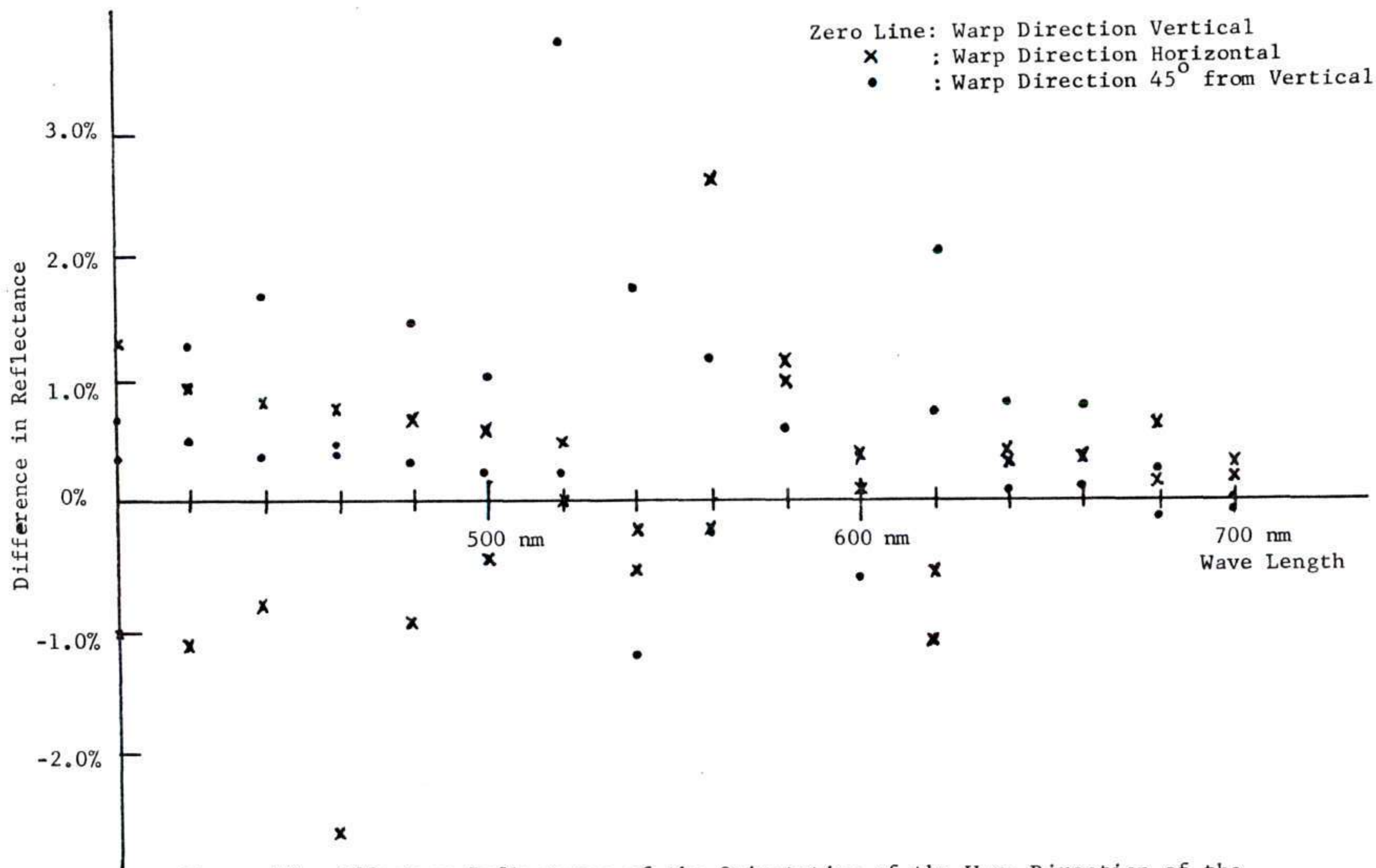


Figure 10. Effect on Reflectance of the Orientation of the Warp Direction of the Carpet Specimen in the Compression Sample Holder

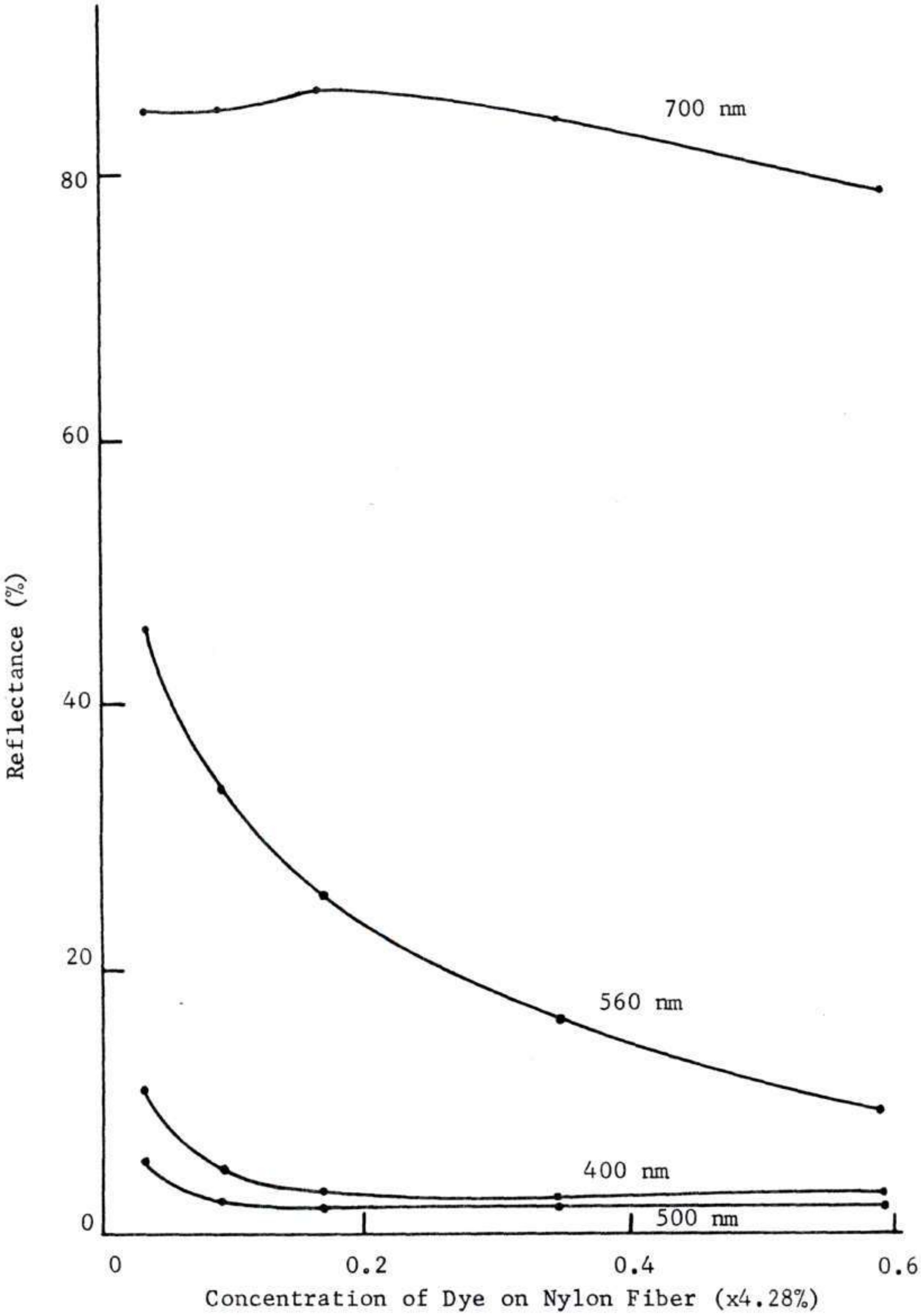


Figure 11. Reflectance versus Dye Concentration on Fiber at Selected Wave Lengths

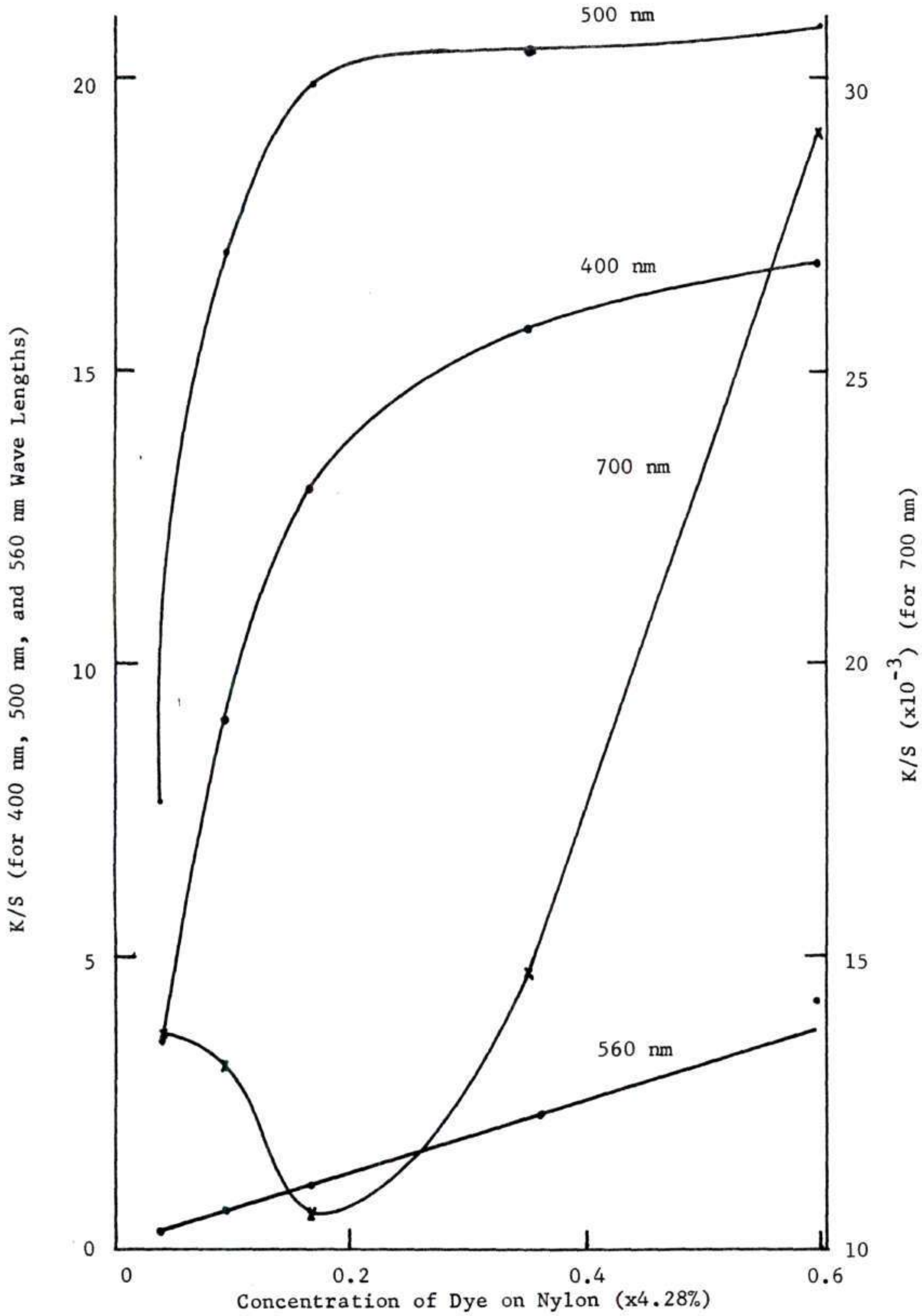


Figure 12. K/S versus Orange II Concentration on Nylon Fiber at Selected Wave Lenths.

Variation of Carpet Construction

Variation Due to Pile Form

All the loop form carpet specimens had exhibited essentially the same reflectance data under 80 pounds/square inch compression both before and after their loops have been cut. The difference between the per cent reflectance (R) readings was only $\pm$ 0.50. The nylon tufts, after cutting the loop and combing, still retained the curved shape and did not stand perpendicularly to the backing under 80 psi pressure. The changing appearance of the sample was undetectable instrumentally as a result of cutting the loops. However, after the loop pile carpet was passed once through the Shearing Board, its reflectance was decreased.

Variation Due to Pile Height

Figures 13, 14, 15 and 16 show the effect of pile height on the spectra (R or K/S) of cut pile carpets with different dye concentrations. All the data indicate that when pile heights are shortened, reflectance of specimens, regardless of different dye concentrations, tends to converge to the points which are the reflectance of the carpet backings at the given wave length. Figures 13 and 15 indicate that convergence is more rapid at the last stage before the final shearing. This is due to the fact that the reflectance of the carpet is considerably different from that of the backing of 560 nm wave length. In Figures 14 and 16, it is obvious that the reflectance is changing gradually when the pile height is lower than 0.24 inch and for pile height higher than this, the reflectance reading is constant. This indicates that a minimum required pile height at a density of 0.476 pounds/square yard is 0.24 inch for a carpet to have consistent reflectance readings.

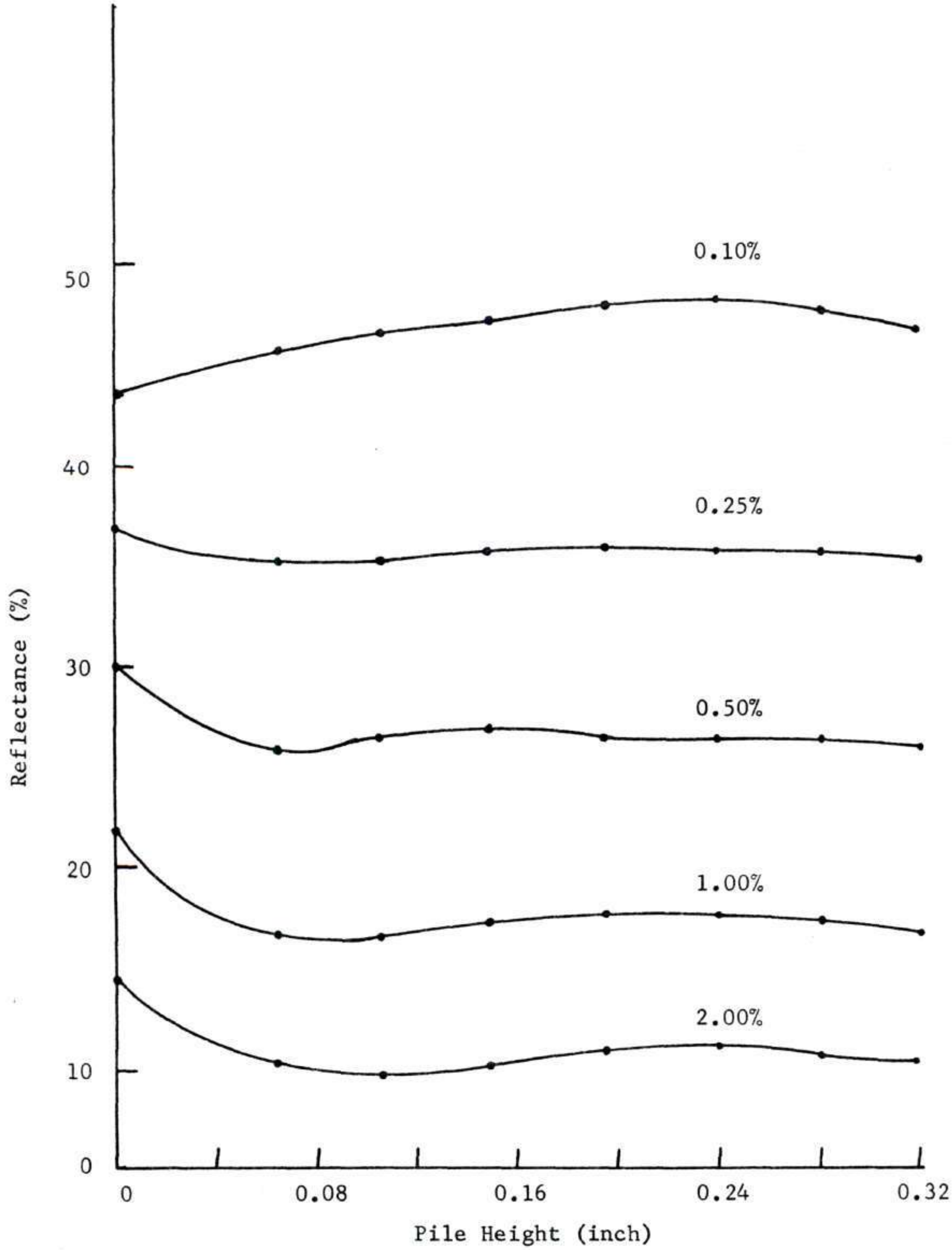


Figure 13. Effect of Pile Height on Reflectance of Cut-pile Carpet at Selected Dye Concentrations at 560 nm

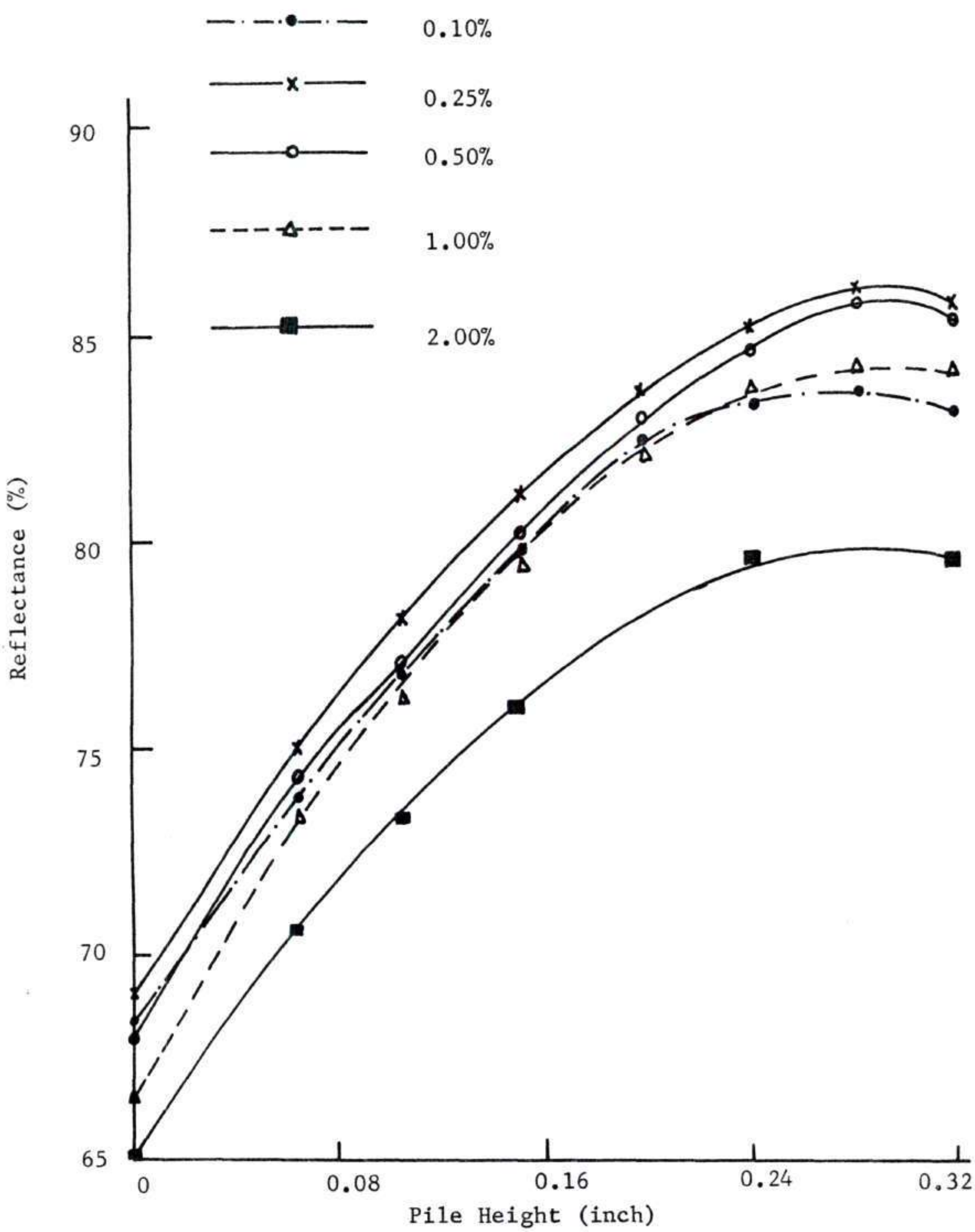


Figure 14. Effect of Pile Height on Reflectance of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

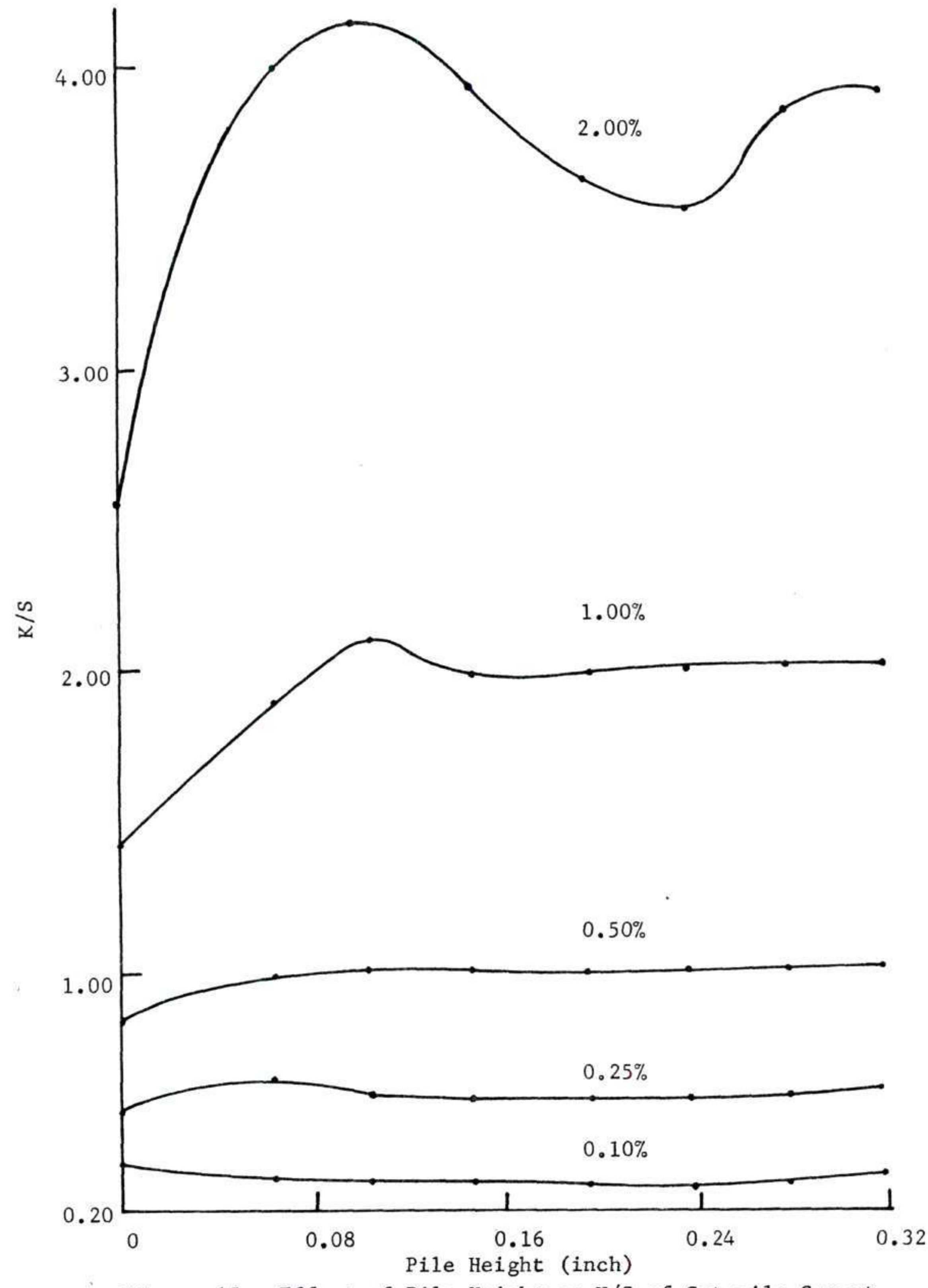


Figure 15. Effect of Pile Height on K/S of Cut-pile Carpet at Selected Dye Concentrations at 560 nm

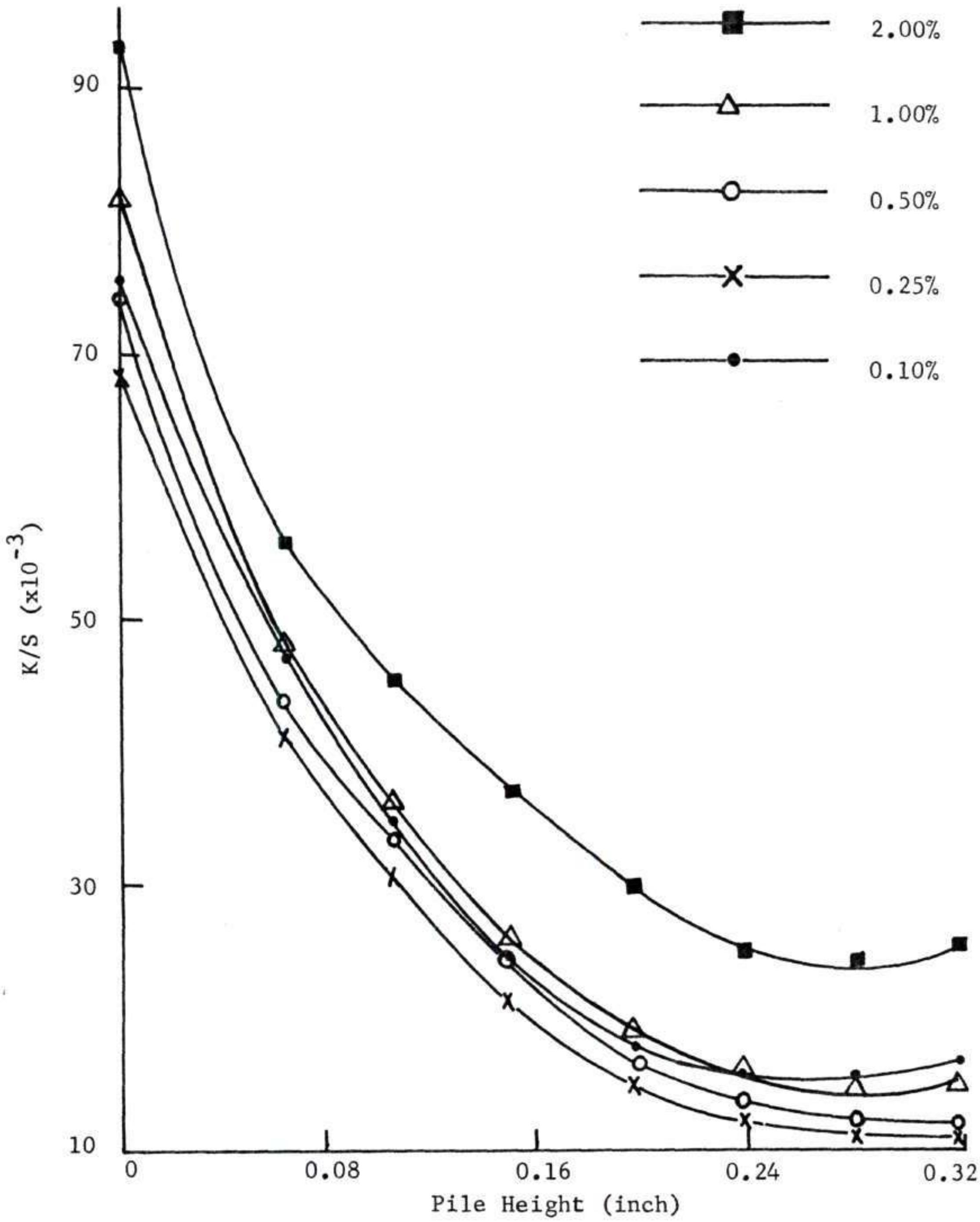


Figure 16. Effect of Pile Height on K/S of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

Figures 17, 18, 19 and 20* indicate the effect of pressure on the reflectance of carpet specimen dyed to different levels, regardless of pile height and dye concentration, the compression pressure applied for reflectance measurement should be higher than 60 psi to obtain a reproducible result.

Variation Due to Pile Density

Figures 21, 22, 23 and 24** show the effect of pile density on reflectance data in terms of both reflectance (R) and K/S. These curves also display a tendency to converge on the reflectance of the backing as do the plots of the data for the various pile heights. These curves indicate that the jute backing is stained to different intensities by various concentrations of Orange II. It was calculated that the minimum density of carpet pile for reproducible spectral results at a pile height of 0.32 inch is 0.635 pounds/square yard.

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*See Appendix pages 40-43.

**See Appendix pages 44-47.

CHAPTER V

CONCLUSIONS

Kubelka Munk's equation can not be applied for reflectance spectral analysis of dyed carpets as accurately as Beer's law is applied to absorbancy measurement of dyes in solution. The K/S versus dye concentration on the fiber must be evaluated over a selected range of wave lengths of visible light in order to determine if a linear relationship fitting the Kubelka Munk equation exists. A working wave length can then be chosen. For the leveling acid dye Orange II, at a wave length of 560 nm and only at this wave length, the K/S obtained from the reflectance (R per cent) is proportional to the dye concentration on the nylon fiber. The minimum requirements of pile height and pile density for constant reflectance are 0.24 inch (at 0.476 pound/square yard pile density) and 0.635 pound/square yard (at 0.32 inch pile height), respectively, for a 16 denier nylon carpet. Under this condition, variation in the scattering coefficient of the carpet and "grin through" of the carpet backing can be assumed to be negligible in computer color-matching programs.

When measuring the reflectance by employment of a compression sample holder in the large sphere Color-Eye, the greater the pressure, the greater and the more reproducible are the reflectance readings (R per cent) obtained. For practical measurements, the pressure should be above 60 psi and kept constant in all measurements to obtain reproducible readings.

The effect of pile form on reflectance could not be quantitatively defined by the experiments performed. However, for the same dye content cut pile carpets will generally appear darker than a corresponding loop pile carpet of similar pile density and pile height.

CHAPTER VI

RECOMMENDATIONS

A pile form effect on the reflectance reading was shown for two carpet specimens of the same pile height and pile density, one in loop form and the other in cut pile form. The effect of pile form on reflectance should be further investigated.

The denier of the fiber and the dichroism of the dye on the fiber may also affect the reflectance measurements and these effects should be examined.

APPENDIX

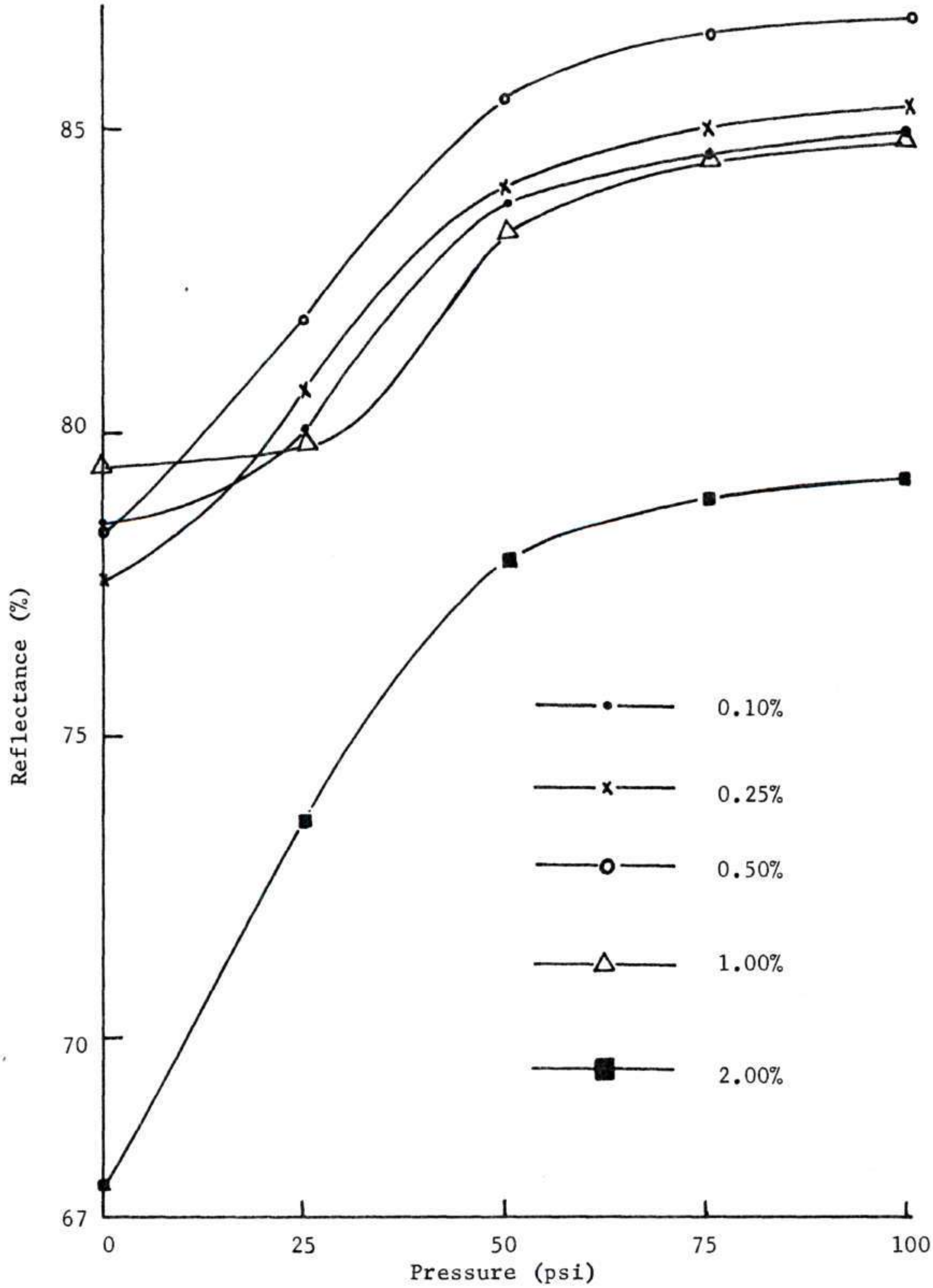

Figure 17. Effect of Pressure on Reflectance of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

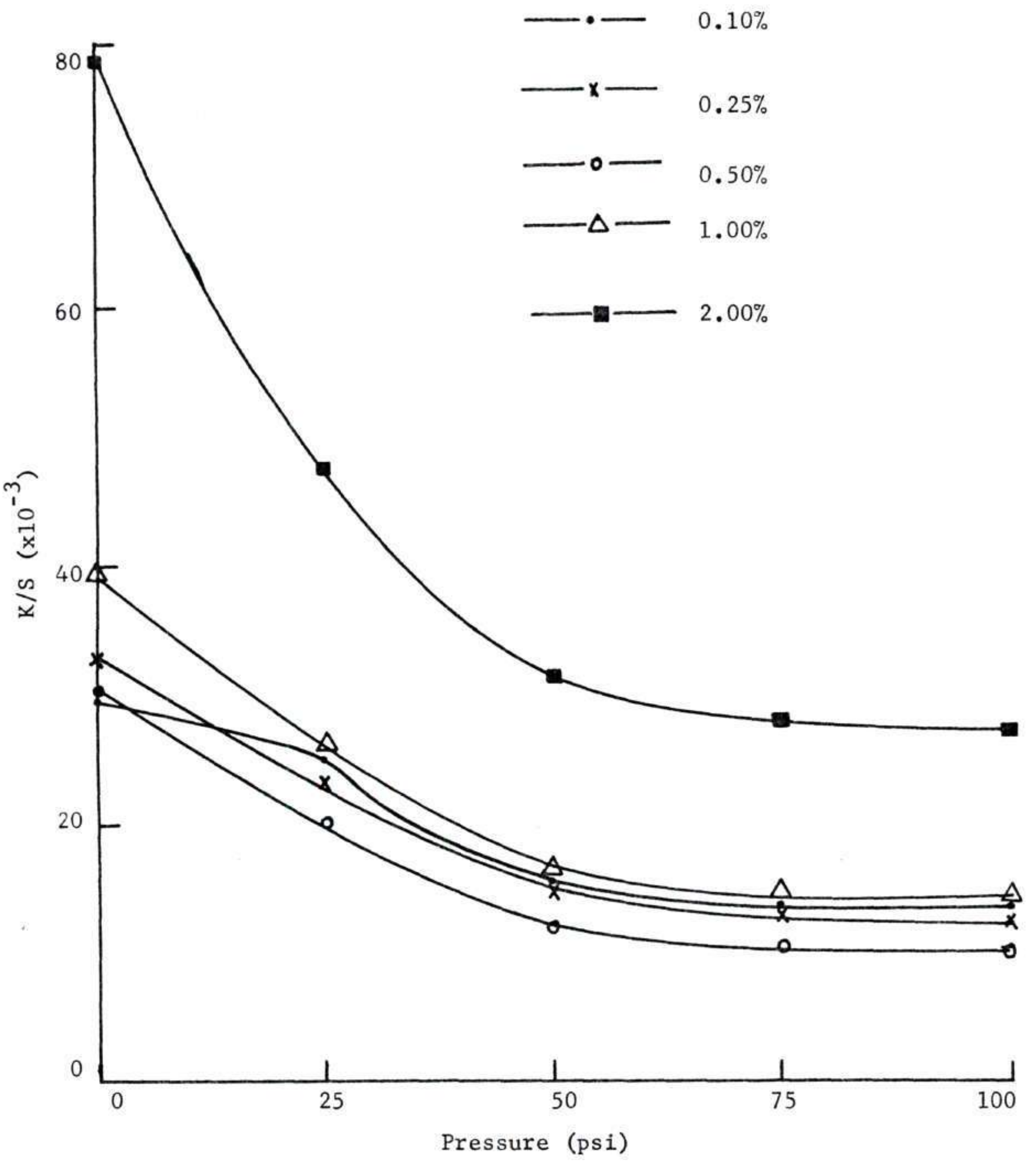

Figure 18. Effect of Pressure on K/S of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

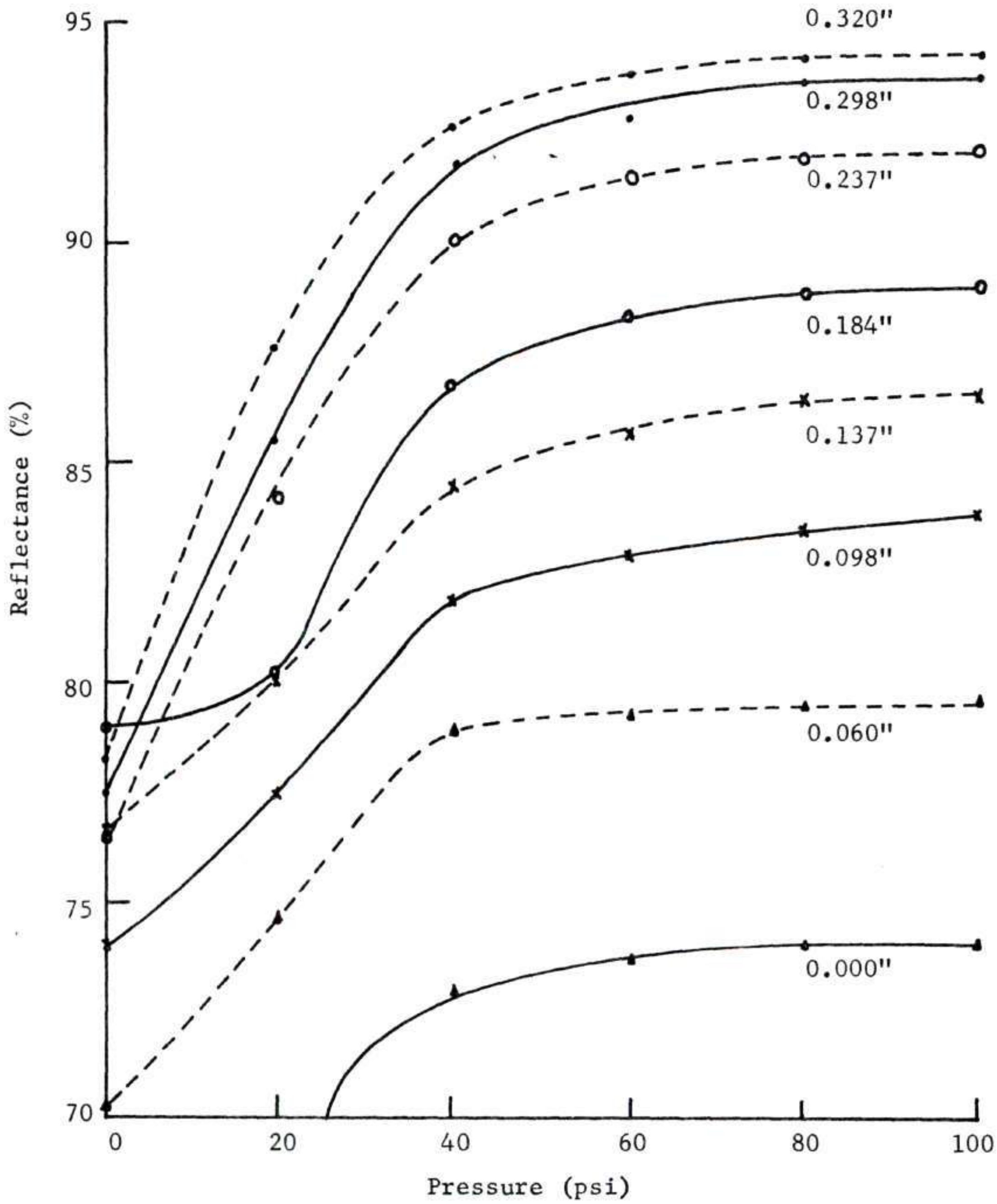

Figure 19. Effect of Pressure on Reflectance of Loop-pile Carpet Dyed by Orange II 0.50% Initial Dyebath Concentration at 700 nm

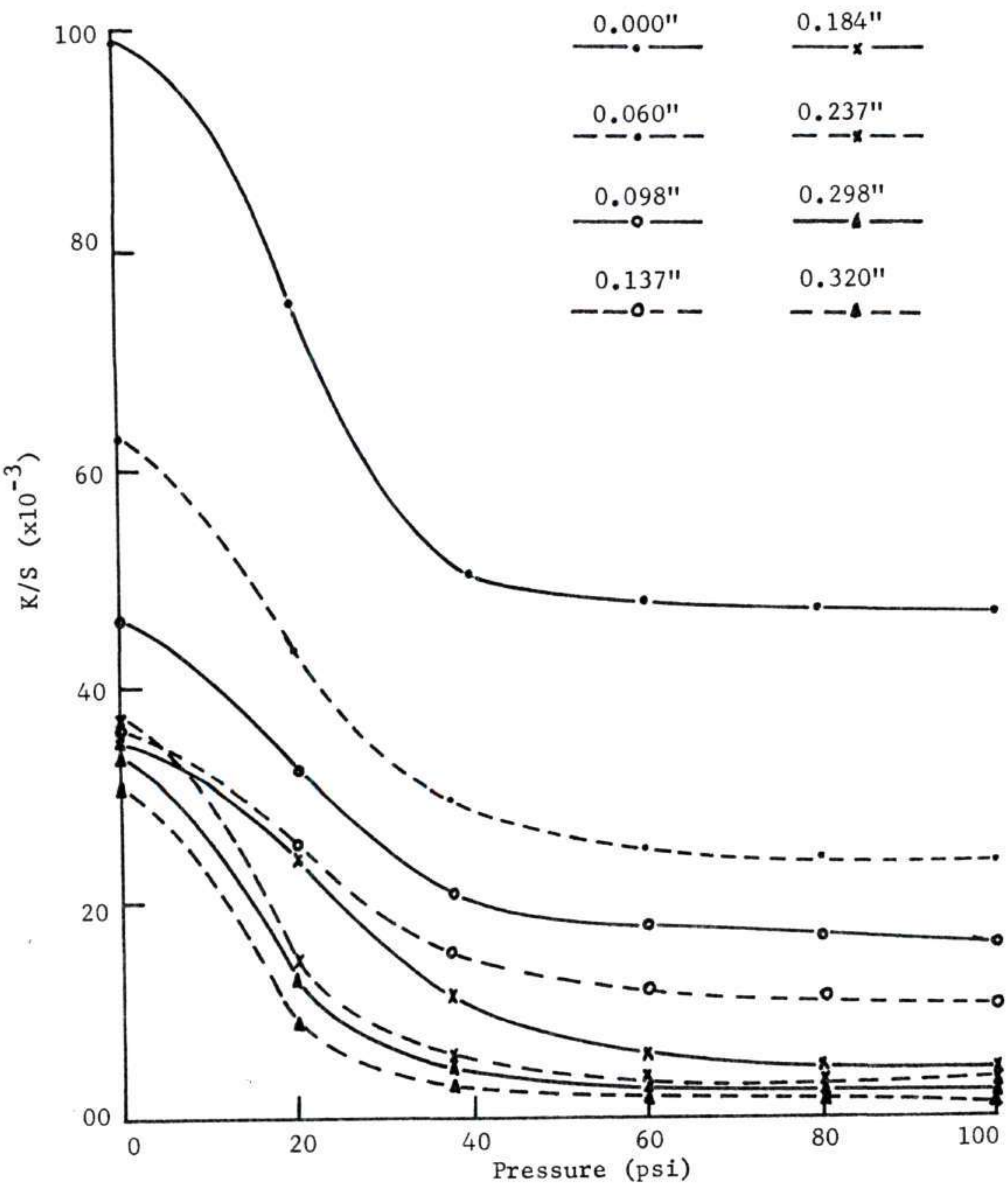

Figure 20. Effect of pressure on K/S of Loop-pile Carpet Dyed by Orange II 0.50% Initial Dyebath Concentrations at 700 nm

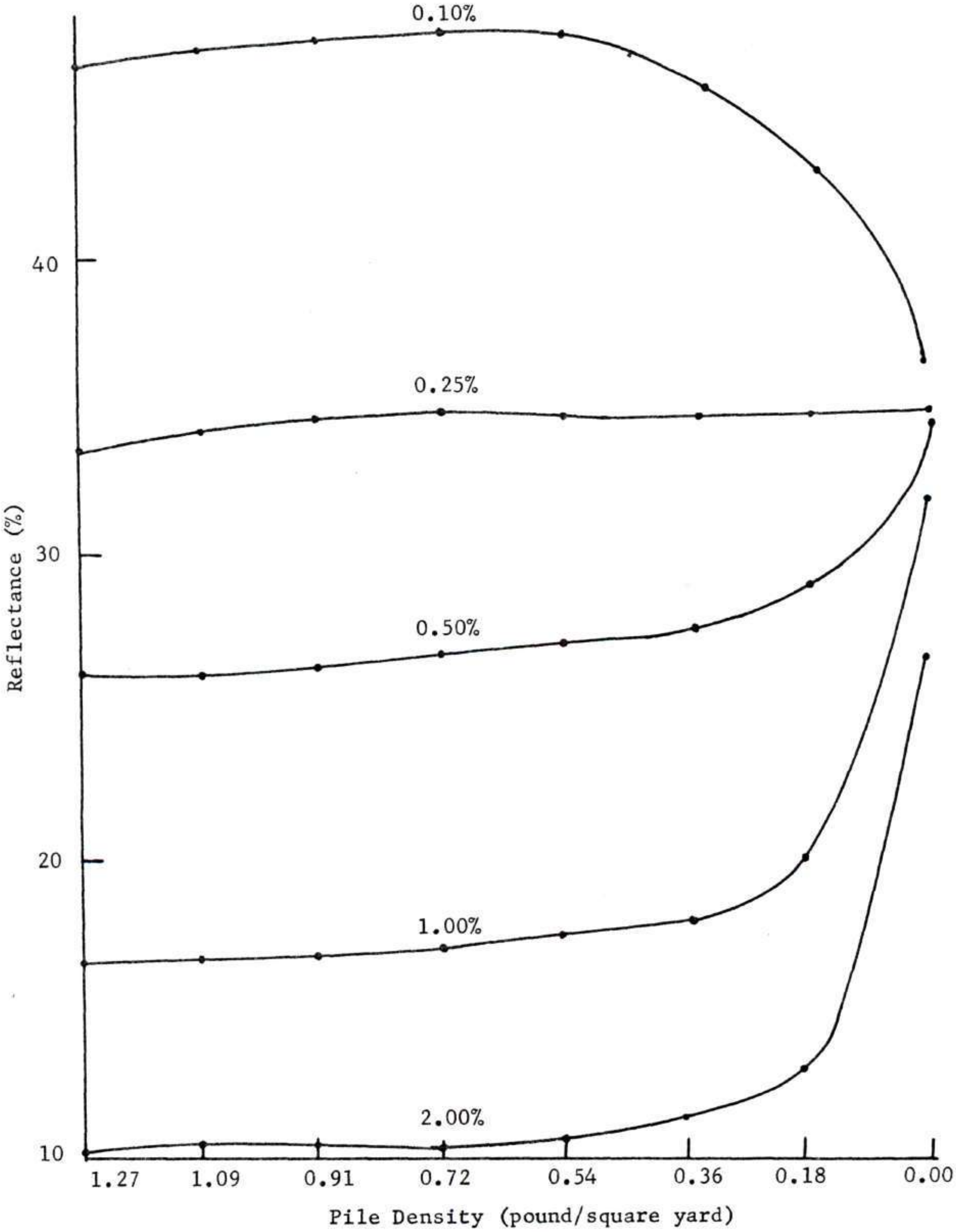

Figure 21. Effect of Pile Density on Reflectance of Cut-pile Carpet at Selected Dye Concentrations at 560 nm

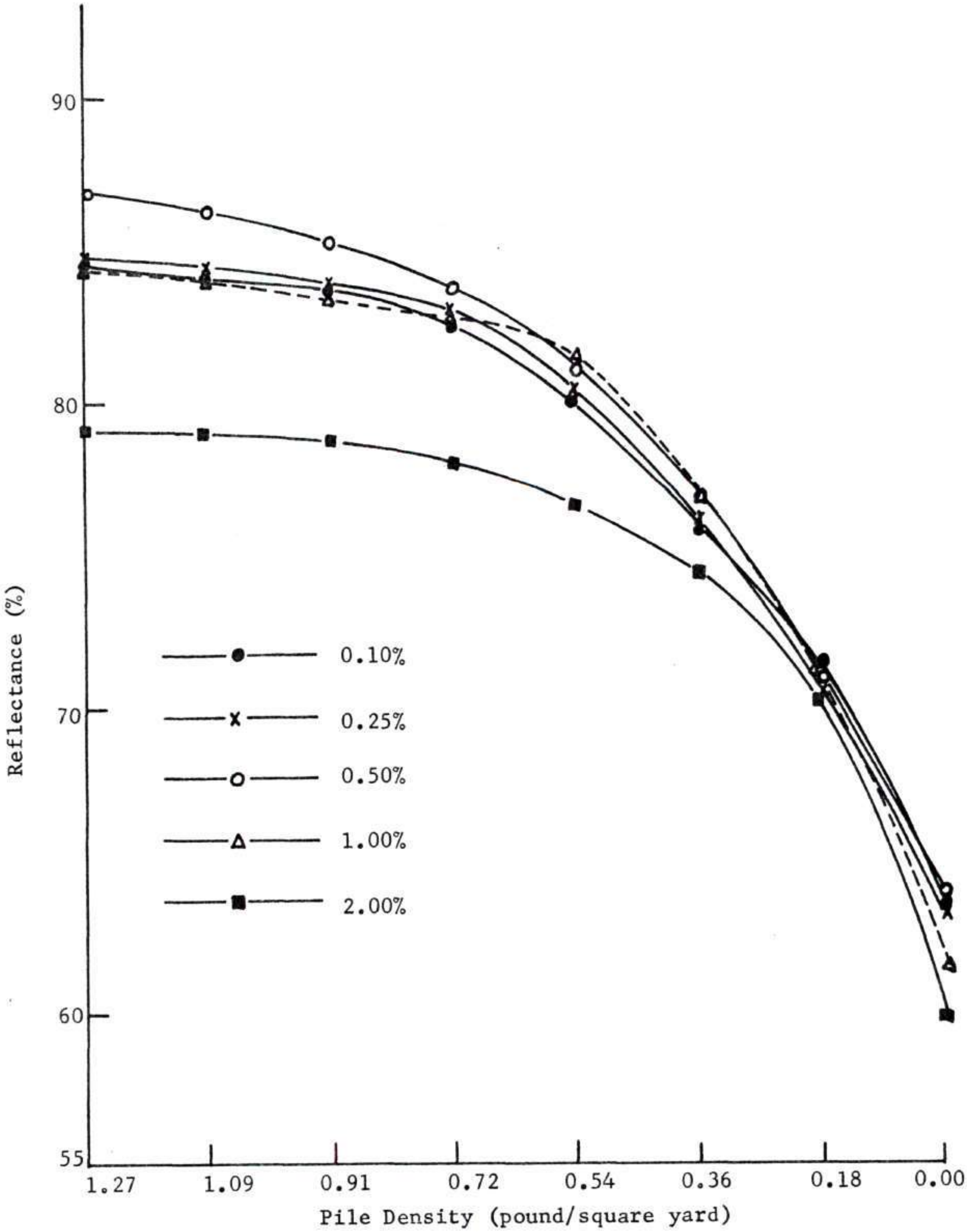

Figure 22. Effect of Pile Density on Reflectance of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

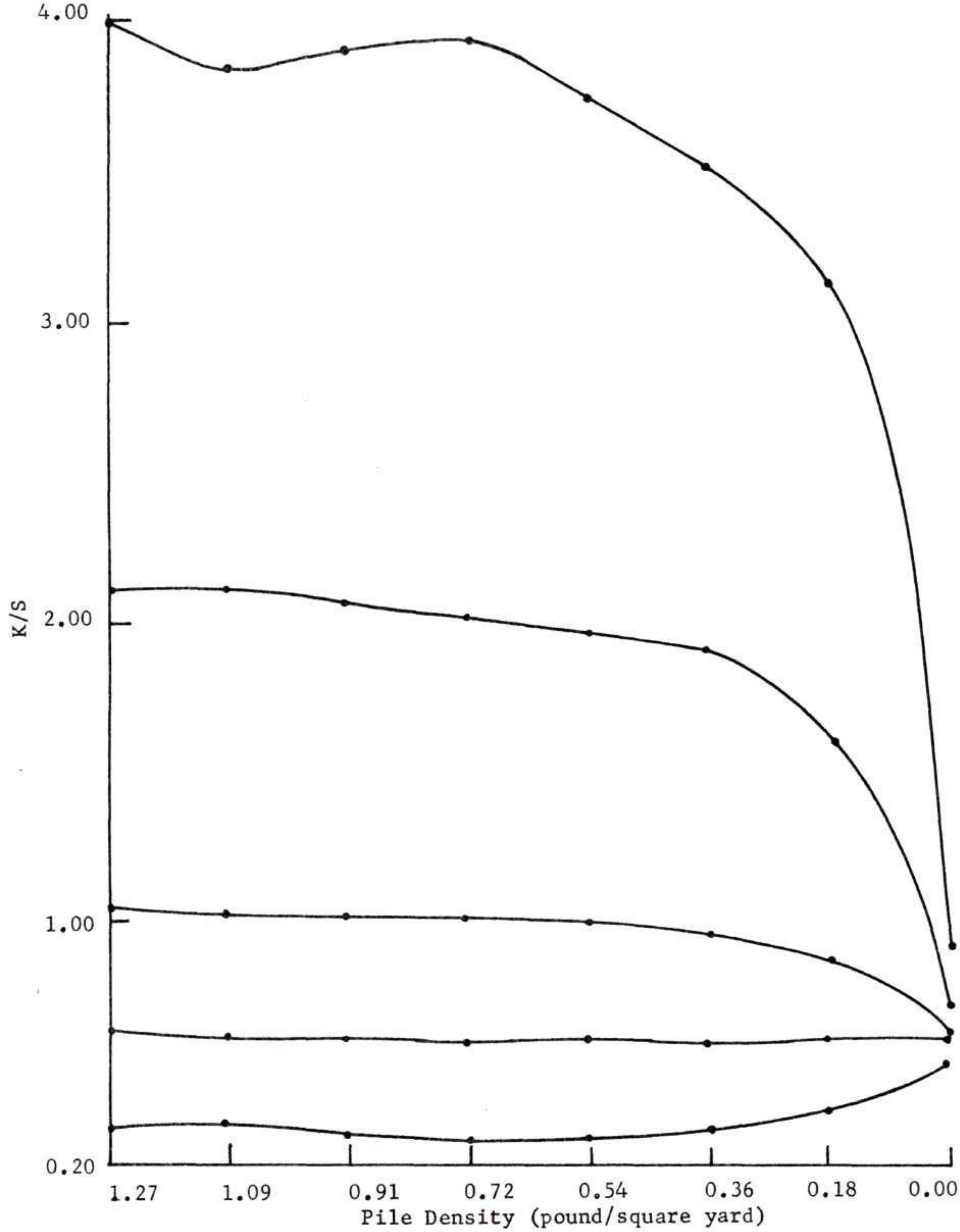

Figure 23. Effect of Pile Density on K/S of Cut-pile Carpet at Selected Dye Concentrations at 560 nm

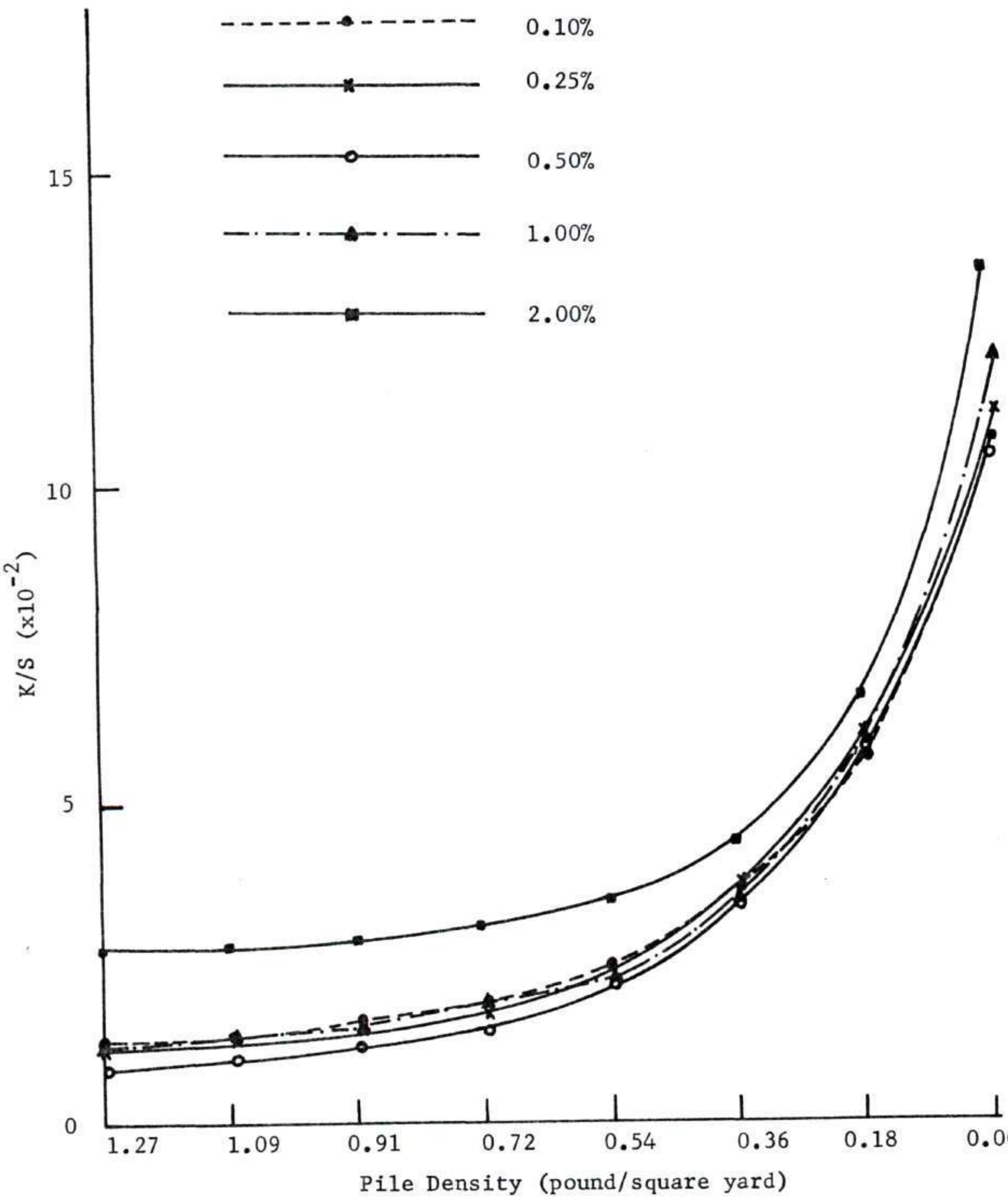

Figure 24. Effect of Pile Density on K/S of Cut-pile Carpet at Selected Dye Concentrations at 700 nm

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