COLOR MEASUREMENTS OF PRINTS OF VARYING HUE AND GLOSS USING SPECTROPHOTOMETERS WITH THREE DIFFERENT GEOMETRIES

NPIRI Color Measurement Task Force*

ABSTRACT

Colorimetric measurements of 54 Pantone® printed color samples, half coated and half uncoated stocks, and covering a wide range of hues, were made with a variety of spectrophotometers. The instruments chosen were both bench and portable types having 0/45, 45/0 and D/8 (sphere) geometries. In all, a total of 702 measurements were made and 3,510 color values were recorded. Some differences were observed between 0/45 and 45/0 geometries, despite the presumed interchangeability of these two optical systems. This may be at least partly due to different optical paths and different manufacturers' instruments. As expected, the D/8 (sphere) geometry differs significantly from the other two. These differences also vary with both hue and surface gloss so that constant correlation factors cannot be used to compare the observed values. The agreement between spectrophotometers of the same manufacturer and geometry was generally good. However, some differences were observed for spectrophotometers having the same geometry made by different manufacturers.

This study shows that when colorimetric data is to be compared in different laboratories, it is essential that spectrophotometers having the same geometry be used. If they are not, it is important to be aware of the type and magnitude of the differences that do exist.

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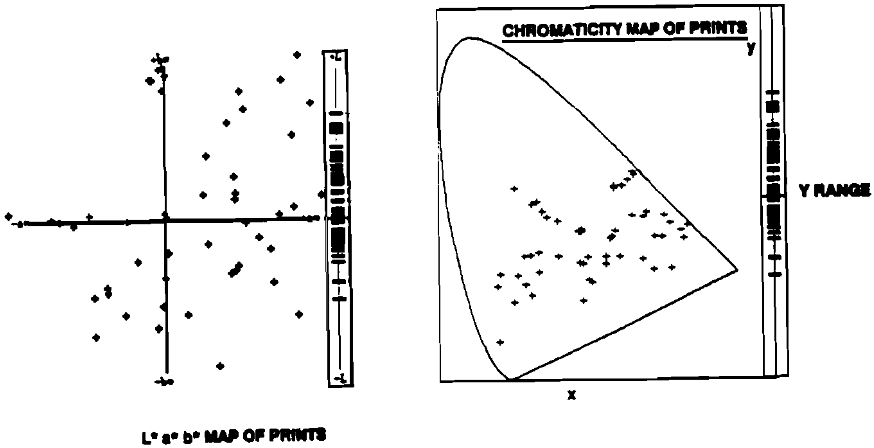
INTRODUCTION

The increased use of spectrophotometers for the measurement and specification of color frequently results in questions concerning the comparability of data from instruments with different geometries. Used intelligently, all facets of the graphic arts industry can benefit from the widespread use of spectrophotometers to reproduce color faithfully. On the other hand, it is essential for all to be aware of, and know, how color measured by spectrophotometers having different optical geometries and made by different manufacturers can vary. Ignoring these differences can result in misunderstanding and incorrect conclusions when trying to satisfy color specifications.

In order to make this study as broad as possible, both portable and bench spectrophotometers made by different manufacturers having 0/45, 45/0 and sphere geometries were used. The list of the spectrophotometers together with their code letter designations is shown in Appendix Table I. In three cases, at least two of each instrument was used to determine what may happen when labs compare results using the same model spectrophotometer. However, it was not the intent of this study to draw conclusions on the variability of instruments having the same geometry made by the same manufacturer. The primary purpose was to compare instruments having different optical geometries.

Equally important was the wide range of colors covered in this study. To that end, the Pantone® basic color standards chosen were ideal in that they cover the complete color spectrum, are actual prints of ink on paper, and are widely used in the graphic arts. Also, each color is printed on coated and uncoated stock making it possible to determine the effect of gloss and penetration effects for the same color. Eight basic Pantone® colors and a grey color were selected together with a lighter and darker shade of each basic color forming a triad. Twenty-seven colors each for coated and uncoated stock were measured for a total of 54 samples. A complete list of the colors together with their 60° gloss readings is shown in Appendix Table 2. A diagrammatic sketch of the CIElab color space and chromaticity map is shown in Figure 1. The absence of color in the green-yellow quadrant is due to the selection of single pigment color, which comprise the basic Pantone® colors.

Figure 1
Color Universe



EXPERIMENTAL

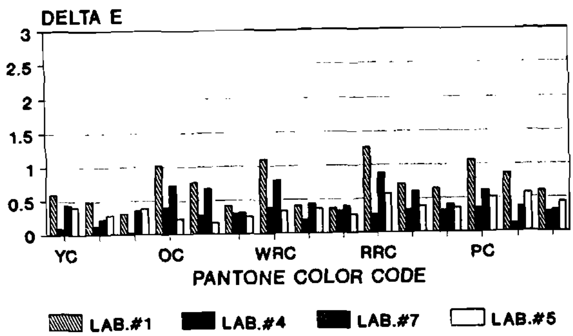
Seven laboratories employing 13 spectrophotometers participated in this study. The same Pantone® color samples were sent from lab to lab so that each lab measured the same sample. The back of each sample was marked to guide the cross hairs of each aperture so that to the extent possible, the same spot was measured. Five sheets of the same stock were used as backing. L*a*b*C*h D50/2° illuminant/observer were recorded for each sample. In all, a total of 702 measurements were made, and 3,510 color parameters reported.

RESULTS

A comparison of four of the same model bench type integrating sphere spectrophotometers is shown in figures 2A and 2B for coated samples. With the exception of laboratory 1, the other three laboratories reported dE* values of less than one with few exceptions. Laboratory 1 suspects a wave length error in its spectrophotometer which was not evident in normal calibration tests. Also, in almost every case, the base color in the triad had higher dE* values than the lighter and darker tint of the same color. (See the bars immediately to the right of each basic color). Highest dE* values were reported for rubine red (RRC) and process blue (PBC). Lowest values occurred with the yellows (YC) and greys (420C).

Figure 2A

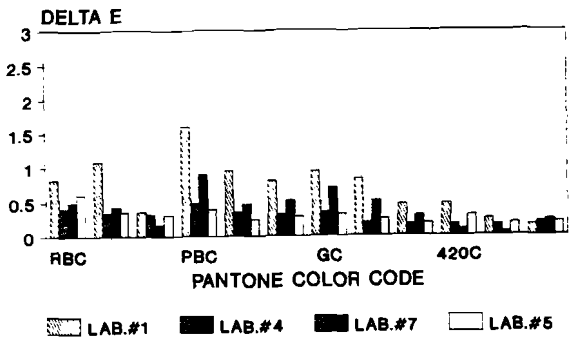
COMPARISON OF SPHERE SPECTROPHOTOMETERS



SA INSTRUMENTS vs AVERAGE OF 4 SA'S.

Figure 2B

COMPARISON OF SPHERE SPECTROPHOTOMETERS



SA INSTRUMENTS vs AVERAGE OF 4 SA'S.

The dE* values for the same bench sphere spectrophotometers for uncoated samples are shown in Figures 3A and 3B. In general, dE* values are lower for the uncoated samples, but here again, differences were greatest for the basic color in each triad. Rubine red, warm red, orange, purple, and process blue all had higher dE* values. Yellow and grey were again, lowest.

Figure 3A

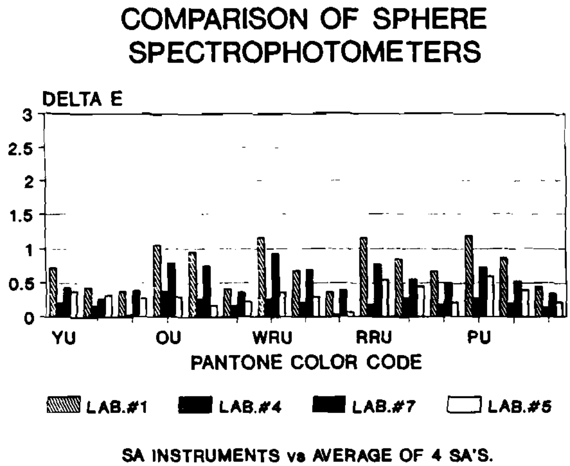
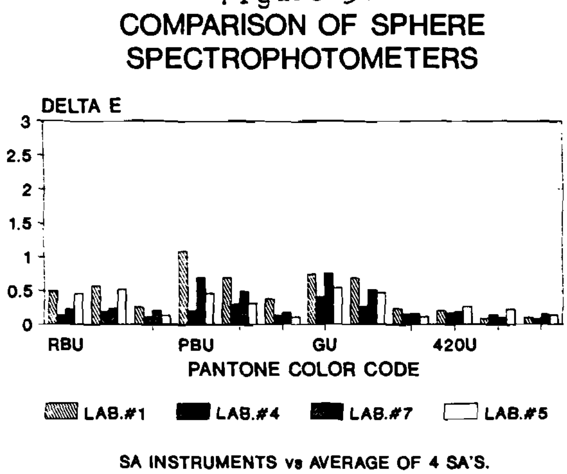
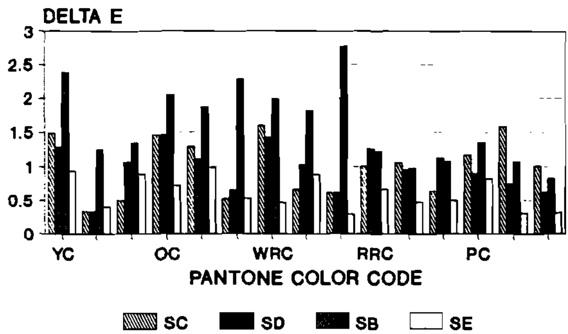


Figure 3B



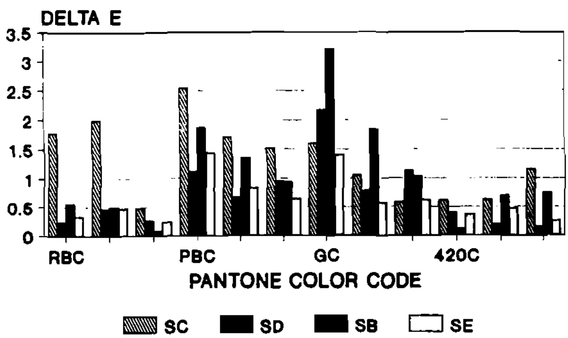
A comparison of other integrating sphere spectrophotometers with the average of four of the same model (SA's) is shown in Figures 4A and 4B. Here it is readily apparent that dE* values are significantly higher when spectrophotometers having the same optical geometry but made by different manufacturers are compared. The SB and SC instruments in particular had higher dE* values even for the yellows and greys. With the exception of process blue (PB) and green (GC), the SD and SE instruments agreed very well with the average of 4 SA's. The SE is a portable instrument.

Figure 4A
COMPARISON OF SPHERE SPECTROPHOTOMETERS



OTHER SPHERES vs AVERAGE OF 4 SA'S.

Figure 4B
COMPARISON OF SPHERE SPECTROPHOTOMETERS

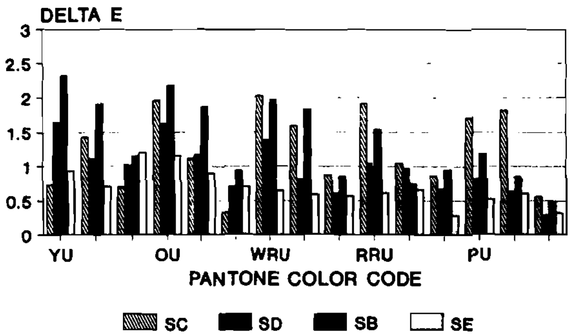


OTHER SPHERES vs AVERAGE OF 4 SA'S.

A comparison of other spheres with the average of four SA's for uncoated stock is shown in Figures 5A and 5B. Although dE* values are somewhat lower than for coated stock, they are still high (greater than 1.5) with the SB, SC, and SD instruments for many colors. Overall, dE* values were significantly lower with the portable sphere (SE) instrument.

Figure 5A

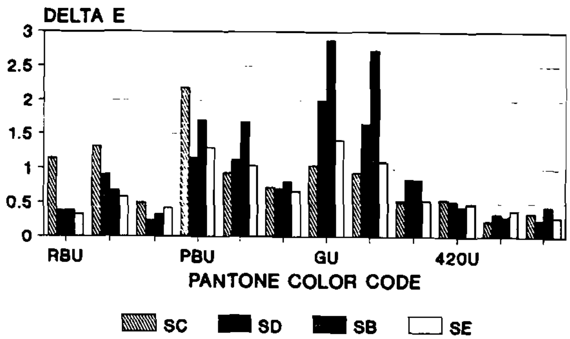
COMPARISON OF SPHERE SPECTROPHOTOMETERS



OTHER SPHERES vs AVERAGE OF 4 SA'S.

Figure 5B

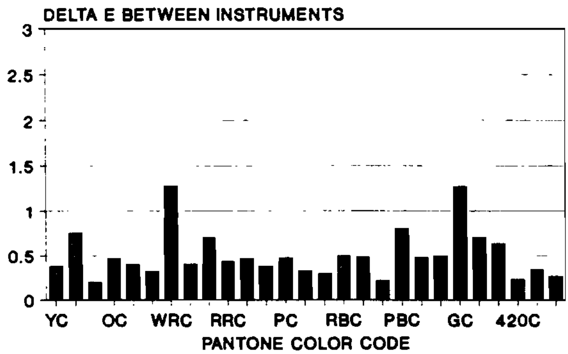
COMPARISON OF SPHERE SPECTROPHOTOMETERS



OTHER SPHERES vs AVERAGE OF 4 SA'S.

Figure 6 presents dE* values for two 0/45(FC) portable spectrophotometers of the same model made by the same manufacturer. With the exception of warm red and green, most values are less than 0.5.

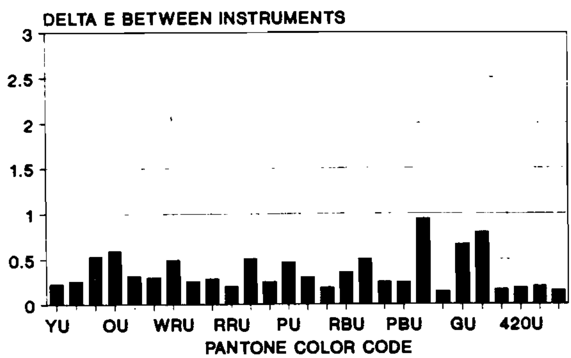
Figure 6
COMPARISON OF PORTABLE
0/45 SPECTROPHOTOMETERS



FC SPECTRO'S LABS.#1 & #5

The same instruments are compared in Figure 7 for uncoated stock. All dE* values are less than 1.0, and most are less than 0.5.

Figure 7
COMPARISON OF PORTABLE
0/45 SPECTROPHOTOMETERS



FC SPECTRO'S LABS.#1 & #5

The comparison between the average of two portable 0/45 instruments (FC) and the average of four bench spheres (SA) is shown in Figures 8 & 9. As expected, dE* values here are totally unacceptable for all colors showing that the two geometries are not comparable. Note that the dE* axis has been increased by a factor of ten for these charts. Although color differences are much lower for uncoated stock (Figure 9), they are still unacceptably high.

Figure 8
COMPARISON OF PORTABLE 0/45
vs SPHERE SPECTROPHOTOMETERS

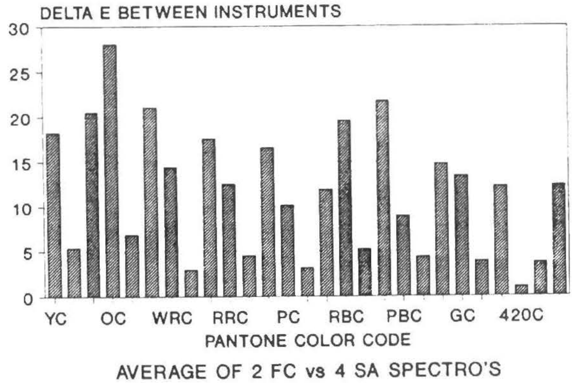
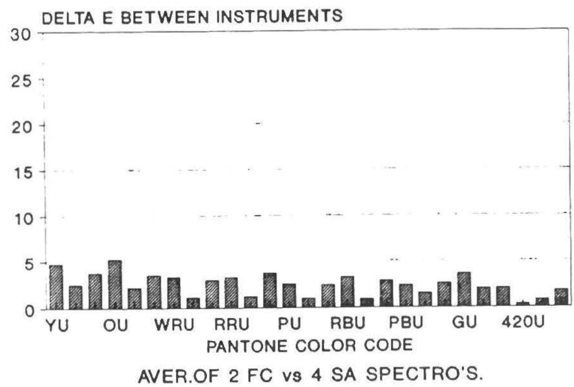


Figure 9
COMPARISON OF PORTABLE 0/45
vs SPHERE SPECTROPHOTOMETERS



Figures 10 and 11 present dE* values for two portable 45/0 spectro's (FB) of the same model by the same manufacturer. For coated stock, differences were highest with reflex blue, process blue, and the dark shade of green. Ten of the 27 colors had dE*'s greater than 1.0. dE* values were also high for the uncoated stock with 8 colors greater than 1.0. Surprisingly, the uncoated yellow sample had a dE* of 1.6.

Figure 10
COATED PRINTS - DELTA E
BETWEEN 45/0 PORTABLES

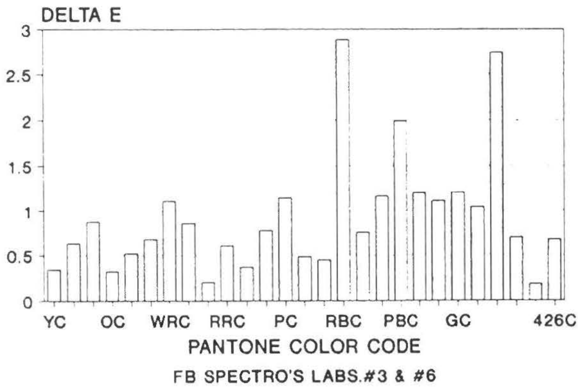
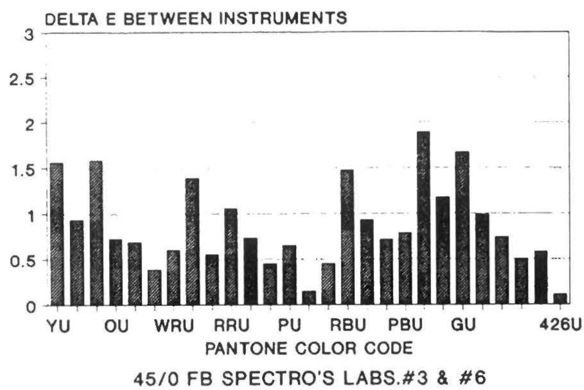


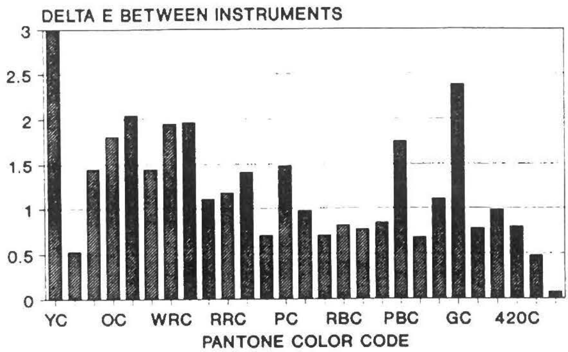
Figure 11
COMPARISON OF PORTABLE
45/0 SPECTROPHOTOMETERS



Figures 12 and 13 compare the average of two portable 45/0's (FB's) with one bench 45/0 instrument (FA). The highest dE* (3.0) occurs with the coated yellow sample. The lighter shade of yellow had a dE* of 0.5, and the darker,1.4. On the other hand the reflex blue colors (RBC) were all uniform and low (0.7). Fourteen of the 27 colors had dE*'s greater than 1.0. dE* values for uncoated stock were slightly lower. Twelve of the 27 uncoated samples had dE*'s greater than 1.0.

Figure 12

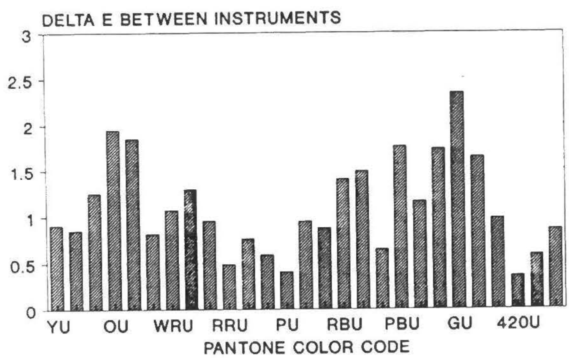
COMPARISON OF PORTABLE 45/0 vs BENCH 45/0 SPECTROPHOTOMETER



AVERAGE OF 2 FB vs 1 FA SPECTRO'S

Figure 13

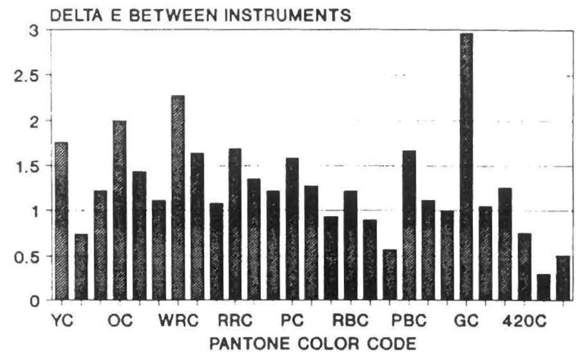
COMPARISON OF PORTABLE 45/0 vs BENCH 45/0 SPECTROPHOTOMETER



AVER.OF 2 FB vs 1 FA SPECTRO'S.

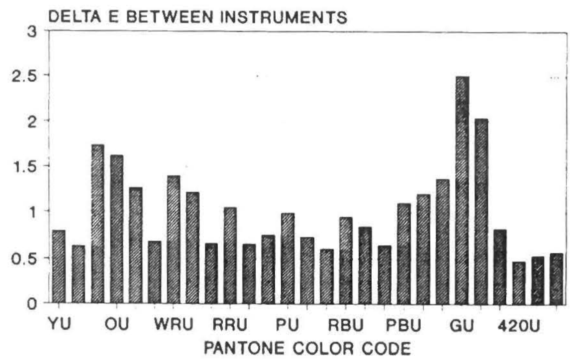
Figures 14 and 15 compare the average of two portable 45/0 spectrophotometers with two 0/45's. For samples made with coated stock, dE's vary significantly with color from a low of 0.3 for a grey tint to a high of 2.9 for green. Also, for every color triad, the highest dE* occurred with the basic color, and not with the lighter and darker shades. The average dE* for the 27 coated samples is 1.33 with 18 having a dE* greater than 1.0. For uncoated stock (Figure 15), the average dE* was 1.09 with 13 colors having a dE* greater than 1.0. dE* again varied significantly with color, with green repeating as the high dE* and grey as the low dE*. Values for uncoated stock by

Figure 14
COMPARISON OF PORTABLE
45/0 vs 0/45 SPECTROPHOTOMETERS



AVERAGE OF 2 FB vs 2 FC SPECTRO'S

Figure 15
COMPARISON OF PORTABLE
45/0 vs 0/45 SPECTROPHOTOMETERS



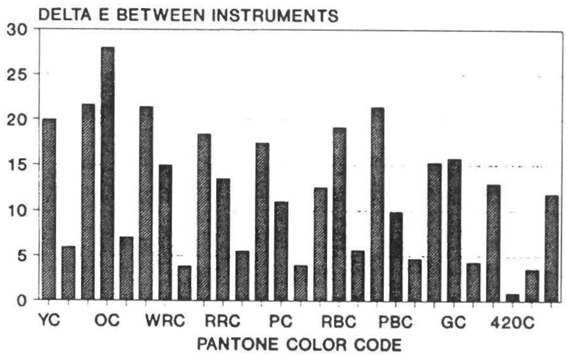
AVERAGE OF 2 FB vs 2 FC SPECTRO'S

comparison, did not uniformly follow the pattern of the basic color having the highest dE*. Yellow and process blue were the exceptions.

A comparison of the average of two 45/0 portable spectro's (FB's) with four bench sphere's (SA's) is shown in Figures 16 and 17 for coated and uncoated stock. As was the case for the 0/45's, the dE* values are exceptionally high (note that the y axis has been increased ten times for these graphs) for coated stock. Although dE*'s for uncoated stock are about one-fifth

Figure 16

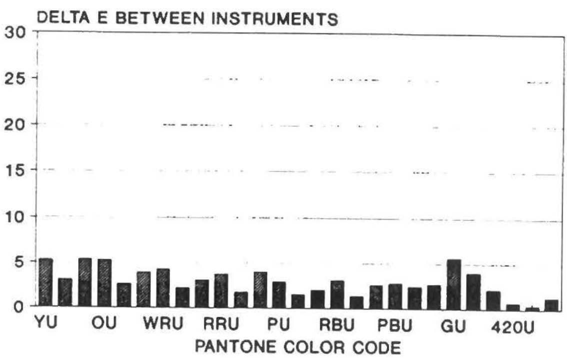
COMPARISON OF PORTABLE 45/0 vs SPHERE SPECTROPHOTOMETERS



AVERAGE OF 2 FB vs 4 SA SPECTRO'S

Figure 17

COMPARISON OF PORTABLE 45/0 vs SPHERE SPECTROPHOTOMETERS



AVER.OF 2 FB vs 4 SA SPECTRO'S.

the values for coated stock, they are also unacceptably high, in the 2 to 5 range.

DISCUSSION OF RESULTS

Integrating Spheres - Results obtained using four of the same model integrating sphere spectrophotometers (SA's) show dE*s of less than one, and with the exception of lab #1, less than 0.5. The results obtained with the spectrophotometer used in lab #1 were surprising since this instrument had been calibrated using accepted calibration procedures. A shift in wavelength is suspected which normal calibration procedures would not pick up.

The comparison of integrating spheres made by four other manufacturers with the average of four SA's (Figures 4 and 5) show dE's greater than 1.0 for 42 of a possible 108 comparisons for coated stock, and also 42 out of 108 for uncoated stock. There were significant differences between instruments. With the portable SE instrument, only 5 color samples out of 54 were greater than 1.0 dE*. On the other hand, with the SB instrument, 31 color samples exceeded 1.0.

Portable 0/45's - The two portable 0/45 (FC) instruments used in this study demonstrated good agreement with each other (Figures 6 and 7). Most dE*'s were less than 0.5, and only two color samples (Warm Red Coated and Green Coated) had dE*'s greater than 1.0.

0/45s vs. Sphere Geometry - The comparison of two 0/45's (FC's) with four spheres is shown in Figures 8 and 9. As expected, there was significant lack of agreement between these geometries. This is particularly true for the coated samples with their higher gloss. dE*'s of 10 to 20 were recorded for many colors. Also, in every case of a color triad, the darker tint (third color in the triad) which had higher gloss (see Appendix Table 2) also had much higher dE* values. Coated samples had 60° Gloss readings in the 40 to 70 range.

Results for uncoated samples (Figure 9) show that even for gloss readings in the range of 3 to 5, dE* values with few exceptions are in the 2 to 5 range. This tells us that even for low gloss prints, there is a wide difference in colorimetric values reported by 0/45 and integrating sphere optical geometries. The systems are not comparable, and the differences vary from color to color.

Portable 45/0's - The dE* values for the two portable 45/0 spectrophotometers used in this study (FB's) for coated stock (Figure 10) had 10 of 27 values greater than 1.0, with 3 of the 10 being greater than 1.5. Eight of 27 dE* values were greater than 1.0 for uncoated stock (Figure 11), with 4 values greater than 1.5.

The comparison of the average of two portable 45/0 spectrophotometers with one bench 45/0 made by a different manufacturer shows poorer agreement (Figures 12 and 13). For coated stock, 14 of 27 colors had dE*'s greater than 1.0. For uncoated stock, there were 12 colors that had dE* values greater than 1.0.

45/0 vs. 0/45 Geometry - In theory, the same color values should be found if incident light strikes the surface at 45 degrees and is recorded at 0 degrees, and if it strikes at 0 degrees and is recorded at 45 degrees. In practice, using printed samples, this was not the case. This may be due in part to different optical paths, and different manufacturers instruments. For coated stock (Figure 14), 19 of 27 samples had dE* values greater than 1.0. The greatest difference in each case was found with each of the nine primary colors. For uncoated stock (Figure 15), 11 colors had dE*'s greater than 1.0.

45/0 vs. Sphere Geometry - Results which compare the two portable 45/0 with the average of four spheres (SA's) are shown in Figures 16 and 17. Firstly, the dE* values are almost identical to those reported for the comparison of 0/45 with the spheres (Figures 8 and 9). Although there were significant differences when 0/45 and 45/0 geometries were compared with each other. these differences were not apparent when each geometry is compared with sphere geometry. Both are the same, and both are unacceptably high. Also, in eight of the nine color triads, the lighter tint shade had significantly lower dE* than the basic color or the darker tint. The one exception was grey (424U), where the lowest dE* occurred with the basic color, and the highest with the darker tint.

CONCLUSIONS

1. Spectrophotometers made by the same manufacturer with the same optical geometry can vary by 0.7 to 1.7 dE* units when measuring printed ink films.

2. Spectrophotometers made by different manufacturers with the same geometry can differ by 1.5 to 3.0 dE* units when measuring printed ink films. These differences vary with hue and gloss so that a constant factor cannot be used to normalize the differences.

3. Both 0/45 and 45/0 portable spectrophotometers when measured against the average of four integrating spheres had dE* values of 2.0 to 28 for glossy prints made with coated stock. For uncoated stock, the dE* differences were in the range of 1.0 to 5.0.

4. The 0/45 and 45/0 portable spectrophotometers tested. when measured against each other, varied from 0.3 to 2.9 for coated stock, and from 0.5 to 2.5 for uncoated stock. For most colors, the difference was in the range of 1.0 to 2.0 dE*.

5. In general. glossy prints made on coated stock resulted in higher dE* values than non-glossy prints made on uncoated stock.

6. In general, the basic color of each color triad had higher dE* values for sphere spectrophotometers. This trend was not consistent for 0/45 and 45/0 geometries.

APPENDIX TABLE 1

List of Spectrophotometers

Spectro	Code	No.	Aperture, mm
Sphere, Bench	SA	4	8
Sphere, Bench	SB	1	10
Sphere, Bench	SC	1	5X10
Sphere, Bench	SD	1	6
Sphere, Portable	SE	1	8
45/0, Bench	FA	1	6
45/0, Portable	FB	2	4.5
0/45, Portable	FC	2	8

/CMB
APNDX.JTD

APPENDIX TABLE II

PANTONE COLOR SAMPLES

Coated			Uncoated	
Pantone ID	Color	60° Gloss	Pantone ID	60° Gloss
YC	Yellow	65.9	YU	4.6
101C	Lt. Tint	53.1	101U	4.4
103C	Dk. Tint	70.2	103U	3.8
021U	Orange	59.4	OU	4.6
1495C	Lt. Tint	43.0	1495U	4.1
1535C	Dk. Tint	57.3	1535U	3.5
WRC	Warm Red	61.2	WRU	4.1
176C	Lt. Tint	45.5	176U	3.9
181C	Dk. Tint	56.8	181U	3.1
RRC	Rubine Red	64.5	RRU	3.9
218C	Lt. Tint	48.5	218U	3.8
221C	Dk. Tint	60.5	221U	3.8
PC	Purple	53.0	PU	3.5
251C	Lt. Tint	44.0	251U	3.7
255C	Dk. Tint	54.1	255U	2.9
RBC	Reflex Blue	51.5	RBU	3.1
279C	Lt. Tint	46.4	279U	2.9
282C	Dk. Tint	54.3	282U	2.7
PBC	Process Blue	55.9	PBU	3.1
306C	Lt. Tint	50.5	306U	3.3
308C	Dk. Tint	57.8	308U	2.8
GC	Green	61.9	GU	3.2
333C	Lt. Tint	51.1	333U	3.8
336C	Dk. Tint	58.6	336U	2.9
420C	Lt. Tint	39.1	420U	3.7
424C	Grey	40.3	424U	2.7
426C	Dk. Tint	46.8	426U	2.5
Coated Stock		48.6		
Uncoated Stock		04.2		