REVERSIBILITY OF 0°/45° & 45°/0° REFLECTION GEOMETRY

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ABSTRACT: Both the 0°/45° and 45°/0° geometries are used in densitometers, reflectometers, colorimeters and spectrophotometers throughout the photographic and graphic arts industries. Data from instruments of varying manufacturers and even among different series of a given manufacturer do not always agree. This investigation was undertaken to critically evaluate the geometry specified in ANSI PH2.17. A robust standard specification is critical because design of commercial instruments usually requires many trade-offs to best meet user needs.

A precision densitometer with high resolution and stability was set up on an optical bench. The optical design was made large scale so that parameters of target area, cone and incidence angles are adjustable and centered on the current ANSI PH2.17 standard values. The illumination and collection systems were designed for field uniformity and flexibility rather than light efficiency.

Phase I of this investigation was a critical test of the current ANSI PH2.17 specifications. From the experiments in this series there are three conclusions:

1) ANSI PH2.17 specifies that illumination exceed collection area by 2mm on each side.** This degree of over-illumination provides reflected light measurement independent of image spread for both 0°/45° and 45°/0° geometry.

2) For uniform targets ANSI PH2.17 produces reflectance factor measurement that is independent of the sample area.

3) Measurements with 0°/45° and 45°/0° geometry may vary significantly, ranging up to 1.5% in Density. Samples with only surface reflectance measure the same with either geometry. Ink-on-paper densities show the greatest differences.

** **ANSI PH2.17 7.2 Sampling Aperture** — Geometric aspects of the optical system of the instrument limit the measurement to a well-defined region of the sample plane, called the "sampling aperture." The sampling aperture shall be determined by the angular field of sensitivity of the receiver. If a mechanical aperture is used in this plane its area shall be greater than the sampling aperture and its boundary shall lie at least 2mm beyond the boundary of the sampling aperture, to permit full evaluation of the flux scattered sideways in the sample.

7.3 Irradiated Area — The irradiated area of the sample shall be greater than the sampling aperture, and its boundary shall lie at least 2mm beyond the boundary of the sampling aperture.

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INTRODUCTION

This brief historical note traces the evolution of ANSI standard PH2.17. The standard has been revised several times as the precision of densitometric instrumentation increased and needs for interchangeable data became widespread. Many early problems of reflectance measurement can now be interpreted with more insight using measurement technology of the 1990's. Differences that would have been perplexing if noticed in the 1950's were ignored because they were near, or below, resolution limits. Today these same differences are real and measurable. The increasing demands of quality improvement will make small variations in measurement the limits of quality monitoring in the next decade.

REFLECTION DENSITY AND COLORIMETRY IN THE 1950's

In 1940 there were few reflection densitometers. These were built for special measurements in the laboratories of photographic manufacturers or academic institutions. Two collection geometries were used. Either the sample was illuminated normal to its surface and the reflected light collected at 45° to the normal, or the total reflected energy was collected with an integrating sphere. The early model for explaining the reflection process assumed that a ray of light not absorbed was reflected only at that point on the surface. This process was considered identical whether for a single ray or for a bundle of rays spread across a surface. Notation describing reflection density was loosely defined in the 1950's*

1952 several General Electric-Hardy spectrophotometers at Eastman Kodak were modified by reducing the sample reading port size from 25.4mm to 8mm. This modification made it possible to read the standard 0.4 inch steps on sensitometric scales. Intercomparison of the modified instruments showed excellent agreement. However, data exchanged with the wider community through the Inter-Society Color Council showed the small reading port instruments to have a significant offset in the measurement of Y, CIE visual reflectance. ($D_v = -\text{Log}_{10}Y$) This offset was greater for the measurement of Vitrolite tiles, used to establish the reference white than for baryta coated paper used as a photographic substrate. The value shift of the reference white vitrolite tile changed the white point and produced an aperture size-dependent measurement for the sample. This offset was traced to sub-surface reflectance varying with the sample. Physical apertures always limit light reflected from a measurement area. The relative degree of vignetting increases with sub surface reflection. Light reflected by the sample varies with the port area and vignetting losss is proportional to the port perimeter, making the relative reflectance size-dependent. J. E. Pinney

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* Densitometry users were more concerned with experimental data than with accepted optical notation. They called light incident normal to the sample "90° illumination." An early densitometer, built by the physicist Abbé, was described in conventional optical notation, i.e. all angles were measured from a reference line normal to the surface. Because photographic sensitometrists remained isolated and independent, they continued to call normal incidence 90°. As a result early literature refers to 90°/45° geometry rather than the proper convention 0°/45°. In the second half of the 50's decade, standard optical notation and nomenclature gradually were accepted.

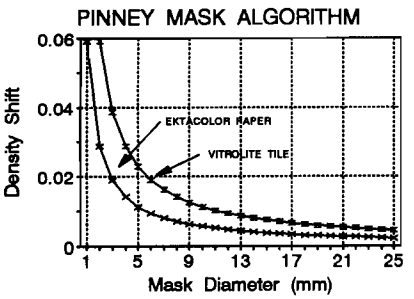

Fig 1. Mask Algorithm

modeled the vignetting effect as shown in Figure 1. Pinney's model replaced the point spread function with a triangular function whose absolute slopes matched the microdensitometer trace of a knife edge exposure. Slopes were obtained by deconvolving the micro-reflectance trace with the effective slit width. In 1952 this phenomenon was explained but ignored. With the General Electric-Hardy sphere geometry there was no way to prevent the masking errors. Since spectrophotometric data were used in relative and not absolute computations, they provided useful color information even with the masking error. The Pinney Vignetting Algorithm shows losses in both the white reference and the sample to be measured. The displacement between the two curves indicates the density error for each measurement spot size. When this algorithm was developed, physical masks were the method of limiting sample size measurement in densitometers. Pinney concluded that measurements of sample areas limited by physical masks would always be size-dependent. The 1950's solution to this problem was building all densitometers with a common aperture.

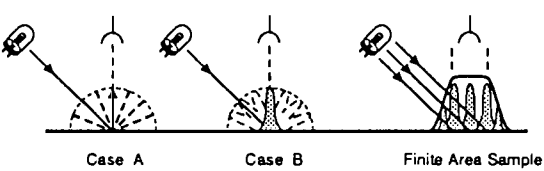

FIGURE 2 Reflection with and without image spread

The early, simple, model for the reflection process is represented by a single ray of light being absorbed or reflected at one point of the surface as shown in Figure 2 as Case **A**. Here a ray of light striking a reflective surface is attenuated by the absorption process and the remaining light is reflected at many angles depending upon the nature of the surface. The ray at 0° to the normal is collected for the 45°/0° measurement. The relative reflectance is defined by the ratio of the incident and reflected rays, related to a reference white. When the image is spread by any mechanism, the model is represented in Figure 2 as case **B**. Each emergent ray is collected as a point spread function rather than a Dirac delta*. If the model is extended to cover a finite area, the single rays are treated as a bundle. The energy returned at the angle of collection is the surface integral of the point spread functions. There is no sharp edge to this collected bundle. It returns over a larger area than that covered by the incident bundle. If the light collection area is limited to the illumination size, there is no true measure of reflectance. Light lost at this unsharp edge results in an increase of measured density.

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* The Dirac Delta is a discontinuous function whose dependent variable has a finite value at a single value of the independent variable. At all other values of the independent variable the Dirac Delta has the value 0.

Pinney reported the mask vignetting effect to C. N. Nelson, chairman of the ANSI PH2-28 subcommittee on densitometry. The next revision of the ANSI standard for 0°/45° reflection densitometry included a requirement for illumination to exceed the measurement area by 2mm. This was assumed to be adequate excess illumination to compensate for light piping in photographic coatings only a few microns thick. By 1954 a model for explaining reflection in these images was extended to include light-piping and internal reflections, but assumed a hard reflection at the baryta coated substrate. This model assuming all image spread was caused by light piping was derived by F. C. Williams and F. R. Clapper.[7]

In 1955 Eastman Kodak Company entered a consent decree with the United States Justice Department that extended color print processing to independent photofinishers. The new need to use densitometers in distributed processing locations changed the methodology and made the need for densitometry standards more urgent. The Kodak Densitometer Control Center, W. N. Fitzgerald, E. K. Letzer and S. A. Powers, in consultation with M. Sweet of Ansco Corporation drafted, proposed specifications for the "Trade Densitometer." Surface irregularities such as finger prints, textured surfaces, scratches and dirt caused large density variations in the measurement of D_{max}. Densitometers at this time collected the reflected component at a single azimuth angle. The concept of multi-azimuth geometry was borrowed from a cross-fire illumination system used for reducing the visibility of scratches in projection printing and the practice of reflection microscopy. This type of illumination reduced the dependence on collection azimuth. The ring collection did not produce a better measurement of D_{max} but reduced the variability and hid the defects. The common belief prevailed that anything reducing the measurement process standard error brings the data closer to truth. This multi-azimuth geometry was added to the proposed specification. This new design for a reflection densitometer was agreed upon and made public in 1955 by an ad-hoc committee made up of W. Carnahan, E. K. Letzer, W. N. Fitzgerald and S. A. Powers all of Kodak along with M. Sweet of Ansco, W. Reeves of Macbeth Corporation and C. Williams of Welch Scientific. Following this design, the Macbeth *Quantalog*™ and Welch *Densichron*™ densitometers were marketed for the photofinishng trade. These recommendations were the basis of the new ANSI standard.

In 1972 the ANSI densitometry standards were reorganized to form four modular parts in order to specify a large number of specific and specialized instruments from a limited number of standards. These four modules are:

1) Terms Symbols and Definitions[1]
2) Illumination-Collection Geometry, Transmission Measurement[2]
3) Illumination-Collection Geometry, Reflection Measurement[3]
4) Spectral Products for Densitometry[4]

The 1972 ANSI Standard PH2.17 defined reversibility in terms of exchanging the light source and receiver. ANSI PH2-28 chairman, C. S. McCamy, supported the reversibility concept with a ray tracing theorem from geometrical optics. The concept of reversibility was also supported by a model derived by F. C. Williams and F. R. Clapper[8] tracing the light path in photographic images made on a reflective support. However, the Williams and Clapper model was based on the assumption that the

image forming media are isotropic. Empirical measurement of the reflection process by J. E. Pinney and W. F. Voglesong[6] showed color photographic paper to be anisotropic. This raised a question about reversibility as defined in the ANSI standard. In 1973 C. B. Swartz at Kodak Park set up a densitometer on an optical bench so the source and receiver could be interchanged. Swartz took great care to make all measurements at the same electrical and optical levels. Within the measurement noise level of that time, ±0.01D, reversibility remained a valid assumption. Because this experiment was carried out in the photographic metrology community, no measurements were made of ink-on-paper images. With the better knowledge of hindsight, that was unfortunate. The 1973 test for reversibility was carried out to test the design of a new densitometer and only one measurement spot size was used, an 8mm circular area.

In the late 1970's J. Hamilton and J. Altman measured a point spread function for a number of reflection supports. They demonstrated that the image spread in the suport was the major factor in determining apparent sharpness. Their work showed that the light spread in the support was a major contribution to limiting the image sharpness for photo typesetting paper.

J. J. Hsia described the variation of reflectance measurement with aperture size and called the phenomenon *Translucence Blurring* in a 1976 technical report at the National Bureau of Standards.[1] The practical measurement limitation in commercial instruments was reported at the 1991 TAGA meeting by D. Spooner.[7]

In 1987 PSI ASSOCIATES began certifying a Standard Reference Material (SRM), T-Ref™, for graphic arts densitometry. This SRM was designed by a densitometry committee of The Graphic Communications Association. The SRM is printed on Carolina coated-one-side card stock with standard process color inks. The certified densities are computed from 45°/0° reflectance data obtained on a Milton Roy Color Scan 45 spectrophotometer. The spectral products specified in ANSI PH2.18 are used in this computation. The Color Scan optical system was modified to read a 5mm spot size. At the onset of this program, a series of spectrophotometer data round-robin interchanges were made. The major variable in this series of intercomparisons was the values of white references used in the various laboratories to correct to absolute reflectance. Transfer standards for each laboratory had been derived with different areas of illumination and collection. Round robin tests conducted under the auspices of ANSI PH2-28 provided a basis for a common specification of 100% reflectance reference for these 45°/0° measurements. T. Luminello of Polaroid Corporation coined the term *hard* and *soft* reflectors. Both are close to lambertian for angular distribution; the *hard* reflector exhibits almost all of the reflection at its surface while the *soft* reflector has subsurface reflection or translucence. Ceramic on steel was found to be a hard reflector; Russian Opal Glass and PTFE (Halon) were soft, with enough image spread to make them very poor transfer standards.

In 1991 PSI ASSOCIATES evaluated several reflection spectrophotometers in a comprehensive testing program. With standard reference materials having little subsurface reflection the X-Rite 938 (0°/45°) and Milton Roy Color Scan 45 (45°/0°) produced almost identical data. Densities of targets on photographic paper measured

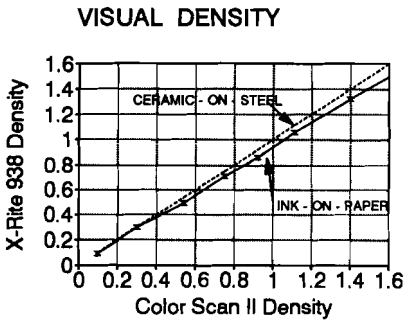

Fig. 45°/0° & 0°/45°

on these instruments differed by about 0.25% D. However, the density of ink-on-paper samples varied by as much as 1%D, as shown in Figure 3. We propose these differences could be introduced by surface reflections, light spreading in the support or an anomoly in the response with the reversal of the illumination and collection geometry. This measurement discrepancy raises several questions about requirements or limits on the target area, the measurement area and the influence of area and the influence of the surround.

This research project was initiated to determine empirically whether the geometry defined in ANSI PH2.17 is complete and adequate for precision densitometry. There are several important questions to answer:

PHASE I

1) Does the over illumination specified in the standard produce measurements that are size independent for uniform samples?

2) Is the principle of reversibility valid with the improved density resolution of modern photometric equipment?

PHASE II

3) The current ANSI standard specifies over illumination. Some designs for commercial densitometers define the measurement area with the illumination spot and over collect the reflected light. Is practice valid?

4) If the surround is included in the zone of over illumination, what effect does this have on the accuracy of the data?

PHASE III

5) How sensitive is this geometry to flare light?

We plan to examine the contribution of each variable. This may lead to revision of ANSI PH2.17 or recommendations for limitations on test target design. This information is more important for obtaining absolute measurements with equipment of varying manufacture than for obtaining relative measurements within a family of instruments. The thrust of ISO 9000, and the need for certified organizations to have very small variation in measurements and products from many locations, makes understanding these phenomena important. The trend toward smaller test targets also requires this knowledge.

EXPERIMENTAL EQUIPMENT

The modern commercial reflection densitometer has exceptional electrical and photometric precision. All of this is contained in a very small volume by virtue of integrated circuit electronics, solid state receptors and new lamp technology. The optical design is frequently compromised by trade-offs required for size, portability, speed and ease of operation. The factors that make this equipment valuable to the

printer and photo processor also make the same equipment incapable of critically evaluating the parameters of the ANSI geometry standard.

To test principles and specifications of ANSI standard PH2.17, a densitometer was built in which both the area of illumination and collection could be changed independently over a range of about 4:1 while maintaining constant but adjustable cones of illumination and of collection flux. To meet this need the densitometer was assembled on an optical bench. This optical bench densitometer had to be very stable and capable of spanning a range of geometrical parameters centered on those specified in ANSI PH2.17. It was set up using long focal length lenses so that angular errors would be small enough to ignore. To minimize variations in the samples tested, uniformity of illumination and detector sensitivity were deemed more important than short reading times. Data should have both resolution and stability of 0.001D as a minimum. Data are reported in density because the final results will be assayed in that space.

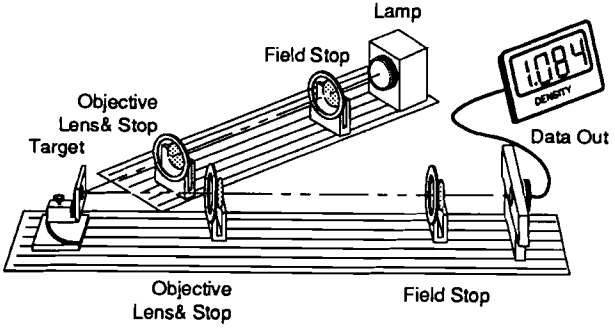

Figure 4. Optical Bench Densitometer

The bench, shown in Figure 4, was constructed using two extruded aluminum channels bolted to a solid maple work surface. A 2 meter leg provides the collection system on the long axis of the work area and a 1 meter leg at 45° to the collection optics supports the illumination system. The sample carrier is located at the intersection of the two axes. The sample plane is perpendicular to the plane formed by the two legs of the bench. The sample rotates about an axis through the front surface of the sample and normal to the plane of the bench at the exact intersection of the optical axes of the two legs. The precise location of the sample in its holder permits illuminating the sample at 0° or 45°. The single azimuth illumination and collection are used to meet exactly ANSI specifications for spot size and cone angles. This configuration also makes it possible to vary both area and cone angles. The sample holder permits rotating the target incrementally so that a multi-azimuth measurements can be derived by repeating readings at many azimuth increments. The working distance from the target to the objective lenses is 200mm. A dark tunnel has been added to both legs of the densitometer to provide added protection against errors introduced by room light flare. The tops of the tunnels are made from a rubberized cloth so there is easy access to change the stops or even adjust the lenses as the experiment needs.

This optical bench configuration makes it possible to examine:
1) 0°/45° -- 45°/0° interchangeability.
2) Over-illumination requirements as function of spot size.
3) Over-collection effects.
4) Effect of target surround.

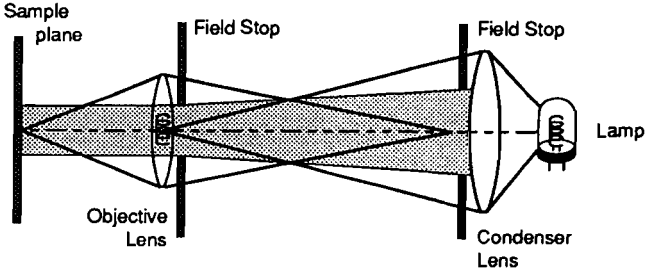

Figure 5. Köhler Illumination

Optical design is based on the Köhler illumination system shown in Figure 5. The lamp filament is imaged on the objective lens. This lens images a field stop on the sample plane. The size of the illuminated area is determined by the size of the field stop. The cone angle of the light incident at the sample plane is determined by the stop at the objective lens. Changing these stops adjusts the size and cone angle of illumination independently. This system produces uniform illumination at the sample plane for 0°±5° cone of incident flux. When the sample is rotated to produce 45°±5° illumination, an elliptical field stop is required to make the projected area projected area circular. A comparable optical system is used in the collection branch where the objective lens is conjugate to the entrance pupil of an integrating box. Collected light is scrambled at this integrating box before being relayed by a randomized fiber optic bundle to a planar silicon cell that has been filtered to match a visual response. The silicon cell is in the receiver pod of a modified ESECO high speed densitometer. The size of the area measured and the area illuminated may be changed independently while keeping the ±5° cone specified in ANSI geometry standard PH2.17.

The circular and elliptical field stops, provided by Eastman Kodak, were cut from spring steel and blackened. These stops are aligned in holders that are pin located on the bench. This method of positioning the stops permits ease of changing yet retains precise location on the optical axis. The combination of stops and positions is determined from the design spread sheets. The stops are centered on the optical axes. A similar set of stops is made for the objective lenses in both the illumination and collection branches. Proper selection of field and objective stops control sample area measured and cone angle of the incident light. A design spread sheet provides the values for setup various conditions.

The two legs of the bench, the lenses, lamp, detector and stops were laser aligned. The overall system alignment was further checked by use of focusing reticules. Having established focus and magnification, a conjugate relationship of the field stops

checked the alignment. A final test for congruence of illumination and collection areas at the sample plane was made by made by measurement of a hard reflector. Matte aluminum was used as a target. The 0° and 45° illumination data were transposed in density space. While there is neither depth or translucence to the matte aluminum surface, graininess caused a shift in absolute reflectance. Attenuation of reflectance with radius change was critical for this evaluation, as plotted in Figure 6. Illumination was varied from "congruent" to "over" by changing field stops at the lamphouse lens. From this size series centering and congruence appear to be aligned within 0.25mm in either radius or centerline. Although neither centering nor congruence can be determined separately, the confidence level in data requiring precise alignment is easily within 0.5mm.

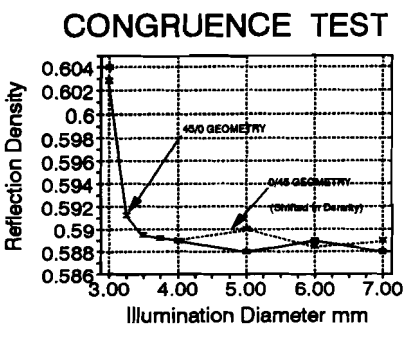

Figure 6. Congruence

Except for the congruence test, all measurements are made with the densitometer calibrated to absolute density. The reference white is an X-Rite ceramic-on-steel tile calibrated to the PSI primary standard. Calibration software records the raw density value from the ESECO densitometer each time the unit is standardized. This value is saved in the data file for each test, serving as a basis for adjusting light levels with geometry change. Thus the electrical and photo diode levels can be matched for comparison experiments. Light levels are changed in 4% increments by placing clear glass sheets between the lamphouse and the condenser lens. A mid-range density was read with 45°/0° geometry, 5mm collection, 9mm illumination while the light level was changed so signal levels spanned the range of all experiments. This test verifies that a non-linear response of the densitometer at various electrical levels will not be confused with an experimental variable. In all tests data points result from the average of 20 replications over a 10 second period. This averaging is internal to the ESECO high speed densitometer. In each experiment the reference white is read before and after each set of test data, assuring these data to be free of drift. Long range drift tests shown in Appendix **A** indicate that, with one hour warm-up time, the drift is in the order of 0.001 density in an 18 minute period. Optical and electrical variations over any test contribute a density variation <0.0007. Dark tunnels protect each leg of the optical system from stray light. The black hole* test produces an output signal is a density of about 2.6 at light levels for 3mm target reading. The laboratory is darkened. Measurements made while operators wearing white shirts moved about the room have no greater variability than tests run with the sample area covered with a black shroud.

In summary the optical bench densitometer has:

1) Illumination and collection circular areas have adjustable diameters from 3mm to 12mm in 1mm increments. Although the cone angles are also adjustable, all tests were made at the PH2.17 standard of $\pm 5°$.

Measurements made while operators wearing white shirts moved about the room have no greater variability than tests run with the sample area covered with a black shroud.

In summary the optical bench densitometer has:

1) Illumination and collection circular areas have adjustable diameters from 3mm to 12mm in 1mm increments. Although the cone angles are also adjustable, all tests were made at the PH2.17 standard of $\pm 5°$.

2) Spectral response is a nominal visual density. Colored SRMs were read producing readings closer to the visual density computed from spectrophotometry than values from most commercial densitometers. Data for these experiments are all from near neutral samples. This minimizes spectral response being a contribution to variability.

3) Repeat readings of a fixed sample had a standard deviation, $\sigma = 0.0004$. When the sample is repositioned for each data point the typical value is $0.0006 < \sigma < 0.0008$ with samples selected for uniformity.

4) Readings of a neutral glass standard reference material (NIST 1930-90) track accepted values within $\pm 0.5\%$ density. Gray ceramic-on-steel samples have reflection densities matching accepted values within $\pm 1\%$ density. The values tend to be slightly higher as they approach 2.2 density.

THE EXPERIMENTS

PHASE I

1) Over-illumination requirements as function of spot size.
2) PH2.17 produces size independent measurements.
3) 0°/45° -- 45°/0° data are interchangeable.

PHASE II

1) Over-collection and effects of target surround.
2) Effect of flare light.

PHASE III

1) Effect on data as color of target and surround varies.
2) Minimum requirements for measurement spot and illumination.

PHASE I —— 2mm OVER ILLUMINATION

The current specification in ANSI PH2.71 calls for the illumination to exceed the collection aperture by 2mm and does not specify any collection spot size. Samples typical of the support and reference white were selected. These included white ceramic-on-steel, pressed PTFE (HALON), 20# offset printing paper, coated and uncoated, 60# cover stock and photographic paper with subcoatings of Baryta ($BaSO_4$) and Titanium Dioxide (TiO_2.) These materials were measured with the collection area having diameters of 3mm, 5mm and 8mm. The illumination diameters varied from equal to collection size up to 12mm in 1mm increments.

For the condition of 3mm measurement 45°/0° the increments were 0.25mm in the interval between 3mm and 4mm. The opal glass and PTFE samples were measured with neutral density added to the collection optics because at very large illumination apertures these samples reflected enough of the incident light to produce negative density readings. Opal glass and PTFE were measured only at the 3mm collection geometry. As the point spread function of the support increased the diameter of illumination required for stable reflection density increased. Typical plots of the 3mm collection are shown in Figure 7.

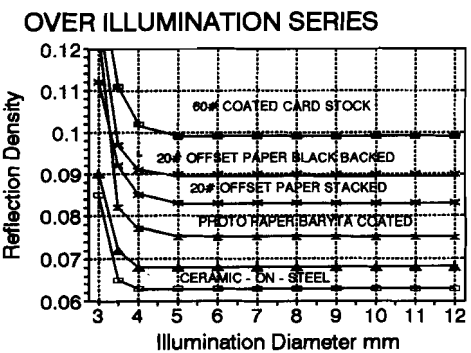

Figure 7. Over illumination

Near neutral samples having a visual density near 1.0 were also read in an illumination series. These samples were on the same supports as in the base tests above. These photographic papers were measured with both silver and dye images. Ink-on-paper samples had both continuous tone gray inks and dot images at approximately 25%, 50% and 75% dot area. The 20# offset samples were backed by 20 sheets of identical paper as well as black. The 60# card stock had a printed black backing as on the GCA T- Ref™. All other paper samples were measured backed by the GCA Backstop™, a material that meets the requirements of ANSI PH2.17. For all of these samples the 2mm over illumination provided an adequate safety factor. Examination of the full data set shows that the opal glass and PTFE require very large over illumination to reach a constant density measurement.

For the supports and imaging materials commonly used ANSI PH2.17 specification of 2mm over illumination is fully adequate.

PHASE I —— MEASUREMENTS INDEPENDENT OF SIZE

In the initial phase I experiments it was established that 2mm over illumination provided adequate protection from the edge losses associated with the point spread function of the support. This set of experiments was designed to determine whether or not the geometry specified in ANSI PH2.17 maintains density measurement independent of the sample aperture.

Samples were screened for uniformity by measuring each one five times with the X-Rite spectrodensitometer using the 4mm aperture. The measurements were made displacing the densitometer 4mm from the center; up, down, right and left. Density resulution for these tests was 0.001D. Samples having density ranges greater than 0.001 were eliminated from the test. All samples were read at both 45°/0° and 0°/45° configurations with the collection target area being 3mm, 5mm and 8mm diameter circles. Density values were measured at the white level, at a mid level

(0.8 to 1.0 density) and at a dark (1.4 to 1.6 density) level. The samples were; photographic paper, offset printing paper, coated card stock and ceramic-on-steel tile. Photographic paper samples included both dye and silver images on baryta and resin coated supports. Graphic arts papers were printed with gray and black inks as well as some screen pattern images. All were backed with GCA Backstop™ also the 20# offset was backed with several sheets of matching paper.

Individual data points are averages of 20 densitometer readings over a 10 second period. Readings are timed in the computer program so that each data point is initiated 30 seconds after its predecessor. The white reference tile is read first and last as a control for monitoring drift. The reference - test data - reference series were replicated on different days.

The data spread for each sample, examined in terms of standard deviations σ, was slightly larger than the spread for the same number of samples for a single size collection aperture. It is not possible to state that the readings made by strictly meeting the criteria of ANSI PH2.17 are identical for all sizes. The density values for varying target sizes remained constant. The departures from the 3mm density as reference were small — (D_3-D_n < 0.001) with 2mm over illumination. This was true for both the 0°/45° and the 45°/0° geometries. The imperfections of samples and the variation in reflectance encountered by changing the surface sampling may be the cause of size variation. No aperture size dependence was found for a resolution of $\pm$0.001 and a measurement standard error, σ=0.0007.

For both the 45°/0° and 0°/45° geometries the 2mm over illumination provides data independent of collection aperture size.

PHASE I —— 0°/45° - 45°/0° ILLUMINATION/COLLECTION REVERSIBILITY

Gray scale samples consisting of ceramic-on-steel tiles, photographic papers having dye and silver images and ink on paper both coated and uncoated were selected for uniformity and read using the reference - test data - reference technique previously described. The selected samples were read at both 0°/45° and 45°/0° with 5mm collection aperture and 9mm illumination. Density values from the two geometries differ by a significant amount. Ceramic-on-steel readings were identical for the two geometries and within the standard error of repeat readings alone. For other samples 0°/45° geometry produced density values lower than those from 45°/0° geometry.

For ceramic-on-steel the source-collector reversibility principle holds. In every test the value of $D_{45°/0°}$ - $D_{0°/45°}$ < 0.001. For density measurement of photographic papers the values of $D_{45°/0°}$ - $D_{0°/45°}$ varied from 0.1%D to as much as 0.4%D. For ink-on paper the variations were in the same class as for the photographic images except that $D_{45°/0°}$ - $D_{0°/45°}$ varied from 0.2%D to as much as 1.2%D. These variations did not follow a uniform pattern with density measured. An anomaly was found in measurement of the process inks on coated paper the cyan and magenta geometry differences were near 1%D while for yellow they were zero or slightly reversed.

We have formed the hypothesis that multiple point spread functions exist; in the support, in the image former and at the surface. The overall effect of these spread functions effects the reversibility of measurements. When data differences in the order of ± 0.014 density are of no concern, reversing of illumination and collection has little limitation. When values with greater accuracy are needed, differences introduced by geometry are important. Different responses for reading samples of ceramic-on-steel and practical images on paper raise a new set of questions on Standard Reference Materials. These phenomena indicate that both absolute and functional SRMs serve a real need in the standardzation of densitometers. The topic of SRMs is outside the scope of this set of experiments. Some images from "multi layered" off press proofs and instant photography products were included and with the limited measurement seemed to present even wilder variations.

CONCLUSIONS

1) When the condition that the sample be illuminated with a spot 2mm larger than the measured area is met, measurements made with 0°/45° or 45°/0° geometry are independent of measurement dimension *within* either geometry.

2) The 2mm over-illumination specification includes an adequate safety factor for all materials used in forming a practical sharp image.

3) Measurements of the same sample with 0°/45° and 45°/0° geometry may be significantly different. The factors influencing these variations are:

a) Point spread function for the support (translucence.)

b) Non-isomorphic optical qualities of the image layer.

c) Surface uniformity.

STRONG OBSERVATION

Highly translucent materials such as Opal Glass and PTFE are very sensitive to the ratio of illuminated to collected light areas. For this reason they may be good RELATIVE white references but make very poor transfer standards.

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