Pitfalls of Color Densitometry

A TUTORIAL PAPER

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This paper points out a number of false notions about the design, operation, maintenance and control of a color densitometer, and the utilization of its measurements. The basic optical principles of a typical color densitometer are described. The relationships between these color density measurements and any other set of reliable color density measurements is discussed. The common pitfalls are discussed in detail. These are classified into operational, control and maintenance errors.

Introduction

The increasing use of color sensitometry in the past several years has been necessitated by the greatly increased sale and processing of color photographic materials. While the use of sensitometric controls has been a great aid in black-and-white processing, the added complexity of the materials and processes in color photography makes the use of precise measurements and controls a practical necessity in order to maintain acceptable picture quality. In addition to the larger number of variables that must be controlled, the limits of permissible variation are very much narrower than they are in black-and-white photography.[1]

A color densitometer is the basic measuring instrument in the application of color sensitometry. Sensitometric controls cannot be any more reliable than the densitometer used for making the necessary measurements. Reasonably good color densitometers have been available commercially for the past 10 or 15 years and a great many have been sold to color processing laboratories.

Mere possession of a good color densitometer is not sufficient. Even the best color densitometer will not be fully effective unless it is used with a complete understanding of its limitations and the care that is necessary in order to realize its full capabilities. The purpose of this paper is to review briefly the basic features of color densitometers[2] and to emphasize some of the pitfalls to be avoided in their use. The densitometers discussed in this report are not used as laboratory standards for making basic measurements to a high degree of accuracy. Rather, they are used as photographic process control instruments for making measurements to a high degree of reliability.

A *color densitometer* is a specialized instrument used for measuring the optical densities of photographic dyes, inks, or other colorants used in photography or the graphic arts. *Optical density* is defined as the logarithm of the reciprocal of the transmittance of a film or the reflectance of a paper as given by the simple relationship, $D = \log_{10} (1/T)$ or, $D = \log_{10} (1/R)$. Functionally, a color densitometer provides "red," "green," and "blue" density measurements that are related to the amounts of cyan, magenta, and yellow dyes in a photographic sample.

Table I. Types of Optical Densities.

By Optical Geometry	
For photographic films	For photographic papers
* Standard diffuse	* Standard diffuse (0°–45°)
Double diffuse	Total
Specular	Specular (gloss)
	Average viewing
By Spectral Characteristics	
Integral densities	Analytical densities
* Arbitrary 3-color	* Equivalent Neutral (END)
Standard spectral (Hg-Cd lines)	Unit Neutral Normalized (UNNAD)
Printing	Spectral analytical
Visual	Equivalent Neutral Printing (ENPD)
Colorimetric	

* In greatest use in color densitometry.

Table I lists most of the types of density, first in terms of the optical geometry of measurment, and then classified by the spectral characteristics of measurement. Most density measurements made today on color films and papers are intended to be of the *arbitrary 3-color, standard diffuse* type. This paper deals largely with this type of density as measured by the transmission type of color densitometer.

Basic Elements of a Transmission Color Densitometer

The optical systems of all physical color densitometers have certain basic features in common. The characteristics of the optical system of the Type 31A Eastman Electronic Densitometer, the instrument with which we have had the most experience, will be used as a typical illustration.* The optical components are shown in schematic form in Fig. 1. Starting at the source at the top, the light passes through a heat-absorbing glass, a dichroic filter, one of the three

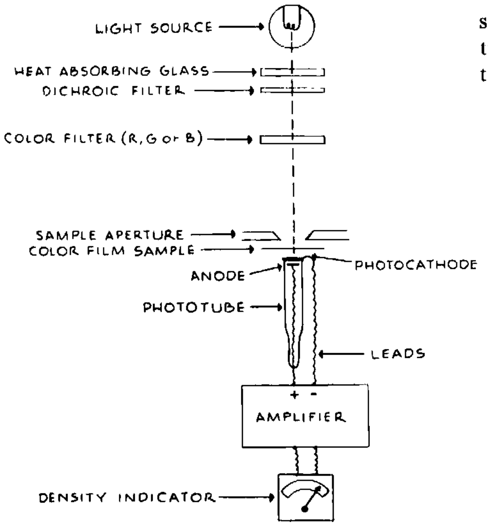

Fig. 1. Optical schematic of the Type 31A Eastman Electronic Densitometer.

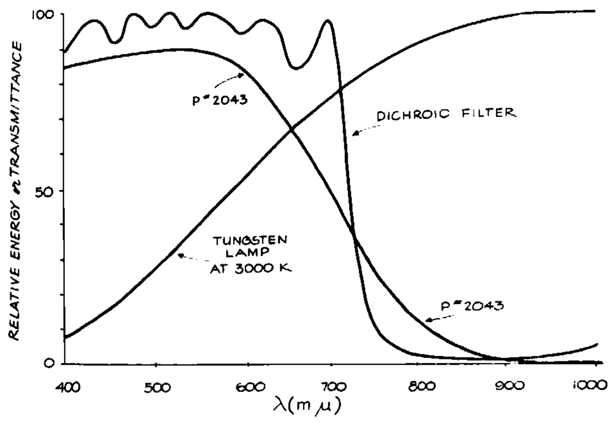

Fig. 2. Spectral characteristics of the light source, heat-absorber, and dichroic filter of the densitometer.

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*This transmission color densitometer is no longer available from the Eastman Kodak Co.

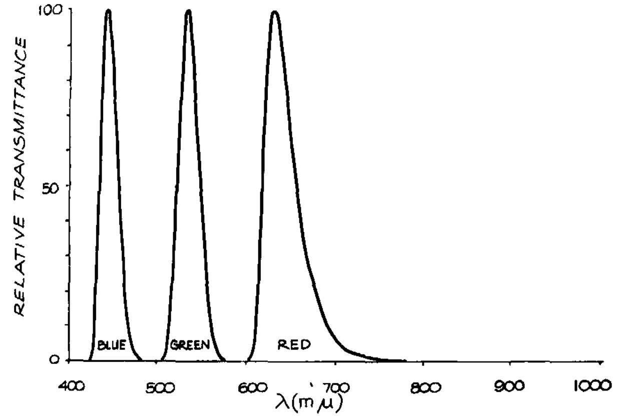

Fig. 3. Spectral transmittances of a set of red, green and blue filters used in the densitometer.

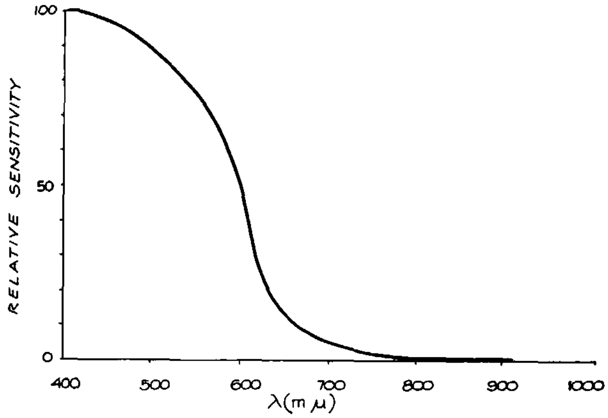

Fig. 4. Spectral sensitivity of a phototube used in the densitometer.

color filters, and a color film sample to be measured; finally, the light is incident on the photoreceptor.

The light source is a tungsten incandescent lamp, an inexpensive, fairly efficient, easily controlled source of the spectrally continuous radiant energy required in the various wavelength regions of the filter passbands. The lamp normally operates at a color temperature of about 3000 K.

Next in the optical system are two infrared rejection filters: a heat-absorbing filter, and a dichroic infrared-reflecting interference filter.[3] The heat-absorber removes the greater part of the infrared radiation that might cause undue heating of either the densitometer filters or the sample being measured. The dichroic filter cuts off sharply in the near infrared and, in conjunction with the heat-absorber, practically eliminates phototube response in this region. The dichroic filter has 50% transmittance at approximately 720 mμ, as seen in Fig. 2 where the spectral characteristics of the light source and the heat-absorber are shown along with those of the dichroic filter.

Next are the color filters, red, green, and blue, which serve to define the bands of wavelengths desired for the density measurements. Readings are usually desired at three wavelengths near the regions of maximum density of the three dyes of the process. The filter designs are arbitrary but are usually a good compromise between the desire for narrow bandwidth and the necessity for enough transmitted energy to provide the required sensitivity to measure high densities. Some filters are designed to provide printing densities of color negatives or intermediate materials.[4] In this case the design objectives are somewhat different. Here, the purpose is to design a set of filters that produce spectral responses that match the spectral responses of the printing process. Printing densities are beyond the scope of this paper, as are the various types of analytical densities.[5]

Filters may be made from dyed gelatin or colored glass, or a combination of both. Their spectral properties must be stable over long periods of time against fading or damage under normal conditions of use. Combination gelatin-glass filters are usually cemented with the gelatin inside for protection against moisture. Figure 3 shows the spectral transmittances of a set of filters designed for use with the densitometer to make arbitrary three-color density measurements of color print and color reversal films.

The next important feature in the optical path of the transmission densitometer is the sample aperture, where the sample is inserted in the light beam for measurement. The cross-section of the beam at this point determines the area of the sample that is measured. This is usually determined by the image at that point of a stop located farther back in the optical system. It is important that the beam be of reasonably uniform intensity over its cross-section and that its size and position in the sample aperture remain fixed.

As seen in Fig. 1, the optical system terminates at the light-sensitive receptor. In a physical densitometer the light-sensitive device is some type of photoreceptor; it may be a gas or vacuum phototube, a multiplier phototube, a photovoltaic cell, or a photoconductive cell. The receptor must have sufficient spectral sensitivity in the red, green and blue regions required for the measurements. It would be desirable if the receptor had no sensitivity in the near infrared; but all receptors have some sensitivity in this region, hence the need for the infrared rejection filters.

Most physical color densitometers employ some type of phototube. The sensitive element of the phototube is the photocathode. Light incident on the photocathode releases electrons that move to the anode under the influence of an applied electric field. Electrons are supplied to the photocathode through an external circuit in which the photocurrent is amplified and measured on a meter. The flow of electrons is proportional to the amount of light falling on the cathode. Insertion of the sample reduces the light intensity and therefore the photocurrent. The meter scale is marked into divisions numbered to read in density units. In many instruments the meter has a shaped pole movement that provides a logarithmic needle movement in order to give a fairly uniform density scale.* The relative spectral sensitivity of the densitometer phototube in our example is shown in Fig. 4.

The spectral response of a densitometer is determined by the product of the spectral distribution of the radiant energy of the source, the spectral sensitivity of the receptor, and the spectral transmittance of all the optical elements traversed by the light beam in going from the source to the receptor. This is seen in Fig. 5, which shows the three relative spectral responses computed for the densitometer with red green and blue filters and plotted on a linear wavelength scale. The *electrical* response of the instrument is proportional to the area under the appropriate solid curve in Fig. 5, the additive or integrated effect of all the wavelengths represented in the spectral response. The circled points were taken from the relative transmittance curves of Fig. 3. The dashed curve is the only region where the transmittance curves of the filters differ significantly from the response curves. This effect on the red response is a result of the spectral sensitivity of the phototube and can

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* Densitometers using electron multiplier phototubes generally employ some version of the Gunderson circuit[6] to obtain an output signal that is linearly related to density. These instruments operate the photomultiplier at constant anode current. Under this condition, the photomultiplier dynode voltage is nearly a logarithmic function of the radiant flux incident on the cathode. The Gunderson circuit automatically adjusts the dynode voltage to maintain constant anode current. The voltage is measured on a voltmeter calibrated directly in density units. Actually, this logarithmic relationship is usually not sufficiently exact over the required density range. Therefore, in practice, the output of the photomultiplier is modified by a special "compensating circuit"[7] so that the instrument may be trimmed to approximate true density at all points on the density scale.

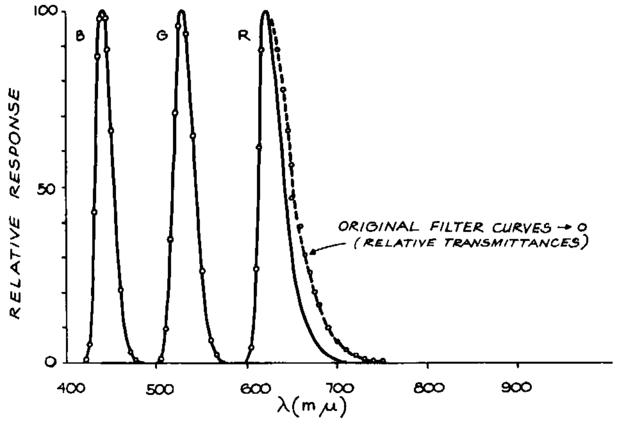

Fig. 5. Spectral responses of the densitometer through the red, green and blue filters.

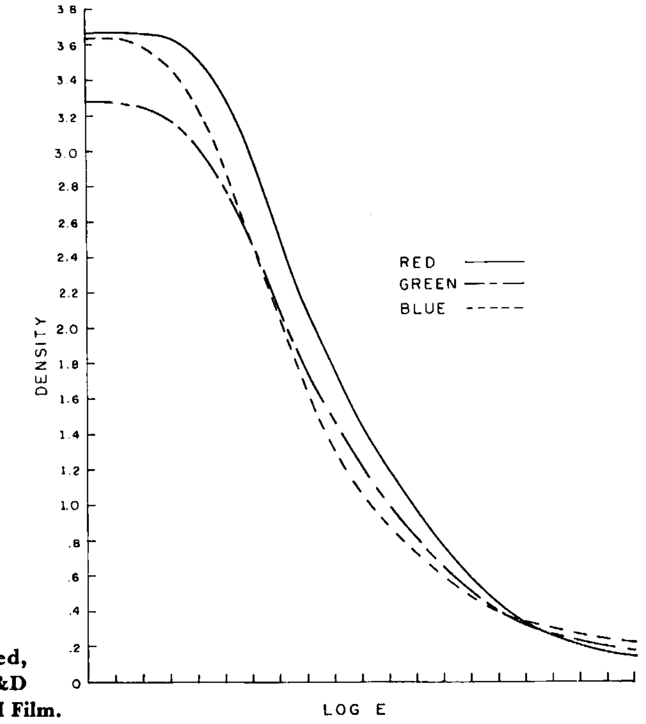

Fig. 6. A sample set of red, green and blue H&D curves of Kodachrome II Film.

affect red density measurements, as will be shown.

Measurement of the Dye Images

The samples of photographic color films to be measured on a color densitometer are normally prepared by exposure on a sensitometer followed by development in the appropriate process. From the known standard exposures given by the sensitometer and the optical densities measured through the red, green and blue filters of the densitometer, it is possible to plot the *D*-log *E* sensitometric curves for the process. A sample set of H&D curves is shown in Fig. 6. From such curves, showing the dependence of density on exposure, one can deduce the necessary information about the process to maintain control or to correct a process that is out of control.

In order to understand the physical process of measurement by a densitometer, let us take as an example a high-density step of a sample strip of Kodachrome II Film.* The spectral transmittance curve of the sample is shown by the solid line in Fig. 7. The cyan, magenta and yellow dye absorption peaks located by the arrows C, M, and Y are too small to be seen on the normal transmittance scale. The dashed curves are the transmittances multiplied by 300 to show the curve shapes of the dyes in the regions of greatest absorption where the density measurements are to be made. To measure this sample on the densitometer, first the gain of the amplifier is adjusted until the density reading with each of the filters is zero with no sample in the beam. (The instrument is equipped with three separate zero controls, one for each color filter.) Then the sample is inserted over the aperture, and the density is read through each of the three filters in succession, giving a quick and easy measurement of the red, green, and blue densities of the sample. Of course, with the spectral transmittance information in Fig. 7 and the spectral responses of the densitometer from Fig. 5, the same three density values could have been obtained by calculation but with considerably more effort. The *red* density, D_r, for example, is calculated according to the formula

$$D_r = \log_{10}\left(\frac{\Sigma P_r(\lambda)\Delta\lambda}{\Sigma P_r(\lambda)T_s(\lambda)\Delta\lambda}\right)$$

where $P_r(\lambda)$ is the spectral response of the densitometer through the red filter and $T_s(\lambda)$ is the spectral transmittance of the sample. The summation is taken over the entire wavelength range in which the densitometer has a measurable sensitivity. The denominator and numerator, respectively, are the relative densitometer responses with and without the sample. The spectral responses of the densitometer through the red filter, $P_r(\lambda)$, and through the filter and sample, $P_r(\lambda)T_s(\lambda)$, are shown in Fig. 8 with the

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* Kodachrome II film will be used in most of the examples throughout this report because of its spectral characteristics. The dyes in this product are highly selective and serve to amplify some of the weaknesses in densitometer design that will be described and illustrated. These effects can occur in the densitometry of any color product, but, generally, with smaller effects.

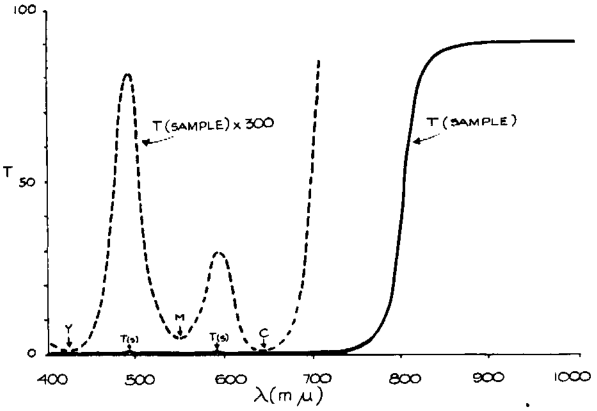

Fig. 7. The solid line gives the spectral transmittance of a high-density Kodachrome II Film sample. The dashed line is the spectral transmittance multiplied by 300.

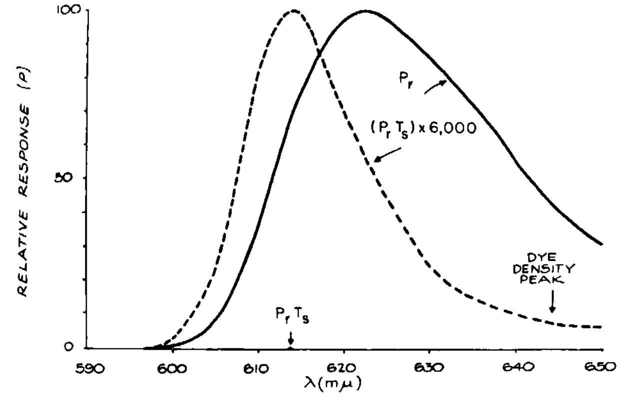

Fig. 8. Densitometer response through the red filter with and without the Kodachrome II Film sample. The dashed curve is the red response attenuated by the sample and multiplied by 6,000.

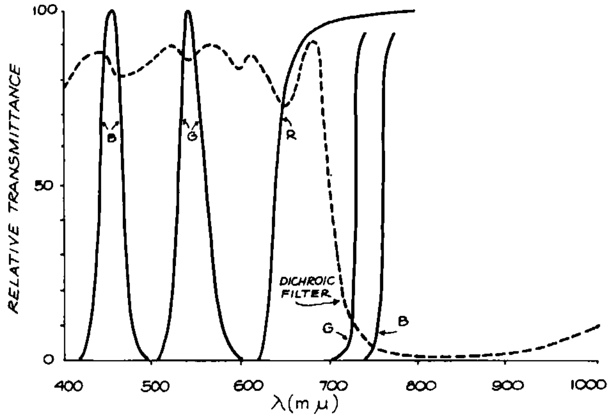

Fig. 9. Spectral transmittances of the Wratten Filters 92, 93, and 94 for use in color densitometers. The dashed curve is the spectral transmittance of the dichroic interference filter recommended for use with these Wratten Filters.

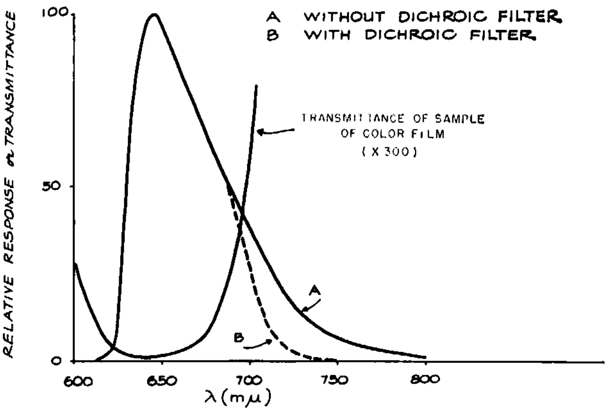

Fig. 10. Densitometer response through the Wratten 92 red filter, with and without the infrared rejection filter, in relation to the spectral transmittance of the high-density Kodachrome II Film sample.

wavelength scale somewhat magnified. One must look carefully to see the response curve after it has been attenuated by the sample since it appears on the scale as a mere "pip" just above the wavelength axis at about 610 mμ. The logarithm of the ratio of the area under the red response curve to the area under the attenuated curve is the red density of the sample.

In order to see how the attenuation by this high-density sample affected the curve shape as well as the magnitude of the red spectral response, the attenuated response was multiplied by a factor of approximately 6,000, and the result is shown as the dashed curve in Fig. 8. This is an indication of the sensitivity required of the densitometer to measure this high-density sample. Note that the sample was actually measured at an effective peak wavelength approximately 10 mμ shorter than the peak wavelength of the red response of the instrument. This "warpage" of a fairly wide response bandwidth results in nonlinear density measurements. That is, equal increments of sample density will not appear as equal increments in instrument readings. Furthermore, with such a wide bandwidth, differences in spectral sensitivity among phototubes may cause differences in density readings among instruments or on the same instrument when a phototube is replaced. A narrow-band filter would minimize these differences.

Filters for Color Densitometers

Wratten filters* numbers 92, 93, and 94 for reading red, green, and blue densities, respectively, are suitable for use in any good commercially available reflection or transmission physical color densitometer. Figure 9 shows the spectral transmittances of these filters normalized to a peak transmittance of 100%. Since all three transmit some light in the infrared, it is necessary to use an efficient near-infrared rejecting filter such as the dichroic interference filter shown by the dashed curve in Fig. 9. The dichroic filter is necessary in order to eliminate unwanted infrared response and restrict measurements to the red, green and blue regions. The need for the infrared rejection filter is especially great in the case of the W92 filter. This is seen in Fig. 10 on an expanded wavelength scale. The response through the W92 filter is shown, with and without the infrared filter, in relation to the spectral transmittance of the high-density film sample. The density of the sample of Kodachrome II film measured through the W92 filter was 2.58 *without* the infrared rejection filter and 3.30 *with* the infrared filter. Making the same type of measurement of a sample of Kodacolor film gave a density of 1.71 *without* the infrared filter compared to a density of 1.89 *with* the infrared rejection filter. The higher densities indicate that the infrared filter attenuates the infrared response of the densitometer and thus limits the measurement to the wavelength region nearer to the peak density of the dye in both cases.

The advantages of this set of filters are: (1) cost is low relative to glass-gelatin or interference-type filters[3]; (2) Wratten filters of consistent quality are readily available; (3) they may be easily cut into any size or shape and quickly installed; (4) if treated with reasonable care they usually permit very reliable densitometry for a period of a year or more; (5) good spectral selectivity and uniformity assure reasonably good agreement among densitometers, provided the photometric properties of the instruments are similar; and (6) because of the fairly narrow passbands, measurements of near-neutral samples will be linearly related to analytical densities,[5] and to ASA spectral densities[8] to a good approximation.

These filters represent a highly acceptable set of filters for color densitometry of photographic color films and papers. We should recognize, however, that certain precautions are necessary with the use of these filters. (1) Gelatin filters contain dyes and, although the dyes are chosen for maximum stability, no dyes are completely stable. Since gelatin filters will change slowly with age, the filters should be replaced periodically. (2) Gelatin filters need protection from moisture and excessively high temperature. Ambient temperature in the compartment where they are used should not exceed 120 F, and they should be protected by a good quality of heat-absorbing glass. A dichroic filter, which is needed to limit the infrared response, also offers additional heat protection to the filters.

Pitfalls Regarding Precision and Accuracy

One major pitfall is the naive assumption that a color densitometer is a completely precise instrument whether maintained or not. Densitometer precision or repeatability usually cannot be significantly improved by purchasing a more costly instrument. Generally, higher priced instruments are more automatic and have greater strip-reading capacity but their inherent precision is no better than less expensive densitometers. Most densitometers of the physical type, whether manual or automatic, are capable of making measurements with high reliability, only provided they are adequately checked and maintained.

To give some insight concerning the precision capabilities of a color densitometer, the following example is given. The precision or repeatability of a good transmission color densitometer at a density level of 3.00 is ±0.01 density. This, expressed as transmittance, is a variation of ±2%. A density of 3.00 is a transmittance of 0.001, and 2% of 0.001 is 0.00002. Such a densitometer detects reliably a difference in transmittance of 2 parts in 100,000.

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* These filters are listed in the data booklet, *Kodak Wratten Filters for Scientific and Technical Use.*

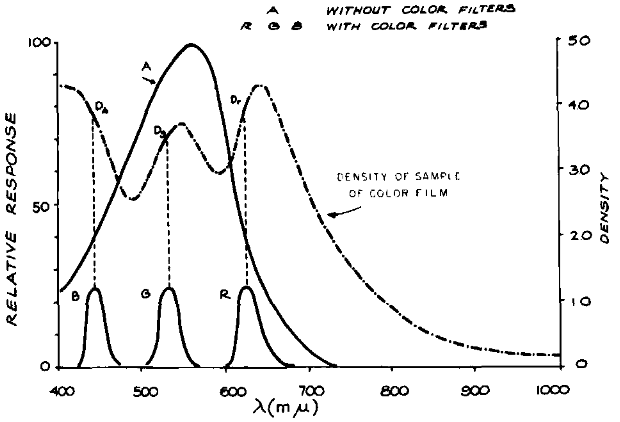

Fig. 11. Densitometer response, with and without its color filters, shown in relation to the spectral densities of the high-density Kodachrome II Film sample.

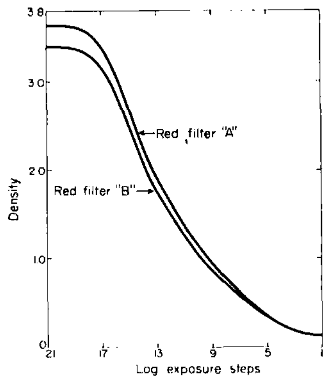

Fig. 12. Two H&D curves obtained from measurements of the Kodachrome II Film sample strip read on the same densitometer with two different red filters.

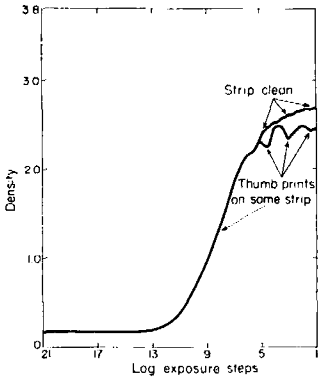

Fig. 13. H &D curve of an Ektacolor Paper strip with and without thumbprints on the entire strip.

Another pitfall concerns the question of densitometer accuracy. This question naturally arises if measurements from two densitometers, disagree. Usually the principal source of disagreement arises from the differences in their spectral responses. The chief cause of these differences is in the choice of the red, green and blue filters used with the instrument. The effects of spectral differences in phototubes, lamps and other selective components in the optical system are secondary. The reason for this becomes apparent in Fig. 11. The solid curve A is the spectral response of the densitometer *without* its color filters. Contributing to this response are the spectral characteristics of the lamp, heat absorber, dichroic filter, and phototube as described earlier. When the color filters are inserted into the optical system the spectral response is restricted to relatively narrow red, green or blue wavelength regions shown by the three solid curves, R, G and B, in Fig. 11. In simple words, the color filters form three spectrally narrow passbands that determine almost completely the wavelengths in the spectrum where the measurements are made. The spectral densities of the Kodachrome II sample are shown here by the dashed curve, except those portions of the curve measured by the phototube through the red, green and blue filters, which are shown as solid-line segments, D_r, D_g and D_b, respectively.

With another choice of color filters the readings would be different because the spectral response bands would be different. Strictly speaking, accuracy means conformance to a recognized standard. In this sense few commercially available instruments can be said to be accurate as defined by the American Standard for Spectral Diffuse Density of 3-Component Subtractive Color Films (PH2.1-1952). Conformance to this standard has been found difficult and expensive so that instrument manufacturers have arrived at practical filter designs which can be obtained at reasonable cost and that permit useful and practical measurements on color films.

For process control an arbitrary choice of filters is permissible provided one recognizes that differences among instrument readings are to be expected. Such differences should not cause undue concern. The important thing is that the readings from a given instrument be stable and reproducible so that a change in the process can be detected and interpreted with confidence. However, if correlation is desired with another good densitometer having a different set of color filters, this can be done to a good approximation by simple linear equations such as:

$$D_r(1) = aD_r(2)$$
$$D_g(1) = bD_g(2)$$
$$D_b(1) = cD_b(2)$$

where a, b, and c are numerical factors and (1) and (2) refer to the two densitometers under comparison. Different numerical coefficients are generally required to relate the same two densitometers for different dye systems.

The fact that two densitometers having different filters are linearily related means that when reading a sensitometric strip of a color product, the principal differences between the two instruments will appear as differences in contrast and maximum density in the H&D curves plotted from the readings.

An example of these differences is shown in Fig. 12. The two H&D curves in this figure were obtained from density measurements of the sample strip of Kodachrome II film read on the same densitometer with two different, but commonly used, red filters.

Since certain other aspects affecting the accuracy of a densitometer, such as its optical geometry, are not of primary importance in process control of color products, these will not be discussed in this paper. Standards for the optical geometries of densitometers may be found in the publications of the American Standards Association.[9,10]

Pitfalls in Operating, Controlling, and Maintaining a Color Densitometer

The foregoing discussion has dealt with some of the pitfalls in the design, construction, and calibration of color densitometers. In what follows, several possible pitfalls in the operation, checking or maintenance of a color densitometer will be pointed out.

Pitfall A: Speed

Since production people often need and demand fast answers, there is often the temptation to operate a densitometer in haphazard fashion. But speed at the expense of precision can be very costly. It can result in chaos. A few good measurements are better by far than many bad ones.

Our experience has shown that a great source of variability stems from being too hasty and failing to check the "zeros" of the color densitometer as often as necessary. The finest measuring instruments must be referenced or "zeroed" periodically.

Pitfall B: Sample

It is characteristic of photographic color materials that uniformly exposed and processed samples may have small nonuniformities in the resulting image, and the spectral absorptions of the dyes can vary with changes of temperature and moisture content. Although the magnitudes of these effects generally are small, they can, particularly in combination, adversely affect the precision of a sensitometric test by increasing measurement variability. Also, the exposing device may not expose the sample uniformly. In this case, the position of the sample in the aperture of the densitometer becomes critical and can affect the measurements.

In addition, persons handling sensitometric strips should be cautioned to keep the strips clean and free of abrasion marks and thumbprints. White cotton gloves should be worn while handling strips. Figure 13 shows an H&D curve of

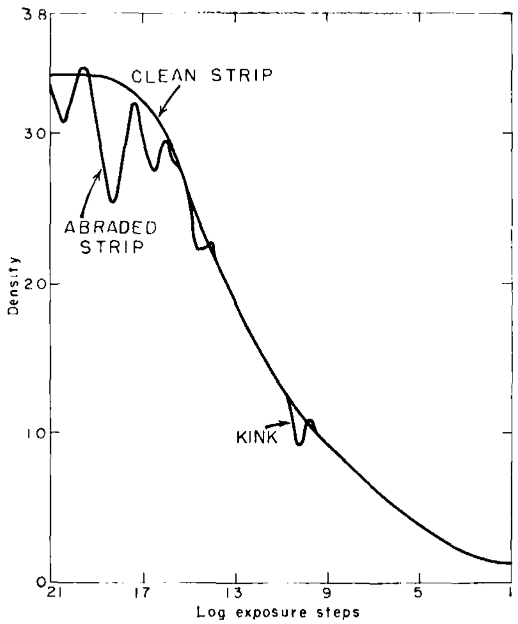

Fig. 14. H&D curve of a Kodachrome II Film strip with and without dirt and abrasion marks on the entire strip.

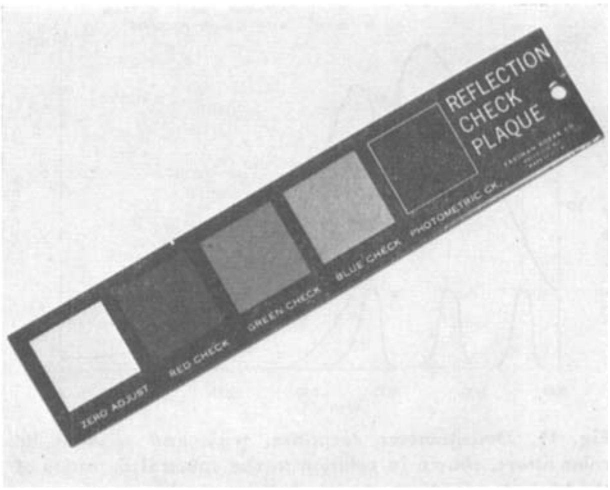

Fig. 15. A reflection densitometer check plaque developed by the Eastman Kodak Co.

an Ektacolor Paper strip with and without thumbprints on the entire strip. Note that the thumbprints significantly reduce the higher densities and change the shape of the curve in the shoulder. Dirt and abrasion marks can significantly affect the H&D curves of film strips, especially at the higher densities. Figure 14 shows an H&D curve of a strip of Kodachrome II film *with* and *without* dirt and abrasion marks on the entire strip. (The break in the curve near step 11 was caused by a kink that was accidentally put in the film strip.) While the treatment of this strip was intentionally severe, it was done to emphasize that reasonable care must be exercised in the handling of strips. The point to be stressed is that a serious variation caused by an artifact of the sample may be misconstrued to be a real variation in the densitometer or a serious shift in the process.

Pitfall C: Statistics

Much has been written about the wonders of statistics. In fact all physical measurement has its statistical aspect. But blind acceptance of statistical results without an acute awareness of the physical aspects can be hazardous. The interpretation should always include consideration of the reasonableness of the results in terms of the physics of the experiment, which includes the densitometer measurements.

Pitfall D: Control

Very few densitometer owners spend enough time checking their instruments. The tendency is to neglect the densitometer. Actually, very simple, reliable control methods are available that will detect the great majority of densitometer malfunctions.[11]

The number and character of densitometer check samples should be selected on the basis of their sensitivity to instrument change, stability, uniformity and cost. The frequency of checking the densitometer should be decided on the basis of balancing the cost of checking the instrument against the cost of the errors that the checking will prevent. A process control densitometer should be checked at least once a day. In this manner the instrument normally will be in control, ready for immediate use. Without adequate control insidious trends may occur that are difficult to detect or prove with only occasional control check data. Components that are gradually wearing, fading, or fatiguing are discovered most quickly by faithful day-by-day checking.

A reflection color densitometer check plaque together with a recommended densitometer control procedure have been made available.* A photograph of this plaque is shown in Fig. 15. The plaque is made of sturdy, vitreous-enameled steel and contains five color areas. One area is white for zeroing the reflection densitometer, a second area is dark gray on which photometric stability checks can be made, and the other three areas are specially selected colors for sensitively checking the stability of the red, green and blue responses of the instrument. The plaque surface is hard and uniform, and the pigments are highly stable. Another check plaque is being developed for transmission color densitometers. It will be similar in design to the reflection plaque except that it will contain transmission materials for checking the spectral and photometric responses.

Pitfall E: Maintenance

To avoid pitfalls in densitometer maintenance several procedures are suggested. The following list is based on many years maintenance of various types of densitometers:

(1) Sudden unexpected densitometer breakdowns can be greatly reduced by *scheduled preventive maintenance periods.* It is advantageous to discover incipient troubles and correct them before they can seriously affect process control data.

(2) By using a sensitive and analytical daily check control system, corrective action can be determined from an analysis of the out-of-control information. *A catalogue of symptoms and remedies* can be established to remove much of the guess work. Of course it is important to employ stable check materials and to keep them in good condition. It should be emphasized that the check data can be no more reliable than the materials used for checking the densitometer.

(3) An adequate quantity of high-quality *spare parts should be maintained.* As a minimum, the list of spare parts should include (a) a complete set of amplifier tubes if not a complete spare amplifier, (b) at least two spare phototubes, (c) a carton of lamps, (d) an extra set of filters, (e) one each of each type of motor in the densitometer, (f) one each of each type of relay, (g) spare fuses, (h) a spare set of connecting cables, and (i) one each of every important or hard-to-get component in the instrument.

(4) *Phototubes should be specially selected* to have good signal-to-noise ratio and low drift; in other words, high sensitivity with low fatigue. In some cases phototube selection is necessary to insure proper spectral sensitivity.

(5) A *second densitometer of identical make* that is in control can be very helpful in isolating trouble in an out-of-control instrument. Corresponding components can be interchanged one at a time, in a logical sequence, until the

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trouble moves to the second instrument thus isolating the malfunction. For example, filters might be interchanged first, then amplifiers, phototubes, lamps, meters, etc.

(6) *Give the densitometer plenty of time to warm up.* Whatever the claims of the manufacturer, most densitometers require at least a 30-min warm-up if the maximum precision capability of the instrument is to be realized. It is sometimes advantageous to install preset electric clock switches on densitometers so that they are automatically turned off in the evening and automatically turned on one hour before the start of each work day.

(7) *Increasing the life of the densitometer filters and lamp* is highly desirable and can be done by reducing the voltage on the lamp by 30 to 40% while the instrument is not in actual operation. The lamp will run cooler and last longer and the lower ambient temperature inside the densitometer will prolong the life of the filters. To reduce the voltage, a transformer rather than a resistor should be used to avoid additional heating within the instrument. Of course, the life of the lamp can be further increased by running it at slightly under its rated voltage during normal operation.

(8) *Stray room light can be very troublesome*, especially when measuring high densities. A good, simple test is to determine if a high-density reading *increases* when the room lights are switched off. Densitometers that operate on a-c modulation usually are especially sensitive to the 100% modulated stray light from fluorescent luminaires. Such instruments are, however, very much less sensitive than a d-c instrument to unmodulated stray light such as tungsten light or ambient daylight. In any case, ambient light should be controlled to the extent necessary to avoid any effect on density readings.

(9) *Cleanliness is highly important.* Dust on densitometer optics, including the color filters, can cut efficiency and lower precision as amplifiers are forced to run at higher gain. A good liquid lens cleaner should be used with abrasion-free tissue to clean optical components at regular intervals.

(10) *Air conditioning* is an important asset rather than a luxury as far as color densitometers are concerned. Also, as stated before, temperature and humidity variations can affect the density of photographic samples as well as the performance of the densitometer.

(11) Finally, in the attempt to diagnose instrument troubles, it should never be forgotten that *the operator is an essential and integral part of the measuring system.* A poor or careless operator can make the best densitometer look very bad. Before condemning an instrument it is well to carefully review the procedure used in its operation.

Summary

After a review of the basic principles and design features of a typical physical color densitometer, general operating characteristics have been discussed. A number of key points have been listed that are considered of primary importance to the reliability and repeatability of the measurements. It was emphasized that the measurements are never better than the instrument and that in order to obtain good measurements it is essential to understand the instrument, to use it in a favorable environment, and to follow good control and maintenance procedures. Many of the common pitfalls in the use of color densitometers have been pointed out in the hope that better measurements and hence better quality control may be achieved in all color processing laboratories.

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