Digital Image Analysis: Part II—Redefining Union Shade Index and New Applications For The Measurement Of Uniform Coloration

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Abstract

Image analysis was used in ongoing ARS research on union dyeing wool/cotton blended fabrics after pretreatment with biguanide to selectively modify the cotton constituent so it dyes competitively with wool with one dye in one dyebath under conditions favoring wool. The image analysis system is configured with a personal computer interfaced with a charge-coupled-device (CCD) camera and black/white frame-grabber board for processing a fabric' s digital image to histogram format representing pixel intensity over a 256 gray-scale range. The quality of union shade can be measured simply and quickly in the mill by recording the standard deviation of a dyed fabric' s histogram and comparing it to a preset standard deviation that corresponds to the visual perception of union shade.

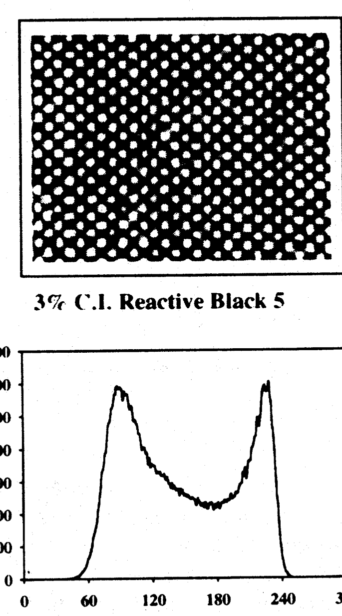
For research applications, the entire set of data points included within the histogram can be examined by curve-fitting the main histogram to resolve its component peaks. The shapes and positions of the component peaks provide a diagnostic tool to determine the conditions that promote union shade. Examples are presented to illustrate the convenience and ease of applying image analysis to determine how biguanide concentration, pretreatment application methods, subsequent reuses of original pretreatment baths, and dyebath pH affect the quality of union shade.

Introduction

The application of digital image analysis for objective measurement of uniform color is a relatively recent development in textile technology. In the imaging process, typically, a standard monochrome or color camera captures an analog image and provides this input to an 8 to 12 -bit gray-scale frame grabber board with up to 3MB frame buffer that digitizes the image at rates up to 40mHz. The board plugs into the expansion slot of a 486 or Pentium™[2] computer with CPU speed up to 200 MHz and bus throughput up to 45 MB, 16 RAM to 32 MB RAM, and 500 MB to 3 GB hard drive. Commercial software for image analysis is device-independent and operates under DOS, Windows™ 3.x and Windows™ NT.

Although a SVGA 1024 x 768 color monitor with live video-in-a-window is interfaced to the computer, external monitors can be added to examine the live image. Also, the computer can be interfaced with an oscilloscope, to aid in adjusting various black and gain set-points on the camera's panel controller in order to bring the camera-signal within the appropriate range for image acquisition. Image analysis can be adapted as machine vision for on-line decision-making without human intervention.

Figure 1: Histogram of untreated wool/cotton union cloth dyed in acidic medium with C.I. Reactive Black S showing selective dye uptake by the wool yarns.



In previous reports, an image analysis system was used in empirical studies to determine the effects of dyebath additives and processing conditions on the quality of *level shades* in dyed textiles of one fiber type and on the quality of union shades in dyed textiles of more than one fiber-type.[1,2] The system was configured for acquisition, processing,

Figure 2: Histogram of union dyed wool/cotton union cloth showing the fit of two peaks and the corresponding F- and G-values calculated from equations 1 and 3.

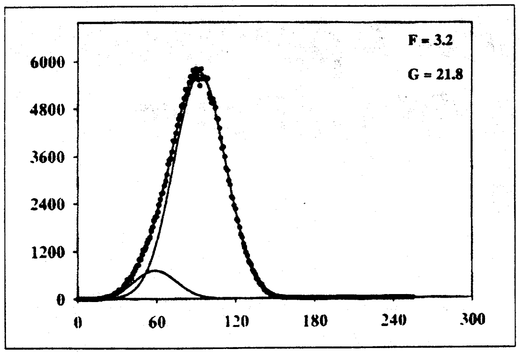


Figure 3: Histograms of union dyed wooVcotton union cloth showing the fit of three peaks and the imprecision in F-val G-values are precise.

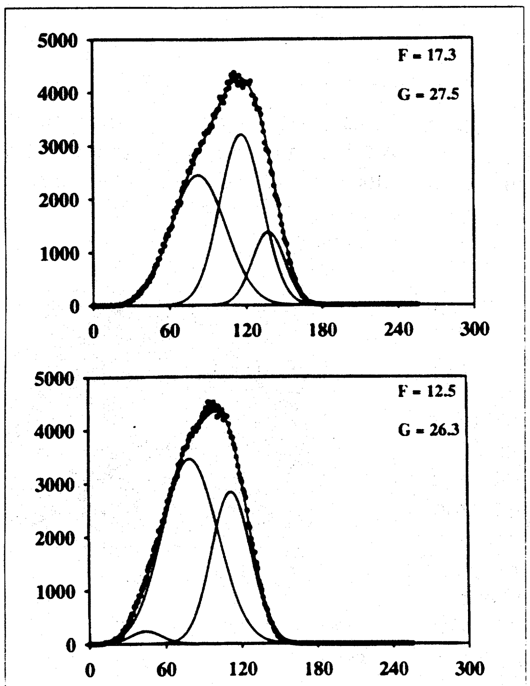
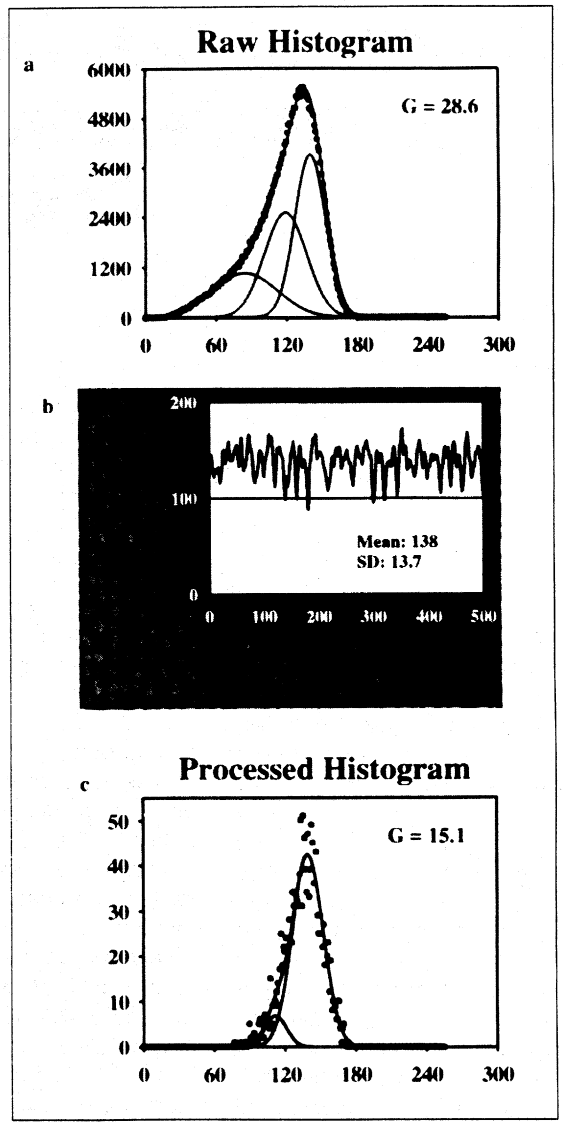


Figure 4: Line profiling to remove anomalous data: (a) "Raw" histogram; (b) average line profile of union dyed wool/cotton fabric; (c) "Processed" histogram constructed from the average line profile.



and analysis. In those reports equations were defined for measurements of *Level Shade Index* and *Union Shade Index*. These measurements were convenient, and provided documentation.

For on-line inspection where the textile is a continuously moving sheet, multiple outputs from networked high speed cameras having high resolutions and data compressing utilities can be combined to supply input to a single frame grabber board. The board can be controlled from a central computer and software. A gray-scale algorithm can be embedded to detect color defects above a certain preset level.

In this article image analysis is utilized to define a new Union Shade Index, G, that provides a more precise measurement than the former Union Shade Index, F. Two software utilities—line profiling and curve-fitting—are applied to image data and the results are diagnostic for how changes in pretreatment and dyeing processes affect the Union Shade Index.

When collecting image data, the camera is positioned at a distance of 3.8 centimeters from the fabric to focus an area of interest of 3.8 centimeters square so that the individual yarns can be resolved and their shades of gray distinguished. The images of the dyed fabrics were captured in 8-bit format for digital displays as histograms that represented gray-scale distribution of pixel intensities, for all the pixels in the entire imaged area, over the 256 brightness range where "0" is black and 255 is white. Histograms that are tall, narrow, and symmetrical have relatively low standard deviations and Union Shade Indices. They typify union-dyed fabrics. Those that are short, broad, and skewed with relatively high standard deviations have corresponding high Union Shade Indices. They typify non-union-dyed fabrics. When untreated wool/cotton union cloth is dyed with an acid dye in acidic medium, only the wool yarns dye and the fabric's histogram is bimodal, as shown in Figure 1.

The bimodality of the main histogram results from the recording and digital display of two sets of pixel distributions each having distinctively different mean values on the gray-scale. The mean value of a histogram defines its position on the gray-scale (x-axis) and as such is analogous to lightness or brightness (the colorimetric term "value").

Redefining union shade index

Union Shade Index, F, defined in Equation 1, incorporated the individual peak mean values, heights, and areas that were obtained from the main histogram after curve fitting. (3) The histograms of dyed union fabrics required two or three Gaussian peaks to represent the shape. Union Shade Index, F, for the two peak resolutions were:

$$F_{two\ peak}=(M_{high}-M_{low})*[A_{small}/(A_{small}+A_{large})]$$

Equation 1

where $(M_{high}-M_{low})$ is a measure of the difference in gray levels (M represents the histogram mean) of the dyed wool and cotton yarns and $[A_{small}/(A_{small}+A_{large})]$ is a correction factor to account for the prominence of the second peak (A represents the areas of the smaller and larger peaks).

When three peaks were required to resolve the main histogram, Equation 2 applied:

$$F_{three\ peak}=(M_{right}-M_{center})xA_{right}/A_{total}+(M_{center}-M_{left})xA_{left}/A_{total}$$

Equation 2

where "A"was the area and "M"was the mean value of the resolving curves denoted by position: "right, center, and left." Although F values generally provided a reasonable measurement of union shade, occasionally, some F values were imprecise because the F-equation did not account for all peak areas. Thus the chance arrangements of the resolved peaks disproportionately influenced the ultimate value.

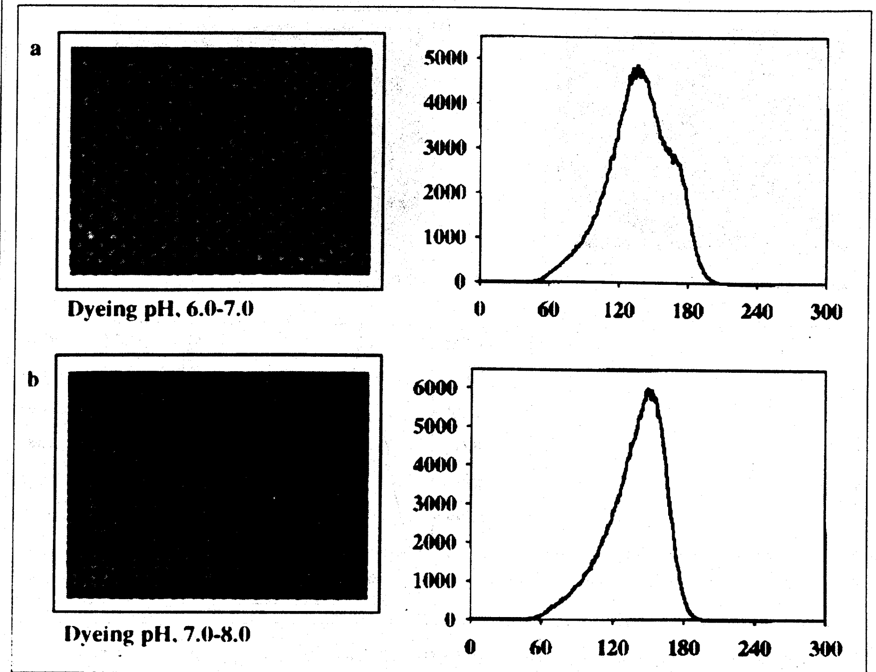
A G-value for Union Shade Index was developed to improve the reliability of measurement. For a sample whose shape can be represented as a single Gaussian peak, G is defined as the standard deviation of the peak, $G^2 = S^2$, where S is the standard deviation. For a sample whose shape is a superposition of two Gaussian peaks, G is defined as

$$G^2_{two\ peak}=(A_1/A)S_1^2+(A_2/A)S_2^2+(A_1A_2/A_2)(X_1-X_2)^2$$

Equation 3

where A_1 and A_2 are the peak areas of the two Gaussian peaks, $A=A_1+A_2$ is the sum of areas, S_1 and S_2 are the standard deviations and X_1 and X_2 are the positions of the two peak means.

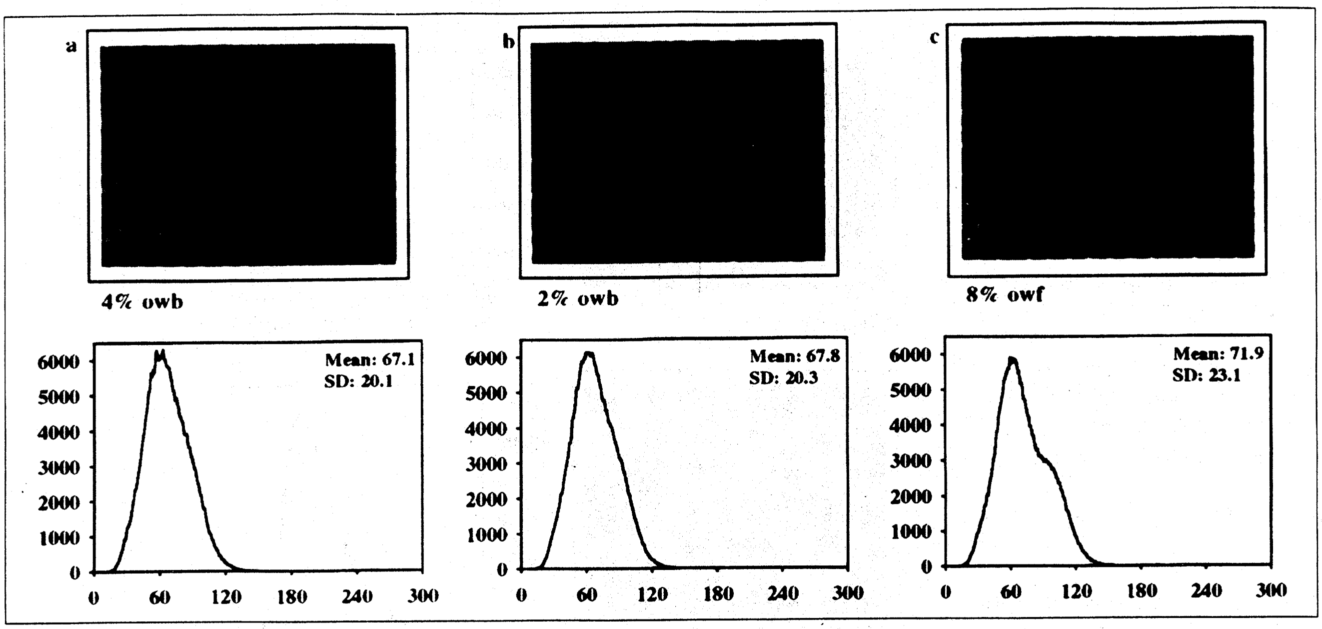
Figure 5: Histograms of biguanide pretreated 62% wool/38% cotton union cloth dyed with 3% C.I. Reactive Blue 69; (a) pH 6.0-7.0, (b) pH 7.0-8.0.



Extension to three peaks gives the formula

$$G^2_{three\ peak}=(A_1/A)S_1^2+(A_2/A)S_2^2+(A_3/A)S_3^2$$

Figure 6: Histograms of 62% wool/38% cotton union cloth dyed with 3% C.I. Reactive Black S after biguanide pretreatments at (a) 4% owb; (b) 2% owb; (c) 8% owf biguanide.



$$+(A_1A_2/A_2)(X_1-X_2)^2+(A_1A_3/A_2)(X_1-X_3)^2+(A_2A_3/A_2)(X_2-X_3)^2$$

Equation 4

where notation is similar to that above and A is the sum of the three areas. The G-value accounts for each area and standard deviation of the resolving peaks and it obviates the ambivalence of the F-value for selecting specific resolved peaks. The histogram of union-dyed wool/cotton union cloth in Figure 2 shows a two-peak fit of the main histogram and the comparison of F- and G-values for union Shade Index.

In Figure 3a and 3b, the histograms of two union-dyed fabrics showed similar main histograms and three curves were required to resolve the fit. One would expect that the values for Union Shade Index in a and b would be similar. This was found to be the case for the G-value but not for the F-value. F-values were imprecise and G-values were precise.

Examples of how peak resolution by curve-fitting can aid in analyzing union shade for the effects of pretreatment concentrations and dyeing conditions are shown in the figures below.

Experimental

Materials and Methods

A balanced plain woven fabric of 62% wool warp and 38% cotton filling yarns (union cloth) was obtained as TF4504 from Testfabrics, Middlesex New Jersey. This fabric could be assessed visually for union shade by comparing the wool and cotton fringes. The fabric was first pretreated and then dyed in a single dyebath with one dye under conditions favoring wool. Ten gram fabric samples were wet out and pretreated in an exhaust bath of liquor ratio 10:1, with a biguanide compound, Sandene™ 8425 Liquid, 55% solids, (procured from Clariant Corporation), over a concentration range of 4% on the weight of the bath (owb) to 4 % on the weight of cotton (owc).

The conditions for pretreatment were one hour with stirring, room temperature, and pH 6.5 (as received). By this pretreatment, cotton was selectively modified with amino groups and cationic charge. Following the pretreatment, the fabrics were rinsed thoroughly and dyed in fresh dyebaths (liquor ratio 20:1) with C.I. Reactive Blue 69 (Lanasol Blue 3R, Ciba Corporation), an alpha-bromoacrylamido reactive dye for wool or with C.I. Reactive Black 5 (Intracron Black VS-B, Crompton & Knowles Colors, Inc.), a bifunctional vinylsulfone reactive dye for cotton. Thus cotton gained affinity for anionic dyes in acidic medium. Also, cotton gained reactivity for reactive dyes by virtue of its newly acquired secondary amino groups. Dyebath pH for the best union shade was found to be dye-specific.

All dyeings were carried out with the conventional time/temperature profile commonly used for acid dyes, that is, primary exhaustion from 40 to 70C and secondary exhaustion at 90C. After dyeing with reactive dyes, a bicarbonate aftertreatment was performed at 80C for 15 minutes in order to remove occluded

Figure 7: Histograms of union shades and the resolving peaks of 62% wool/38% cotton union cloth dyed with 3% C.I. Reactive Blue 69 after biguanide pretreatments at (a) 4% owb; (b) 8% owf; (c) 6% owf.

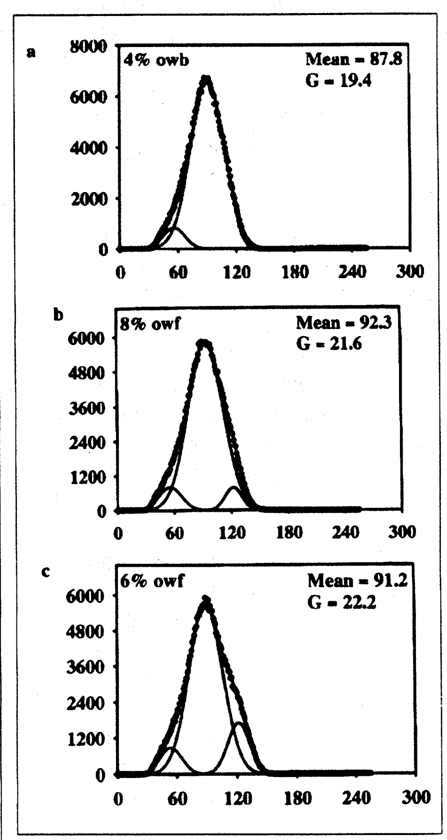
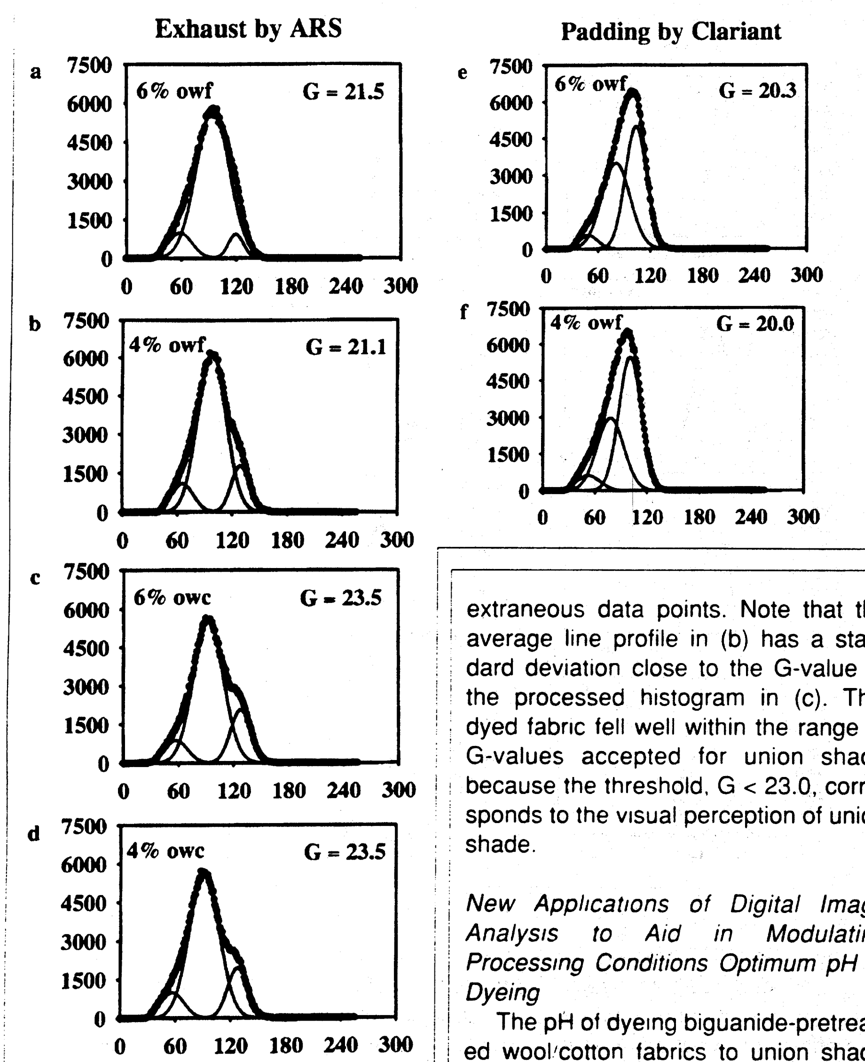


Figure 8: Histograms of biguanide pretreated 62% wool/38% cotton union cloth after dyeing with 3% C.I. Reactive Blue 69. Biguanide concentrations by exhaust: a-d, and by padding: e-h.



and surface dye.

Line Profile: Raw versus Processed Histogram

The digital images of woven fabrics are complicated by the prominence of the black spaces between the yarns that add anomalous pixels and force "tailing" of the histogram at the low (black) end of the gray-scale. Without correction, this histogram is referred to as "raw." To correct the raw histogram shown in Figure 4 (a), three line profiles (one line profile represents pixel intensity variations along a line drawn across the fabric) were drawn with each across the path of one yarn and avoiding yarn interstices. The average of the three line profiles in (b) was converted to the "processed" histogram (c). Thus, the new G-value in (c) excluded those extraneous data points. Note that the average line profile in (b) has a standard deviation close to the G-value of the processed histogram in (c). This dyed fabric fell well within the range of G-values accepted for union shade because the threshold, G < 23.0, corresponds to the visual perception of union shade.

New Applications of Digital Image Analysis to Aid in Modulating Processing Conditions Optimum pH of Dyeing

The pH of dyeing biguanide-pretreated wool/cotton fabrics to union shade with 3% C.I. Reactive Blue 69 was determined by a series of experiments where the dyebath pH was adjusted from 6.0 to 8.0. As shown in figure 5 (a), under slightly acidic conditions, the histogram of the dyed fabric exhibits skewness because wool was more competitive for the dye. In (b) dyeing at pH 7.0 to 8.0 produced union shade.

Limiting Biguanide Concentrations

Pretreatment: 4% owb, 2% owb, 0.8% owb

Dyeing: 3% C.I. Reactive Black 5

Image analysis was used to determine the lowest biguanide concentration required for union shade when dyeing with 3% C.I. Reactive Black 5. In Figure 6, wool/cotton union cloth was pretreated with biguanide at concentrations of 4% owb in (a), 2% owb in (b), and 0.8% owb (8% owf) in (c) for subsequent dyeing with 3% C.I. Reactive Black 5. Note in (a) and (b) that the G-values are below 23.0 and are therefore union shades. In (c) however, at the lowest biguanide concentration, there is borderline acceptance with a G-value of 23.1. Note also that in (c) the relatively higher mean value indicates a lighter shade. These histograms suggested that 0.8% owb biguanide could be the lowest concentration possible to achieve union shade in this system.

Pretreatment: 4% owb, 0.8% owb, 0.6% owb:

Dyeing: 3% C.I. Reactive Blue 69

In the previous example the judgment for union shade was based upon the standard deviation value alone. Alternatively, the entire data set comprising the histogram can be used to set a threshold for acceptable union shade when the G-value (involving curve-fitting) is used. This process is a potentially powerful analysis tool for research conducted on the processing conditions affecting color uniformity and union shade. In Figure 7, the resolved peaks of the main histograms were analyzed to show the progressive loss of union shade with the decrease in biguanide concentrations within the concentration range, 4% owb in (a), 0.8% owb in (b), and 0.6% owb (6% owf) in (c) that were used for pretreatment of wool/cotton union cloth before dyeing with C.I. Reactive Blue 69. Note that according to the G-values shown in Figure 7, all the biguanide concentrations yielded union shades; however, at 0.8% owb, the quality of the union shade diminished somewhat. This is indicated by skewness of the histogram.

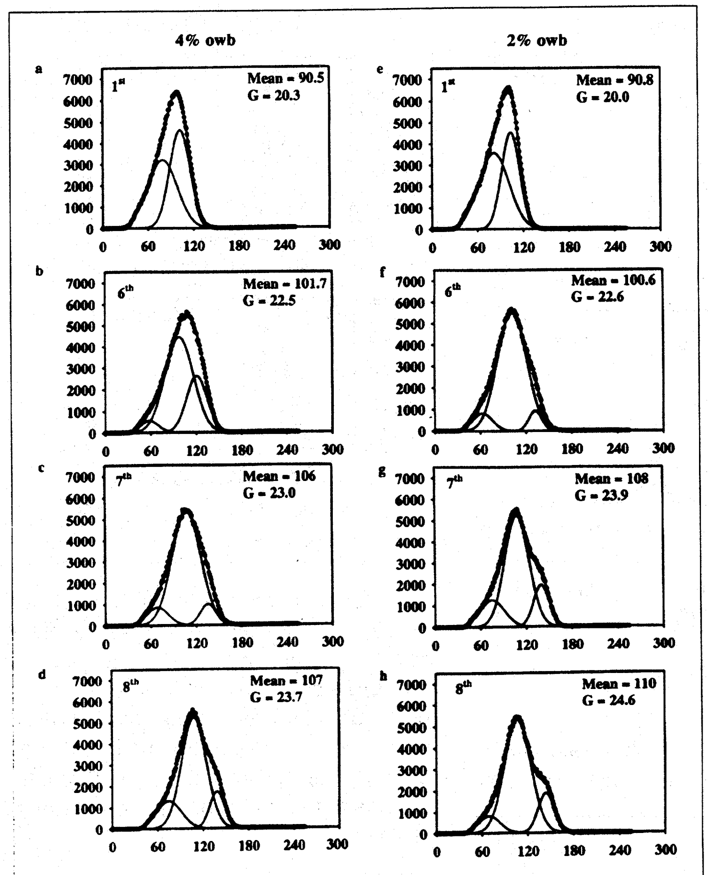
Note that the mean values at the lower concentrations in (b) and (c) are higher and indicate a slightly lighter shade but there would be considerable savings in costs by running the pretreatment process at these lower concentrations.

The specific details of the resolved peaks in Figure 7 (a), (b), and (c) are noteworthy. In (a) the bulk of the pixels represent gray levels falling within the histogram that is tall, narrow, and symmetrical and this is the true representation of union shade. There is a minor contribution of black pixels that results from yarn interstices, for this is a raw histogram. In (b) and (c), two minor resolved peaks represent a cluster of lighter and darker pixels that are discretely enveloped within the main histogram to indicate that the quality of union shade is diminishing. Further reduction in biguanide concentration forces the minor peak on the right to fall outside of the main peak, thereby contributing to the overall skewness of the main peak. Curve-fitting is considered to be a diagnostic tool for following the quality of union shades as they become affected by process variables.

Applications of Biguanide Pretreatment by Exhaust and Padding

Parallel studies were conducted by ARS and Clariant Corporation to compare the effectiveness applying Sandene 8425 Liquid™ by exhaust and by padding for subsequent union dyeing with C.I. Reactive Blue 69. Decreasing amounts of the biguanide in Figure 8, from 0.6% owb (6% owf) in (a) and (e) to 0.15% owb (4% owc) in (d) and (h) were used to determine the lowest concentration of biguanide needed for union shade. The G-values determined from the resolving peaks indicate that the lowest concentration applied, 0.15% owb, can be applied effectively for union shade by padding in (h) but not by exhaust in (d). By exhaust, the lowest concentration that can be recommended is 0.4% owb or 4% owf in (b). Note that the padded samples (e-h) had dyed to a slightly darker shade (mean values lower than mean values in a-d) although this was not visually apparent.

Figure 9: Histograms of pretreated 62% wool/38% cotton union cloth after dyeing with 3% C.I. Reactive Blue 69. Subsequent reuses of biguanide pretreatment baths formulated as 4% owb: a-d; and 2% owb: e-h.



Subsequent Reuses of Biguanide Pretreatment Baths

Image analysis was applied to determine if the original 4% owb and 2% owb biguanide pretreatment baths could be reused for additional pretreatments of wool/cotton union cloth before union dyeing with 3% C.I. Reactive Blue 69. In Figure 9 (a,e,b,f), it is notable that pretreatment baths of both concentrations could be reused up to six times (G-value <23) without losing the quality of union shade. Note that the sixth reuse of the 2% owb bath in (f) shows a significantly higher mean value (lighter shade) than its counterpart, 4% owb in (b). There is essentially no mean value difference in the series (a-d) at 4% owb and (e-h) at 2% owb. Thus, in this system, there is no advantage to be gained for union dyeing by increasing the biguanide concentration from 2% owb to 4% owb.

Conclusions

Fabric blends of wool and cotton present a particular challenge in their dyeing to union shade. The chemistries of wool protein and cotton cellulose require different dye classes for substantive dyeing. The ARS process for union dyeing provides ease of dyeing these blends from one dyebath with one dye that has affinity for wool and cotton because of selective modification of the cotton constituent. Image analysis was used to follow the effects on union shade of introducing various pretreatment compounds, additives, dyes and dyeing conditions.

The unique features of the histogram —its shape, standard deviation, mean, and those of the resolving peaks, were used qualitatively to aide in establishing directions for screening experiments to establish the optimum conditions for dyeing to union shade. They were used quantitatively for objective measurement of Union Shade Index, G.

In this work, image analysis was used to provide documentation to show that the limiting biguanide concentration when applied by exhaust for subsequent union dyeing with 3% C.I. Reactive Blue is 0.4% owb or 0.6% owb; and when applied by padding, a much lower amount, 0.15% owb can be used. It also provided documentation that 4% owb and 2% owb biguanide pretreatment baths remained effective for modifying cotton up to the sixth bath reuse. A relatively inexpensive image analysis system would fulfill the pressing need for quick and efficient monitoring of color uniformity and it would be complementary to an accompanying colorimeter placed sequentially on-line to measure color quality in terms of a color-ordering system. In contrast to the information provided by colorimetry, image analysis can provide documentation that a fabric with high color strength (K/S) may not be uniformly dyed.