Optical Radiation Transmission Levels Through Transparent Welding Curtains

Tests with blue, green, gray and yellow welding curtains from commercial sources indicate yellow curtains transmit a larger component of hazardous wavelengths than the others, although the magnitude of optical energy transmitted by yellow curtains is small

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ABSTRACT. Results are described for tests conducted on 25 transparent welding curtain samples of four colors from five manufacturers to document spectral transmission values of curtains used in welding environments. The conclusion based on the results of these tests suggests that most transparent curtains will afford adequate protection from optical radiation in the ultraviolet region, but that all of them will transmit high percentages of infrared radiation.

Introduction

Numerous skin and eye injuries have occurred in the welding environment from exposure to ultraviolet, visible, and infrared radiation (hereinafter denoted optical radiation).[1-7] A control measure that has been used to reduce the incidence of injuries to bystanders consists of using welding curtains made of metal or flame-resistant fabric that are generally opaque to most optical radiations.

A relatively recent innovation in curtain material has been the use of transparent colored curtains made from polyvinyl chloride plastic film and at least three other components. These components are a color dye, flame retardant chemical, and an ultraviolet absorber. The intensity and spectral distribution of transmitted optical radiation through a given curtain depends, in some manner, on such factors as optical density, thickness, and color.

One of the main advantages of using such curtains is the increased visual communication among workers and with management. Industrial use of the transparent curtains, however, has resulted in questions concerning the protection they afford workers and observers outside the immediate welding area. However, the published literature, excluding manufacturers' specifications, for such curtains is limited.[8] For this reason the National Institute for Occupational Safety and Health undertook tests to determine optical radiation protection provided by transparent welding curtains; this paper describes the results of the tests performed.

Apparatus and Methods

Acquisition of Welding Curtain Samples

Samples of transparent welding curtains were requested from all those manufacturers who were identified through a search of the welding trade literature. Twenty-one curtain samples of various colors and sizes were received.

Manufacturers that provided samples were Davlynne Incorporated, FIRL Industries Incorporated, Frommelt Industries, Singer Safety Products Incorporated, and Wilson Sales Company. As far as it can be determined these were the only known manufacturers of transparent welding curtains at the time of testing.

Some samples had been previously acquired which enabled transmission tests to be conducted on aged curtains. In addition, a used bicolored welding curtain was obtained from an industrial welding facility. Samples from this particular curtain permitted spectral transmission comparisons to be made on a before and after cleaning condition.

Table 1 categorizes the samples tested according to manufacturer, color, thickness, and age.

Transmission Measurement System

All spectral transmission measurements were performed with a Perkin-Elmer Model 323 recording spectrophotometer. This system has a low sensitivity level which makes it a valuable tool to document low transmission values. The spectrophotometer is a double-beam single-pass recording monochromator that uses deuterium and tungsten lamps as the optical radiation sources. The detector used in the system consists of a photomultiplier tube for the ultraviolet and visible regions, and a lead-sulfide cell for the infrared region. The spectral range of the spectrophotometer was 210 to 2600 nanometers (nm), i.e., 8.3×10^{-6} to 102.4×10^{-6} in.*

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**1 nanometer (nm) = 1×10^{-9} m = 39.4×10^{-9} in. = 10 angstroms (Å).*

Table 1—Data on Tested Curtain Samples

Sample	Color	Thickness[a,b] cm	Age in years
A	Yellow	0.0351	> 1
B	Green	0.0356	> 1
C	Gray	0.0328	> 1
D	Yellow	0.0361	> 1
E	Green	0.0328	> 1
F	Yellow	0.0335	> 1
G	Yellow	0.0368	< 1
H	Green	0.0312	< 1
I	Gray	0.0297	< 1
J	Blue	0.0312	< 1
K	Green	0.0305	< 1
L	Yellow	0.0307	< 1
M	Gray	0.0328	< 1
N	Green	0.0307	< 1
O	Yellow	0.0358	< 1
P	Green	0.0300	< 1
Q	Yellow	0.0353	< 1
R	Yellow	0.0310	> 1
S	Blue	0.0297	> 1
T	Yellow	0.0328	< 1
W	Gray	0.0371	> 1
X	Green	0.0351	< 1
Z	Yellow	0.0310	> 1

[a]Thickness given is average of three measurements
[b]2.54 cm = 1 in.

After the recommended warm-up period, the spectrophotometer was calibrated at the lowest wavelength value in each of three optical radiation regions at both the zero and 100% transmission level. The instrument was set for 100% transmission and examined for departure from 100% across the entire spectral range of all regions. A zero-check was made at the end of each region to determine the magnitude and direction of any drift corrections.

A rectangular-shaped segment, approximately 25 × 50 mm (1 × 2 in.) was cut from the center portion of every sample, assigned an arbitrary letter, placed into an envelope until the order of measurement was determined by a random number process, and measured. Each of the samples was positioned at the entrance slit of the detector chamber. Care was taken during the tests to position all samples over the cell window in the exact same manner by the use of adhesive tape strips. Gloves and tongs were used to minimize contamination. A plot of percent transmission vs. wavelength was made on every sample.

Reproducibility

It is important that curtain thickness does not vary too much, since the intensity of transmitted radiation is dependent on thickness. To check how well the manufacturer controlled the thickness of the curtains, transmission measurements were compared among samples cut from separate sheets of the same curtain type. As part of this test a measurement was made to obtain the thickness of each sample with a micrometer. The average thickness is shown in Table 1.

Transformation Technique

A program was developed for a Hewlett-Packard Model 9830A computer to transform transmission values from the three separate optical radiation regions into one continuous curve on semi-logarithmic graph paper. This format permitted better comparisons among the various samples.

Results

A typical sample spectral transmission plot as obtained from the spectrophotometer is shown in Fig. 1. Note that the three optical regions were divided as follows: ultraviolet 210-360 nm, visible 340-700 nm, and infrared 600-2600 nm.

The original data, while informative, have several disadvantages in their existing format. First, curves shown in this manner are difficult to read with samples that have unusual transmission properties. Second, comparisons with samples having different spectral transmission values are laborious. Finally, the curves do not follow the standard division of optical radiation regions which are ultraviolet, less than 400 nm, visible 400-760 nm, and infrared, greater than 760 nm. These

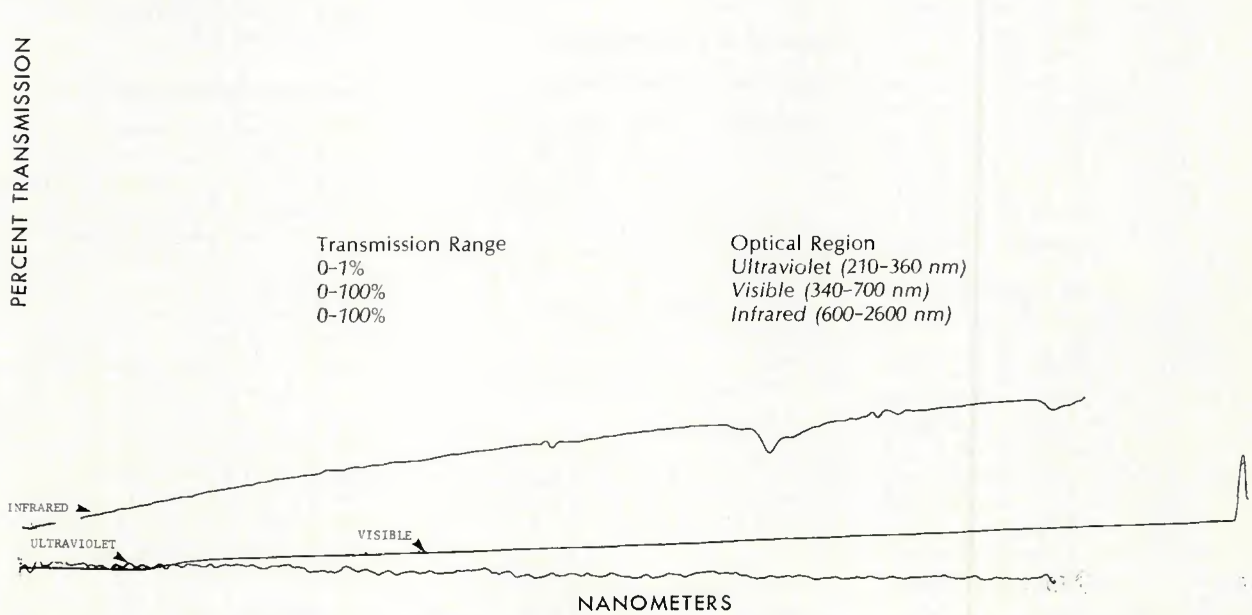

Fig. 1—Typical spectral transmission curve of welding curtain obtained for ultraviolet radiation is 1% and for visible and infrared radiation is 100%

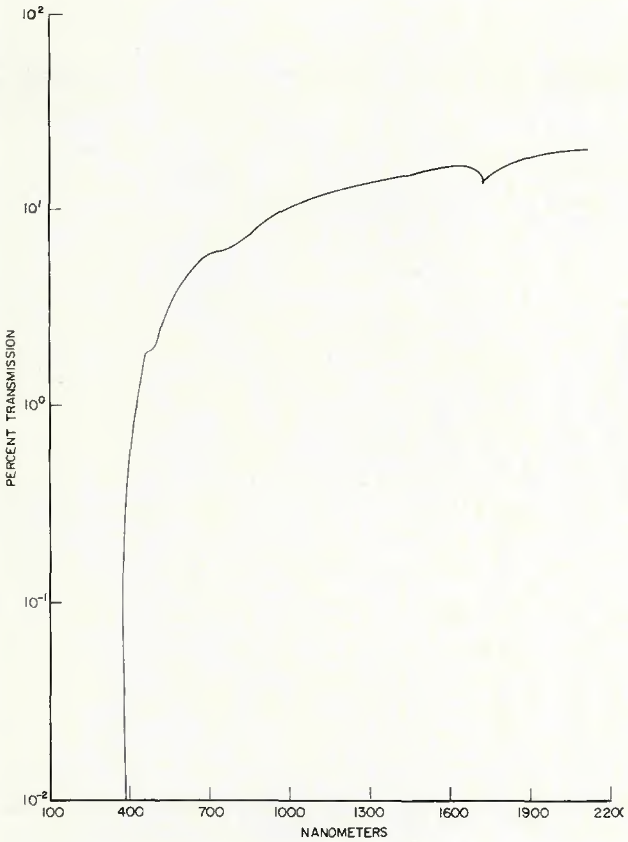

Fig. 2—Typical modified spectral transmission plot

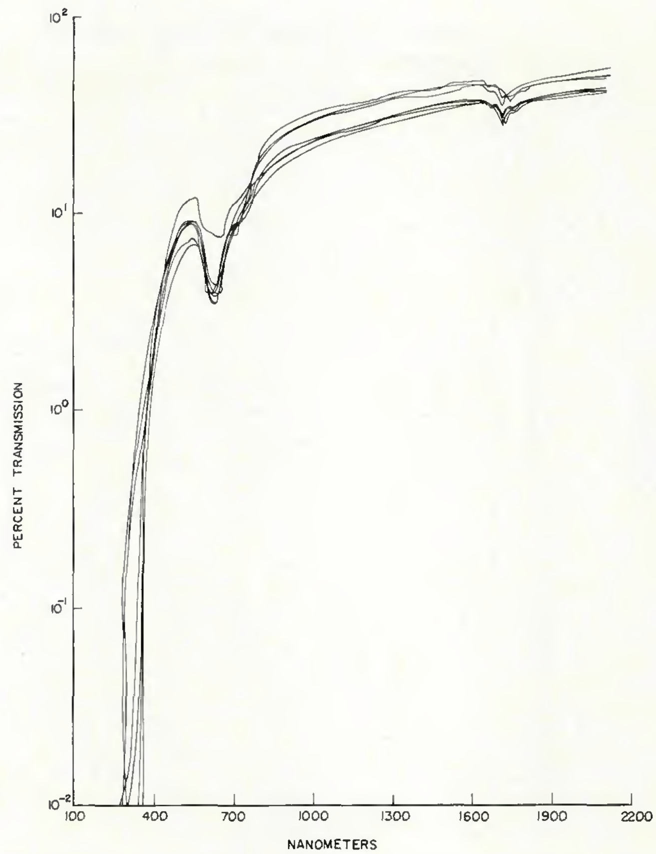

Fig. 3—Composite of green curtains (samples B, E, H, K, N, P and X)

difficulties can be averted by using the previous mentioned transformation format technique. When this format is used, a composite curve such as in Fig. 2 results.

There is a small error in the composite curves due to the difference in sensitivity of the two sequentially used spectrophotometer detectors. The error associated with this factor is about 5% and occurs at the junction of the visible-infrared region.

In order to determine the degree of spectral transmission uniformity in the manufacturing process, a comparison was made among all curtain samples of the same color. Figures 3-6 show sample data according to color. Several characteristics are apparent from these figures:

1. Except for the yellow curtain samples there appears to be relatively good consistency in transmission values, i.e., less than 10% variation over the measured optical region. The yellow samples appear to give consistent values, except in the UV region.

2. All samples experience a drop in transmission around 1700 nm. This particular decrease in transmission is probably due to curtain composition.

3. The shape of the transmission curve undergoes drastic change between the visible and IR regions. For example, the green and gray samples show a gradual transmission progression tendency in this area while the yellow and blue samples demonstrate a very sudden and distinct transmission change around 500 and 800 nm, respectively.

4. All curtain samples transmit infrared radiation. For example, the blue and yellow samples will transmit about 90% in the infrared (IR) region while the gray samples transmit the least at 20%.

Samples of the same color and approximately equivalent thickness, but differing in age, generally show variation of transmission levels over the measured optical radiation region of less than 5% (Figs. 6, 7, and 8). However, Fig. 9 suggests that aging factors may be quite important for yellow curtains in the ultraviolet (UV) region. Figure 9 also shows the older samples permit more transmission near 400 nm. In fact, four of the five new yellow samples, from different manufacturers, have a high absorption level of around 400-500 nm, whereas none of the older samples show this characteristic.

Since none of these curtain samples are older than one year, this particular apparent aging effect could be of major importance. It must be noted, however, that there is no assurance that sample composition or manufacturing methods had not changed during the time of study. Therefore, one should not assume only aging caused the effect observed. Note that with the same curtain, sample transmission values appear to decrease as the contaminant level increases—Fig. 10.

A theoretical relationship exists between spectral transmission levels and thickness of the curtains provided that the curtain tint and its concentration are the same. This relationship is shown as equation (1):

$$I(\lambda) = I_o(\lambda)e^{-k(\lambda)x} \quad (1)$$

In this equation, which is often referred to as Lambert's Law of Absorption, I_o is the optical radiation incident upon the welding curtain, I is the optical radiation transmitted through the curtain, x is the curtain's thickness, and k is the absorption coefficient.

Equation (1) can be rewritten as:

$$\log_e\left(\frac{I}{I_o}\right) = -kx \quad (2)$$

A comparison between two curtains (A and B), identical except for thickness, can be made by taking the ratio R of equation (2) for the two curtains:

$$R = \log_e\left(\frac{I_A}{I_o}\right) \div \log_e\left(\frac{I_B}{I_o}\right)$$

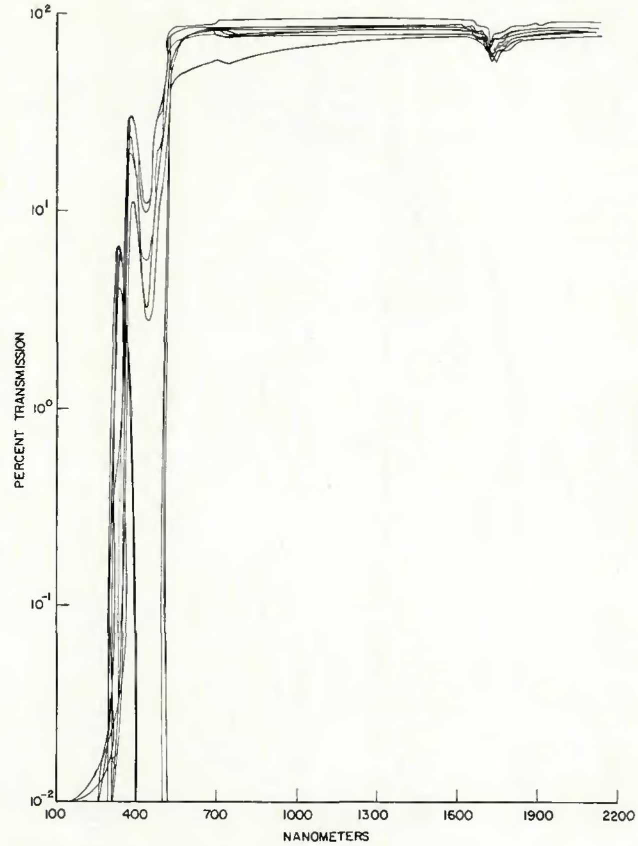

Fig. 4—Composite of yellow curtains (samples A, D, F, G, L, O, Q, T and Z)

Fig. 5—Composite of gray curtains (samples C, L, M and W)

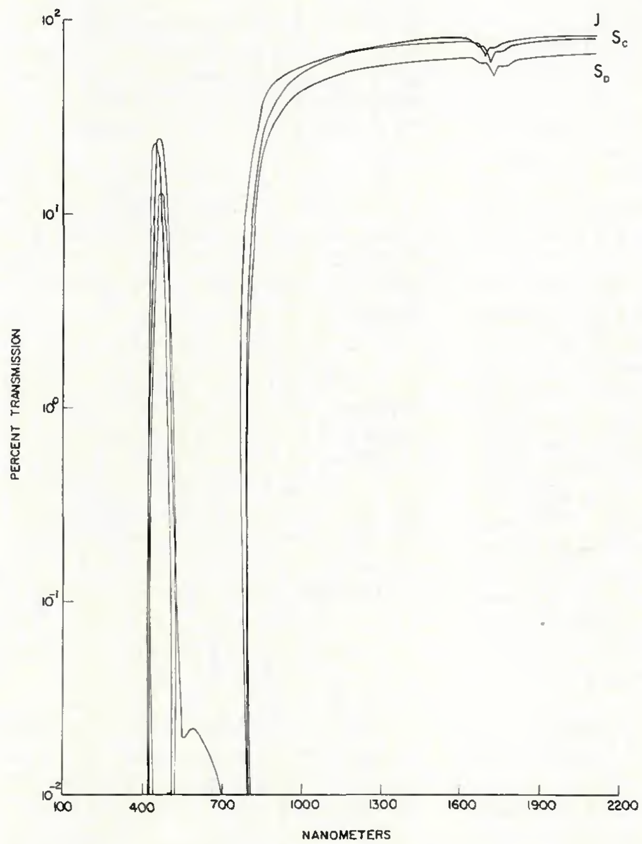

Fig. 6—Composite of blue curtains. J is the old curtain and S is the new curtain.

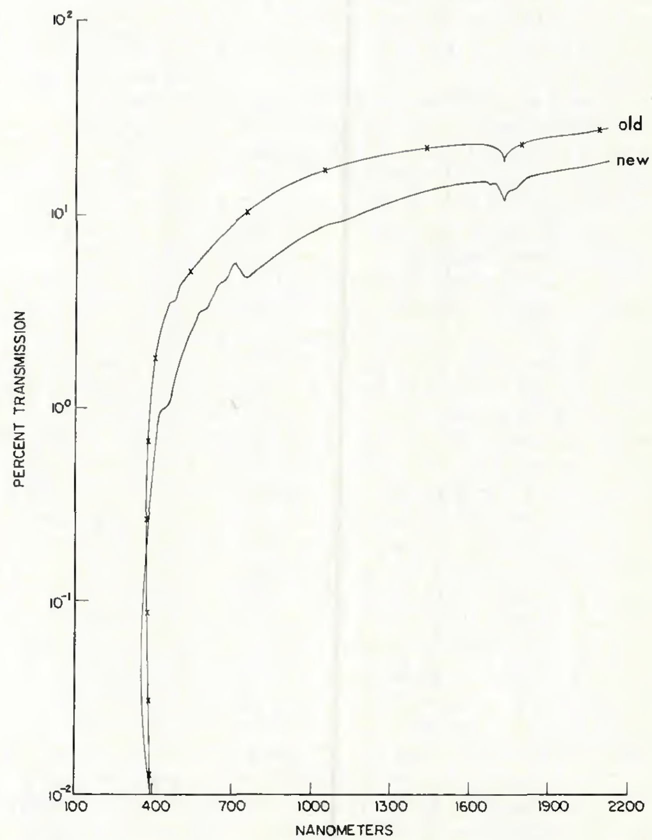

Fig. 7—Comparison of old and new gray curtains (samples C and M)

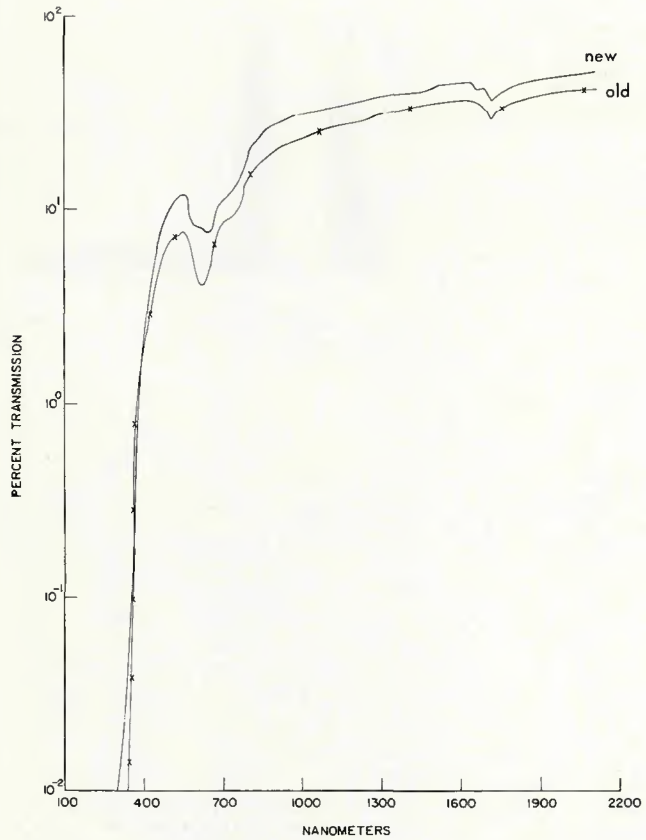

Fig. 8—Comparison of old and new green curtains (samples B and X)

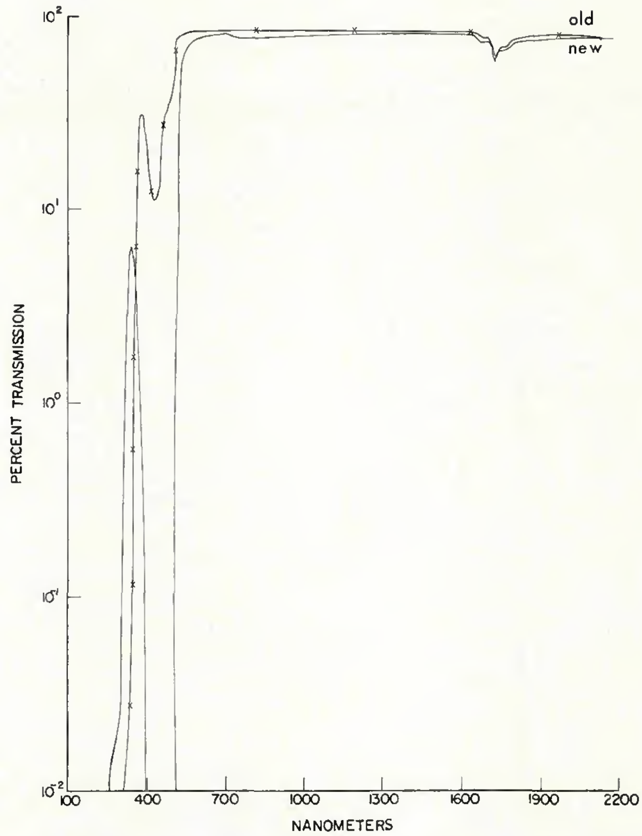

Fig. 9—Comparison of old and new yellow curtains (samples S and Q)

$$= \frac{k_A x_A}{k_B x_B} \qquad (3)$$

Under the assumption that $k_a = k_b$ equation (3) becomes:

$$R = \frac{x_A}{x_B} \qquad (4)$$

This means that transmittance is a function of thickness only. If, however, equation (4) is not valid, then the difference in transmittance has to be explained by more than consideration of thickness. To confirm this observation, transmission values from curtains having the smallest and largest thicknesses of each color were compared. The results indicate that within experimental errors differences in transmittance could be explained by thickness.

Discussion

In determining the degree of protection offered by transparent curtains, it is necessary to define the spectral zones that can produce potentially hazardous optical radiation biological effects. These zones are shown as the shaded area in Fig. 11. Figure 11 was developed by combining data from recent publications.[9-10] The shaded area indicates the relative spectral hazards from broadband non-coherent sources, such as a welding process. Figure 11 suggests the critical wavelengths that cause ocular and skin biological effects, but does not give information on the energy necessary to produce these effects. Not shown is the American Conference of Governmental Industrial Hygienists recommended exposure level of 1 mW/cm^2 for the wavelength region between 320 and 400 nm.

From a protection viewpoint, the best curtain would minimize or eliminate hazardous wavelengths (i.e., shaded area). In almost every curtain tested, wavelengths less than about 340 nm were greatly suppressed. This fact is very important, since it tends to suggest that most transparent curtains give adequate protection in the UV region. However, most curtains also transmit at wavelengths beyond 400 nm which is in the shaded area. Therefore, as far as overall protection from ocular and skin hazards is concerned (i.e., minimizing the shaded area), the grey curtain would appear the best choice. However, if visibility of the workplace is paramount, then one might consider the yellow curtain.

The transmittance results can be compared with the ANSI Z87.1 standard for welding filter plates.[11] Although this comparison is not necessarily valid since transparent plastic curtains can not be considered filter plates, it is informative to note the results (see Table 2). For example, the comparison indicates that certain transparent curtains exceed the absorption properties required of a shade 2 lens. It should be noted that all curtain transmission values in the IR region exceed the values given in ANSI Z87.1. Also, note that only the green and yellow curtain transmittances exceed the UV value listed for shade 2. In particular, 5 of 11 yellow samples and 3 of 7 green samples do not meet shade 2 criteria. Of interest here is that 7 of the 8 that failed were new samples. In no way should this comparison remotely suggest that it is appropriate for the transparent welding curtains to be used as a replacement for welding safety lens.

A summary spectral transmission plot depicting various curtain samples is shown in Fig. 12. Since most samples tested demonstrated little transmission difference between old and new curtains, then Fig. 12 was developed using results from only new samples. Figure 13 shows results provided by one of the manufacturers. Note that Figs. 12 and 13 generally agree with each other except for the blue curtain transmission values. In this case the blue curtain values are smaller in the 500-to-800 nm region than those reported by the manufacturer.

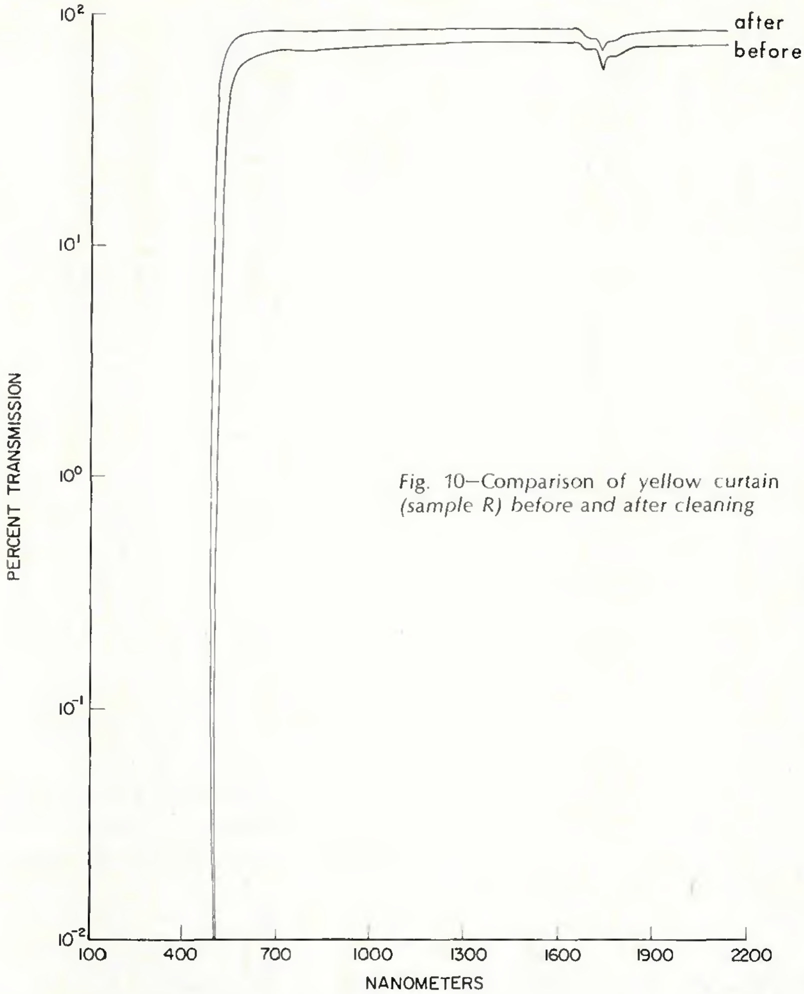

Fig. 10—Comparison of yellow curtain (sample R) before and after cleaning

Table 2—Transmittance Test Results of Welding Curtains Compared with Values Given in ANSI Z87.1

Sample color	Spectral transmittance at selected wavelength, % 313 nm	334 nm	365 nm	405 nm	Infrared transmittance > 760 nm, %
Shade 1.5 lens	0.2	0.8	25.	65.	25
Shade 2.0 lens	0.2	0.5	14.	35.	15
A Curtain yellow	0.03	0.04	10.	23.	86.5[a]
B Curtain green	0.01	0.02	0.1	2.	43.[a]
C Curtain gray	0	0	0	3.	28.[a]
D Curtain yellow	0.03	0.05	5.	7.	78.[a]
E Curtain green	0	0	0.1	1.6	43.[a]
F Curtain yellow	0.35	0.7[a]	16.[a]	12.	79.[a]
G Curtain yellow	0	0	10.	22.	94.[a]
H Curtain green	0.04	0.06	0.5	2.0	48.[a]
I Curtain gray	0	0	0	2.0	23.[a]
J Curtain blue	0	0	0	0.1	80.[a]
K Curtain green	0.27[a]	0.42	1.0	3.	51.[a]
L Curtain yellow	0.25[a]	6.[a]	3.	0	89.[a]
M Curtain gray	0	0	0	1.	20.[a]
N Curtain green	0.34[a]	0.54[a]	0.9	2.1	41.[a]
O Curtain yellow	0.23[a]	5.[a]	2.0	0	81.[a]
P Curtain green	0.33[a]	0.55[a]	1.0	2.3	42.[a]
Q Curtain yellow	0.22[a]	6.0[a]	2.5	0	82.[a]
R_C Curtain yellow	0	0	0	0	78.[a]
R_D Curtain yellow	0	0	0	0	89.[a]
S_C Curtain blue	0	0	0	0	68.[a]
S_D Curtain blue	0	0	0	0	82.[a]
T Curtain yellow	0.17	3.6[a]	2.0	0	86.[a]
W Curtain gray	0.01	0.01	0.04	3.0	51.[a]
X Curtain green	0	0	0	2.0	20.[a]
Z Curtain yellow	0.02	0.03	7.	14.	86.[a]

[a] Indicate values greater than those for Shade 2.

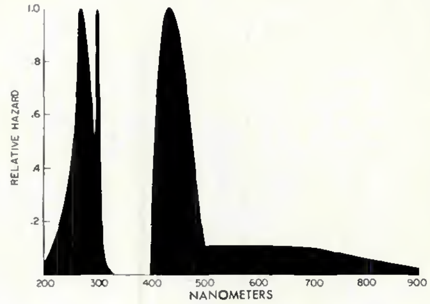

Fig. 11—Envelope (shaded area) of potential hazardous broadband non-coherent optical radiation

The results shown in Fig. 12 could be of vital safety importance in selecting a transparent curtain for use in other than welding applications (i e , shielding a UV curing system) However, since these curtains are intended for use in the welding environment, the spectral distribution of optical radiation from various welding processes transmitted through different curtains is of occupational concern. Using current published welding data[12] and the spectral transmission values in this paper, it is possible to estimate the approximate distribution of optical radiation transmitted through transparent curtains.

Figure 14 shows the actual and approximate optical radiation spectral irradiance values from a typical welding process. Figure 15 shows the product of the approximate irradiance and transmission values; it was developed using the same curtain samples discussed in Fig. 12, with the exception of the yellow curtain. Since this paper finds that older yellow curtains transmit more than new curtains, only older yellow curtain transmission values are shown in Fig. 15.

Conclusion

With this particular welding process, both old and new yellow curtains transmit more optical radiation energy than other curtains.

While the magnitude of optical energy transmitted by a yellow curtain is small, the spectral distribution contains a larger component of hazardous wavelengths than other curtains. Obviously, additional factors such as distance from welding arcs shielding mediums, welding processes, etc., have to be considered before one could recommend a particular curtain for a certain welding event. However, evaluating welding curtains according to welding processes seems more prudent and proper rather than allowing workers/management to select one merely on the basis of eye appeal. In the near future a more comprehensive report will be

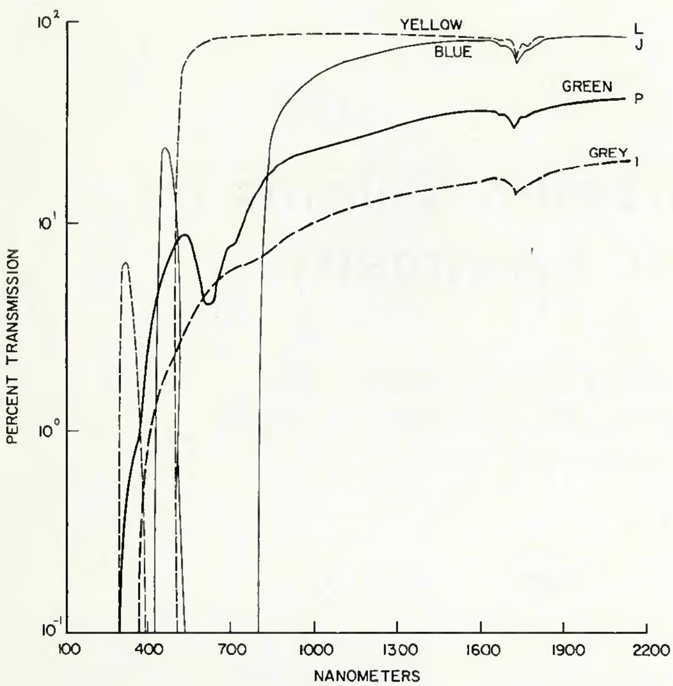

Fig. 12—Spectral transmission measurements found in this paper

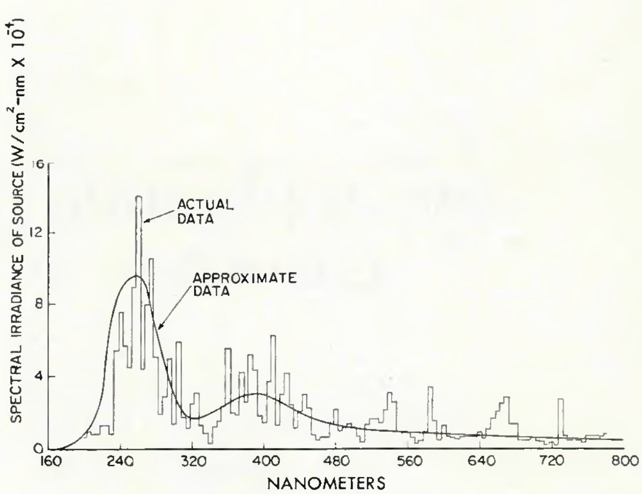

Fig. 14—Absolute spectral irradiance at 1 m for GTAW welding process, on steel, 275 A, 1/16 in. (1.6 mm) arc length, helium shielding gas

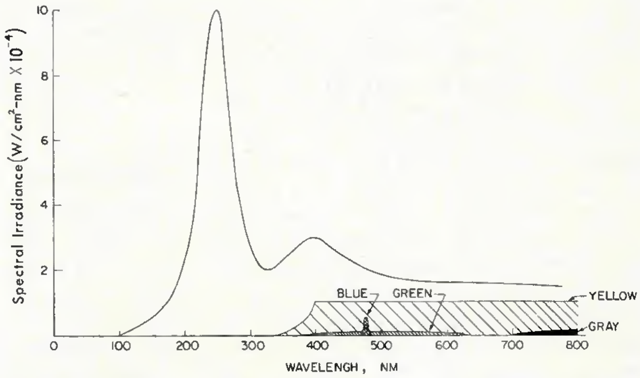

Fig. 15—Approximate spectral distribution of optical radiation (shaded areas) transmitted through various transparent welding curtains from GTA welding process

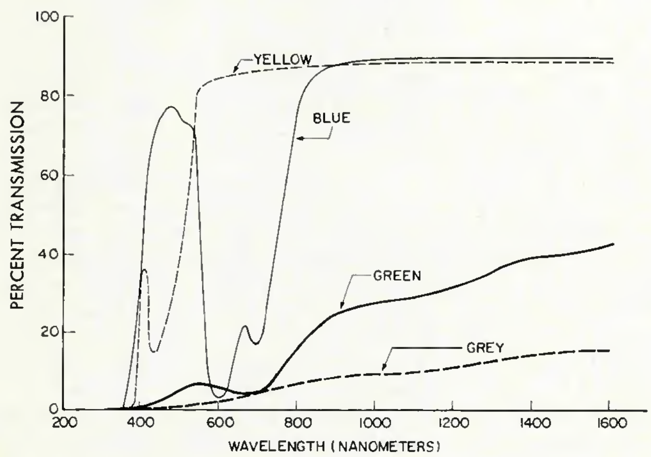

Fig. 13—Spectral transmission measurements reported by manufacturer (modified)

published on this type of evaluation. It must be kept in mind that other curtain selection criteria, such as being able to see through the curtain, may have to be considered.

While this paper has dealt with transparent curtains, it should be mentioned that much more work needs to be done with reflective characteristics of opaque curtains.

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