Transmission of Light Through Pigmented Polyethylene Milk Bottles

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ABSTRACT

Light transmissions through white and yellow pigmented polyethylene milk bottles were measured in the 350- to 800-nm region. The bottles were opaque below 400 nm. Light transmission at 550 nm was 13 and 17% for the white and yellow pigmented bottles, respectively, compared to 72 and 2% for an unpigmented polyethylene bottle and a paperboard milk carton, respectively. The 400- to 550-nm wavelengths, which apparently are harmful to milk quality, were not entirely blocked by the pigmented bottles. A plastic sleeve for fluorescent tubes in dairy cases was opaque below 385 nm and had 92% transmission in the 440- to 800-nm region.

In recent years, milk has been packaged in unpigmented polyethylene bottles and paperboard cartons. Investigations by dairy scientists have shown that protection of milk quality afforded by these containers differs. Their measurements indicate that milk is very susceptible to alteration by exposure to light. Flavor changes as well as loss of vitamins and other nutritional components are attributed to chemical reactions induced in the milk by light with wavelengths below 550 nm.

Light transmission measurements as a function of wavelength have been reported for paperboard milk cartons of various sizes (5). A half-gallon paperboard carton had a low level of light transmission throughout the visible spectral region and was opaque to wavelengths below 450 nm. Some printing inks were very effective in reducing transmission of light with wavelengths below 600 nm.

For unpigmented blow-molded plastic milk containers, light transmissions of 25 to 50% were reported by Barnard (1). Some 3-quart containers had 60 to 80% light transmission in the 400 to 700 nm region. Measurements on various milk containers by other investigators (6) confirm Barnard's results. Light transmission curves for the spectral region from 350 to 800 nm for an unpigmented polyethylene milk bottle were presented by Nelson and Cathcart (5). The transmission values ranged from 50 to 78% and varied with wall thickness.

Information on light transmission by pigmented plastic milk containers is sparse. For protection of milk quality, bottles pigmented with 4% titanium dioxide were an improvement over unpigmented containers, according to Barnard and coworkers (2). Light-induced changes in milk were not entirely prevented in plastic containers pigmented with 0.5, 1 and 2% titanium dioxide (3). Other investigators (4) said milk was satisfactorily protected in a yellow-tinted polycarbonate jug which was opaque to the 380- to 480-nm wavelengths.

Recent availability of pigmented polyethylene milk bottles in the marketplace permitted examination of these containers. Using a scattered transmission accessory on a Cary spectrophotometer, light transmission measurements were made for comparison with results for two commonly found milk containers - an unpigmented gallon polyethylene bottle and a half-gallon paperboard carton.

INSTRUMENTATION

A Cary 17D ratio recording double-beam spectrophotometer with a scattered transmission accessory was used to measure the light transmission of the specimens. In the accessory, the bracket supporting a cell in the sample beam was reinstalled in an inverted position to provide a side guide for the specimens. Using two washers as spacers, the leaf springs were reversed to securely hold the specimens against the sample window. The mirrors in the scattered transmission accessory were locked in place after adjustment to center the light beams in the windows. The photomultiplier tube was moved forward to position the photocathode as close as possible to the intersection of the two light beams.

PROCEDURE

A 15-mm wide by 70-mm long template was used in cutting specimens from the milk containers. The specimens were placed in the scattered transmission accessory with the outer surface facing the light source. The instrumental conditions were 0 to 100, 0 to 50, and 0 to 10% transmission full scale, chart speed of 30 nm/in., wavelength drive speed of 2 nm/sec, pen period 1, slit control switch 1, and slit control knob 0.

RESULTS

Transmission of light with wavelengths from 350 to 800 nm by pigmented plastic milk bottles was measured. These measurements were compared with the transmissions by paperboard and unpigmented polyethylene containers.

Three white pigmented gallon polyethylene milk bot-
ties, which had been blow-molded in different molds, were investigated. Using the template, specimens for light transmission measurements were cut from several areas on each bottle to obtain samples having different thicknesses. A micrometer was used to measure the thickness of each specimen in the area to be illuminated during light transmission measurements. The specimens were from 13.0 to 33.1 mils thick, with the thinner specimens secured from the corners of the bottles. Light transmission curves for one bottle are shown in Fig. 1 with an ordinate scale of 0 to 50% transmission. Similar curves were obtained for the specimens from the other bottles. In Fig. 1, the light transmission decreased from a range of 16 to 29% at 800 nm to a 8- to 20-% range at 420 nm. Below 420 nm, the transmission rapidly decreased as a sigmoid curve to zero at about 400 nm. The bottle was opaque to shorter wavelengths. Pigmentation of each bottle was determined on a composite prepared from pieces cut from various areas. After the composite sample was ashed at 550°C, the elements in the weighed ash were identified by x-ray analysis. One bottle was pigmented with 1.51% titanium dioxide; the other two bottles had 1.63 and 1.65% titanium dioxide, and the elemental analyses of the ashes showed small amounts of aluminum and silicon were present.

For comparison with the plastic milk containers, specimens were cut from unprinted, yellow, and red areas of a half-gallon paperboard milk carton. The light transmission curves for these specimens are shown in Fig. 3 with an ordinate scale of 0 to 10% transmission. In the unprinted areas, the transmission values followed a shallow sigmoid curve decreasing from 3.8% at 800 nm to zero at about 430 nm. The yellow and red inks opacified the paperboard to all wavelengths below 480 and 530 nm, respectively. The red ink reduced the light transmission to less than 0.5% in the spectral region below 580 nm.

Figure 4 compares the light transmissions by the unprinted area of the paperboard milk carton and the unpigmented, white pigmented, and yellow pigmented polyethylene milk bottles. The ordinate scale is 0 to 100% transmission. The specimens from the polyethylene bottles were from the upper surfaces which would be exposed to light. Analysis of the ash showed the presence of small amounts of aluminum, silicon, and iron. Containing less titanium dioxide, this bottle was less opaque than the white bottles at the longer wavelengths. Below 600 nm, the yellow colorant increased the opacity of the bottle.
posed to light in a dairy case. As can be seen, the unpigmented polyethylene milk bottle had 58 to 79% transmission in the 350- to 800-nm spectral region. Light transmission by polyethylene was reduced by pigmenting with titanium dioxide alone but the bottle was opaque only below 390 nm. The yellow bottle, pigmented with titanium dioxide plus a yellow colorant to reduce light transmission below 600 nm, transmitted to some extent in the 370 to 550 nm region. The unprinted area of the paperboard carton had less than 1.5% transmission below 550 nm and was opaque to wavelengths below 430 nm.

![Figure 4. Comparison of light transmission by a 1/2-gallon paperboard milk carton and white pigmented, yellow pigmented, and unpigmented polyethylene gallon milk bottles.](image)

Plastic sleeves are available for installation over fluorescent tubes in dairy cases to shield dairy products from light. The light transmission characteristics of one of these tubular sleeves was measured. This sleeve, a poly(methyl methacrylate) tube with a yellow-green tint, had the dimensions: 46 in. length, 1-11/16 in. outside diameter, and 3/64 in. wall thickness. For light transmission measurements, a 15-mm by 70-mm piece of the sleeve was cut to fit in the scattered transmission accessory of the Cary spectrophotometer. The transmission curve from 350 to 800 nm is shown in Fig. 5. This tubular sleeve had 92% transmission in the region from 800 to 440 nm, then rapidly decreased to zero percent transmission at 385 nm, and was opaque to shorter wavelengths. Although the shield would protect dairy products from ultraviolet light, it would provide little protection in the 380 to 550 nm region. Milk exposed to light of this wavelength region undergoes changes, according to reports by dairy scientists.

![Figure 5. Light transmission by a plastic sleeve for fluorescent tubes in a dairy case.](image)

In summary, pigmenting polyethylene milk containers with titanium dioxide results in a substantial reduction in light transmission. The amount of reduction depends on the level of pigmentation. Use of a colorant with the titanium dioxide pigment further reduces transmission of light with wavelengths less than 600 nm. In the region below 500 nm, the opacity almost equals that of paperboard milk cartons. The significance of differences in light transmission compared to paperboard milk cartons would have to be determined by organoleptic tests. A shield for the fluorescent tubes in a dairy case may not provide sufficient protection to maintain milk quality. Although opaque below 380 nm, the shield examined here would provide little protection in the 380 to 550 nm region.

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