TECHNICAL REPORT

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Paper, board and pulps — Basic terms and equations for optical properties

Papiers, cartons et pâtes — Équations et termes de base pour propriétés optiques

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 6, *Paper, board and pulps*.

Introduction

International Standards published by ISO/TC 6 for the determination of optical properties include a lot of definitions and formulae which are used to perform optical measurements and calculations on papers and boards.

It is very valuable for the pulp and paper industry utilizing these International Standards to have access to a single document which gathers together all the various formulae required for the calculation of these optical properties. This Technical Report is based on a SCAN-test document first published in 1994 and revised in 2003.

This Technical Report includes not only formulae but also the values of various constants which appear in these formulae. It is particularly valuable to have the various formulae but also these constants standardized and gathered into a single document when new software programs are being developed either by an instrument manufacturer or in an independent laboratory to ensure that exactly the same expressions are used for such calculations in all the laboratories worldwide when measurements are made in accordance with the ISO/TC 6 standards.

Paper, board and pulps — Basic terms and equations for optical properties

1 Scope

This Technical Report provides a summary of the formulae used for determining the optical properties of pulp, paper and board. This Technical Report is to be used in conjunction with the particular International Standards for the determination of the desired optical properties.

This Technical Report provides the information necessary for those involved in development of software for computation of optical properties in accordance with current ISO standards.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1 Brightness

2.1.1
ISO brightness, R457
diffuse blue reflectance factor, UV level C
intrinsic diffuse radiance (reflectance) factor measured with a reflectometer having the characteristics described in ISO 2469, equipped with a filter or corresponding function having an effective wavelength of 457 nm and a half bandwidth of 44 nm, and adjusted so that the UV content of the irradiation incident upon the test piece corresponds to that of the CIE illuminant C

Note 1 to entry: The filter function is described more fully by the weighting function factors given in ISO 2470-1, Annex A.

[SOURCE: ISO 2470-1:2009, 3.4, modified]

2.1.2
D65 brightness, $R457_{D65}$
diffuse blue reflectance factor, UV level D65
intrinsic diffuse radiance (reflectance) factor measured with a reflectometer having the characteristics described in ISO 2469, equipped with a filter or corresponding function having an effective wavelength of 457 nm and a half-peak bandwidth of 44 nm, and adjusted so that the UV content of the irradiation incident upon the test piece corresponds to that of the CIE standard illuminant D65

Note 1 to entry: The filter function is described more fully by the weighting function factors given in ISO 2470-2, Annex A and Table A.1.

[SOURCE: ISO 2470-2:2008, 3.4, modified]

2.2
CIE colour matching functions
$R(\lambda)$
functions in the CIE 1931 standard colorimetric system describing the tristimulus values X, Y, Z for monochromatic colour stimuli of equal radiance and where the wavelength λ is a variable

2.3
CIE colour matching functions

$\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$

functions in the CIE 1964 standard colorimetric system describing the tristimulus values X_{10}, Y_{10}, Z_{10} for monochromatic colour stimuli of equal radiance and where the wavelength λ is a variable

2.4
chromaticity coordinates

ratio of each of a set of three tristimulus values to their sum

Note 1 to entry: As the sum of the three chromaticity coordinates is equal to one, two of them are sufficient to define a chromaticity.

Note 2 to entry: In the CIE standard colorimetric systems, the chromaticity coordinates are represented by the symbols x, y, z and x_{10}, y_{10}, z_{10}.

[SOURCE: CIE S 017/E:2011 ILV, 17-145]

2.5
CIELAB colour space

three-dimensional approximately uniform colour space, produced by plotting in rectangular coordinates L^*, a*, b^* quantities defined by the formulae given in 3.7

Note 1 to entry: The quantity L^* is a measure of the lightness of the test piece, where $L^* = 0$ corresponds to black and $L^* = 100$ is defined by the perfect reflecting diffuser. Visually, the quantities a^* and b^* represent respectively the red-green and yellow-blue axes in colour space, such that

- $+a^*$ is a measure of the degree of redness of the test piece,
- $-a^*$ is a measure of the degree of greenness of the test piece,
- $+b^*$ is a measure of the degree of yellowness of the test piece, and
- $-b^*$ is a measure of the degree of blueness of the test piece.

If both a^* and b^* are equal to zero, the test piece is grey.

[SOURCE: ISO 5631-3:2014, 3.6, modified]

2.5.1
CIELAB colour (C/2°)

(L^*, a^*, b^*)

L^*, a^* and b^* values of the sample according to the CIELAB 1976 system, evaluated according to the CIE 1931 (2°) standard colorimetric observer and the CIE illuminant C

2.5.2
CIELAB colour (D65/10°)

(L^*, a^*, b^*)

L^*, a^* and b^* values of the sample according to the CIELAB 1976 system, evaluated according to the CIE 1964 (10°) standard colorimetric observer and the CIE standard illuminant D65

2.5.3
CIELAB colour (D50/2°)

(L^*, a^*, b^*)

L^*, a^* and b^* values of the sample according to the CIELAB 1976 system, evaluated according to the CIE 1931 (2°) standard colorimetric observer and the CIE illuminant D50

2.5.4
CIELAB colour difference
ΔE^*_{ab}
distance in the CIELAB colour space between two colour stimuli

2.6
effective residual ink concentration
ERIC number
ratio of the light absorption coefficient of pulp or paper containing ink to the light absorption coefficient of the ink itself, both being determined at a wavelength of 950 nm

Note 1 to entry: The ERIC number is dimensionless.

[SOURCE: ISO 22754:2008, 3.6]

2.7
fluorescence component
$F_{\mathrm{B,S}}$ or $F_{\mathrm{W,S}}$ for specified CIE illuminant
S
fluorescence component is used as a measure of the extent to which the brightness (F_{B}) or whiteness (F_{W}) of the material is affected by emission from added fluorescent whitening agent (FWA) when the light source of the specified CIE illuminant (S = C or D65) emits UV radiation

Note 1 to entry: Relevant standards: ISO 2470-1, ISO 2470-2, ISO 11475, ISO 11476.

Note 2 to entry: Examples of codification:

— $F_{\mathrm{B\ C}}$: fluorescence component calculated for C/2° brightness measurement;

— $F_{\mathrm{W,\ D65}}$: fluorescence component calculated for D65/10° whiteness measurement.

2.8
fluorescent whitening agent
FWA
fluorescing materials absorbing ultraviolet light and converting it into visible blue light

Note 1 to entry: The fluorescing light adds to light reflected by the pulp in the blue range and compensates for the absorbed share of the light.

Note 2 to entry: The absorption maximum of the usual FWAs is around 360 nm in the UV range and their maximum of emission is in the blue range of the visible light at approximately 440 nm. By this fact, the yellow tint of the bleached pulp is compensated and seen by the human eye as white.

Note 3 to entry: FWAs in paper can only be effective when they are exposed to a light source with an adequate component of UV light. Light emitted by incandescent lamps and some LEDs have practically no UV component, ie radiation with a wavelength of less than 400 nm. FWAs are not sufficiently activated by such light sources. Daylight does contain an adequate UV component although the intensity of the light and the relative contribution of the UV component depends on the time of day, time of the year, geographical standpoint, weather conditions, etc.

Note 4 to entry: This term is often equivalent to *optical brightening agent (OBA)* (2.25).

[SOURCE: Bayer Blankophor — fluorescent whitening agents for the paper industry]

2.9
gloss
<of a surface> mode of appearance by which reflected highlights of objects are perceived as superimposed on the surface due to the directionally selective properties of that surface

[SOURCE: CIE S 017/E:2011 ILV, 17-500]

2.10
illuminant
radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception

Note 1 to entry: In everyday English, this term is not restricted to this sense, but is also used for any kind of light falling on a body or scene.

[SOURCE: CIE S 017/E:2011 ILV, 17-554]

2.11
light-scattering coefficient
s
fraction of the spectral radiant flux diffusely incident on a differential layer within a material that is reflected when the flux passes through the layer, divided by the thickness of the layer

Note 1 to entry: The flux referred to is a radiant flux across the differential layer.

Note 2 to entry: It is assumed that no reflection occurs at the boundaries of the material.

Note 3 to entry: In a two-flux system, the scattering coefficient is equal to the net transfer of flux from the stronger flux to the weaker flux in a differential layer within a material divided by the product of the thickness of the layer and the difference between the fluxes.

[SOURCE: ISO 9416:2009, 3.7]

2.12
light-scattering coefficient by reflectance factor measurements
s_V
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to luminance factor data weighted with respect to the CIE illuminant C, obtained in an instrument having a specified geometry and calibrated in a specified manner, on the basis of grammage

Note 1 to entry: s_v is expressed in square metres per kilogram (m^2/kg).

2.13
light scattering coefficient at 950 nm by reflectance factor measurements
s_{950}
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to reflectance factor data obtained at a wavelength of 950 nm in an instrument having a specified geometry and calibrated in a specified manner and taking into consideration the grammage

Note 1 to entry: Units: m^2/kg.

Note 2 to entry: The relevant equations are given in ISO 22754, Clause 9.

[SOURCE: ISO 22754:2008, 3.4, modified]

2.14
light-absorption coefficient
k
fraction of the spectral radiant flux diffusely incident on a differential layer within a material that is absorbed when the flux passes through the layer, divided by the thickness of the layer

Note 1 to entry: The flux referred to is a radiant flux across the differential layer.

[SOURCE: ISO 9416:2009, 3.6]

2.15
light-absorption coefficient by reflectance factor measurements
k_V
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to luminance factor data weighted with respect to the CIE illuminant C, obtained in an instrument having a specified geometry and calibrated in a specified manner, on the basis of grammage

Note 1 to entry: k_V is expressed in square metres per kilogram (m^2/kg).

Note 2 to entry: *light-scattering coefficient* (2.11) and *light-absorption coefficient* (2.14) are strictly applicable to monochromatic light but, for the purpose of this International Standard, the relevant light absorption and scattering coefficients apply to broad-band radiation. In research work, s_V and k_V can and should be determined at the relevant wavelength for the study concerned. As general descriptions of a given paper, they are defined here in relation to the $V(\lambda)$ function and the CIE illuminant C.

[SOURCE: ISO 9416:2009, 3.9, modified]

2.16
light absorption coefficient at 950 nm by reflectance factor measurements
k_{950}
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to reflectance factor data obtained at a wavelength of 950 nm in an instrument having a geometry according to ISO 2469 and having been calibrated as specified in ISO 2470-1 and ISO 11475 and taking into consideration the grammage

Note 1 to entry: Units: m^2/kg.

Note 2 to entry: The relevant equations are given in ISO 22754, Clause 9.

[SOURCE: ISO 22754:2008, 3.5]

2.17
luminance factor (C), R_y
luminous reflectance factor, Y(C/2°)-value
reflectance factor defined with reference to the spectral luminous efficiency function $V(\lambda)$ and the CIE illuminant C

Note 1 to entry: The visual efficiency function describes the sensitivity of the eye to light so that the luminance factor corresponds to the attribute of visual perception of the reflecting surface.

Note 2 to entry: For computational purposes, the $V(\lambda)$ function is identical to the CIE 1931 colour matching function $\bar{y}(\lambda)$.

Note 3 to entry: The luminance factor (C) is also known as the Y(C/2°)-value. In previous editions of ISO 9416 and ISO 2471, it was referred to as the luminous reflectance factor.

Note 4 to entry: The CIE term "luminance factor" is a more general term since it does not specify the illuminant or observer condition.

2.18
single-sheet luminance factor (C)
$R_{y,0}$
luminance factor (C) of a single sheet of paper with a black cavity as backing

[SOURCE: ISO 9416:2009, 3.3, modified]

2.19
intrinsic luminance factor (C)
$R_{y,\infty}$
luminance factor (C) of a layer or pad of material thick enough to be opaque, i.e. such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured reflectance factor

[SOURCE: ISO 9416:2009, 3.4, modified]

2.20
spectral luminous efficiency
$V(\lambda)$ for photopic vision
ratio of the radiant flux at wavelength λ_m to that at wavelength λ, such that both produce equally intense luminous sensations under specified photometric conditions, and λ_m is chosen so that the maximum value of this ratio is equal to one

Note 1 to entry: Function describing the sensitivity to light of the human eye at different wavelengths.

Note 2 to entry: $\lambda_m = 555\,\text{nm}$.

Note 3 to entry: For computational purposes, the $V(\lambda)$ function is identical with the $\bar{y}(\lambda)$ function for the CIE 1931 (2°) standard observer.

[SOURCE: CIE S 017/E:2011, 17-1222]

2.21
metameric colour stimuli
spectrally different colour stimuli that have the same tristimulus values in a specified colorimetric system

Note 1 to entry: Equivalent term: “metamers”.

Note 2 to entry: The corresponding property is called “metamerism”.

[SOURCE: CIE S 017/E:2011: ILV, 17-768 and 17-769]

2.22
metamerism index
degree of colour mismatch, calculated in the form of a colour difference, caused by substituting a test illuminant (observer) of different relative spectral composition (responsivity) for the reference illuminant (observer)

Note 1 to entry: The colour difference is evaluated using a CIE colour difference formula and it should be clearly stated which formula has been used.

[SOURCE: CIE S 017/E: 2011: ILV, 17-770]

2.23
diffuse reflectance factor
diffuse radiance factor
for the purpose of this Technical Report, only diffuse reflectance factor is considered.

Note 1 to entry: For non-fluorescent materials, the diffuse radiance factor, β, is simply the diffuse reflectance factor, R.

