Translucency, its Perception and Measurement

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ABSTRACT

Scaling *translucency* directly is difficult so it is more common to use *transparency* and/or *opacity*. Two observer populations exist: those regarding absorption as adding to *opacity* in dilute scatterer suspensions and those who do not. *Translucency* is commonly visualized as occupying a point on a scale linking opaque and transparent, but this is inadequate and a model that includes absorption and scattering is suggested. It is possible that a measure of *opacity* may be obtained from calculation of tristimulus values calculated from the Kubelka-Munk internal transmittance spectrum. This however may only be valid for simple coloured suspensions. It may not be adequate for more complex biological materials containing many types of scatterer and absorber.

1. INTRODUCTION

The Total Appearance of a material can be defined in terms of its elements of Visual Structure. Each element possesses properties of Surface Texture, Colour, Translucency, Gloss, and each of these varies across the element[1]. These properties are the basic visual perceptions we have evolved to detect and differentiate, but all involve colour and colour contrast in their perception. There are two types of translucency: pseudo and material. Pseudo translucency occurs in two-dimensional art and may be used by the package designer. It can be described in terms of spatial and colour relationships. This paper will be confined to translucency as a property of three-dimensional objects and materials.

Using the food industry as an example there are many problems concerning translucency. For example, there are unknowns about the formation and perception of *haze* in beer, tea, and wine, also about the efficient colorant formulation of processed food products such as sauces and non-alcoholic drinks. In everyday life different words are used to describe or scale translucency. These tend to be situation or industry dependent. For example, *cloudiness* occurs in apple juice, *mist* and *fog* in the atmosphere, *clarity* in wine, *turbidity* in water, and *opacity* in shower curtains. All concern the scattering and absorption of light occurring in the material. This paper includes a brief outline of psychophysical data obtained in the 1970s and 80s, as well as that obtained more recently. This summary is appropriate because of the current interest in measurement of individual properties of total appearance[2,3].

2. TRANSLUCENCY PERCEPTION

There are two broad sets of viewing conditions involved in the perception of translucency. First, when viewing and illumination tend to take place from the same side of the object and second, when light source and eye are on more or less opposite sides of the object. There are two examples of the former: first, where there is a contrast behind the translucent material, and second, where in a deep translucent material scatterer within the bulk of the material acts as its own background. That is, we can see into the material but the scatterer prevents us from seeing through it. For the second viewing condition translucency is perceived when there is a contrast with the light source, also, if the translucent object is seen as a light source. All perceptions of translucency involve a colour contrast, but intensity of the perception is affected by illumination and viewing light intensity through modification of the colour contrast.

An attractive option is to visualize a translucent material as situated somewhere along a line joining the extremes of *opaque* and *transparent*. Onto this line we can ‘plot’ the above specific attributes such as *cloudy* apple juice, *haze* in beer, and *turbidity* in water. As indicated later this approach has limitations because it fails to take into account effects, for example, of absorption. Also, attempts to scale *translucency* using such a simple scale will fail because translucency perception increases from both ends. Hence, scales of *transparency* and/or *opacity* were used in psychophysical experiments[e.g.4]. Preliminary psychophysical studies on thin plastic plaques, covering the range from transparent to opaque, placed on a contrasting background indicated that *transparency* and *opacity* are not equal and opposite as might have been expected[5]. Most subsequent work was confined to the scaling of *opacity*.

3. MEASUREMENT

The major need for opacity measurement in the paper and paints industries has been traditionally solved using contrast ratio measurements on the relevant pigmented/dyed white substrates (e.g. ASTM D344, D2805). Methods of opacity measurement of bulk samples of relatively opaque, purely scattering, uncoloured materials include the Dia-Stron instrument. The nephelometer is used to indicate degree of haze in, for example, beer and water (e.g. ASTM D1889). However, measurements made using these instruments are affected by colour. That is, there is no method that can give a reliable measurement of opacity independent of colour, or which will separate effects due to scattering and absorption.

Hence, these measurements are not sufficiently sophisticated to solve problems of prediction of dye and pigment formulations. This has resulted in advances in theories involving the consideration of light fluxes occurring within materials. The success of the two flux Kubelka-Munk approach in attacking such formulation problems is largely due to a combination of the use of closely controlled highly scattering non-absorbing substrates and a limited number of pure light absorbing species. Scattering intensity and wavelength (λ) depend on particle radius (r), as indicated in the table[1]. Also indicated are the theories used to account for these dependencies.

Effect of particle r and light λ on scattering intensity as r increases >>>>>

Theory required	Rayleigh theory	Mie,Multiflux theories		Optical limit
scattering depends on r	r^6	r^4	r^2	r^2
and on wavelength λ	λ^{-4}	λ^{-2}	λ^0	λ^0

Birkett[6] confirmed the success of this approach using a non-absorbing model food sauce system of glass ballotoni in a paraffin-in-water emulsion. Using the Mie and Kubelka-Munk theories separately he was able to predict the relationship between the scattering coefficient per unit volume of scatterer in terms of particle diameter for ballotini diameters from 1 to 100μm. However, in biological materials such as foods this idealized situation does not occur and normally such samples contain a range of particle sizes and shapes, and perhaps a dozen absorbing species. There is a need to extend these treatments to predict robustly effects of such complex biological materials. Many flux and energy transfer approaches maybe appropriate.

4. PSYCHOPHYSICS

Reported work can be divided into two categories: application of the Kubelka-Munk theory to food materials, and opacity perception experiments using model system studies. Angela Little realized that tristimulus measurements of thin layers of light scattering food systems, such as apple sauce, could very successfully account for the consumer perception of quality. Little found that using the Kubelka-Munk theory on tristimulus values (rather than at single wavelengths for which the theory was originally developed) could also account for consumer perceptions of appearance quality. She was the first to find that such measurements made at sample depths of ‘a few mm’ could unlock some of the secrets of quality perception[7].

An example of a study using Kubelka-Munk attributes of scattering (S) and absorption (K) coefficients and internal transmittance (Ti) were concerned with consumer perceptions of visually perceived *creaminess* and *strength* of milked coffee viewed in the cup. Contours on a plot of K/S and Ti at 550nm reveal the separate directions of increased *creaminess* and increased *strength*. Also indicated are contours for *opacity* when the coffee was viewed in a thin layer. Such results can be used in product development to manipulate visual impressions. Similar investigations on orange juices showed that perception of orange juice viewed in the glass as a *breakfast drink* or a *refreshing drink* could be explained using a combination of K/S and hue measurements made on thin layers. The same plots indicated that different populations of consumers judged orders of perceived *strength of flavour* in different ways. 64% judged increase in strength on the basis of an increase in scattering (that is, high K/S), 36% on the basis of hue (redder juice being seen as stronger). That is, consumer reaction to this product is based on an interaction between colour and translucency[1].

As K and S are wavelength dependent they are normally calculated one wavelength at a time. However, for broadband absorbers K and S values have been calculated using tristimulus values. For example, MacDougall[8] has elegantly explained the appearance of pale, soft, exudative and dark, firm and dry fresh pork muscle as an interaction between colour and Kubelka-Munk K and S values.

Psychophysical studies on the subject of translucency as a phenomenon were carried out using a model system of lecithin based clear substrate in which dyes would dissolve and particles could be suspended. The suspensions were in thin layers viewed against a sharply defined black and white background. Using three concentrations of a green dye and eight levels of white scatterer it was found that there were two populations of observers. Both populations agreed that at high concentrations of scatterer an increase in dye concentration increased perceived *opacity*. At low scatterer concentrations, however, one population regarded an increase in dye concentration of increased perceived *opacity*, while the other population regarded clear coloured solutions as being very low *opacity*. This occurs because there are three clearly recognized observable states in such a series of suspensions. First, as concentration of additives is increased there is a reduction of contrast between the black and white in the background, second there is a further reduction in contrast accompanied by a reduction in the sharpness of the black/white boundary, and third the background entirely disappears. Further increase in scatterer produces an increase in perceived *whiteness* which may be interpreted as a further increase in *opacity*[5,9].

A further experiment was designed to find out whether a measurement could be found for opacity that is independent of colour. In a preliminary experiment eight of red, green and blue containing different concentrations of scatterer were scaled for *opacity* and their transreflectance spectra were measured. When the peak value of Ti for each suspension is plotted against *opacity* a continuous relationship is produced. From a colour science point of view this is unrealistic so values of X, Y and Z were calculated from the Ti spectra. The peak tristimulus value obviously depended upon the colour of the suspension and it was found that when this peak value, indicated by the letter in Figure 1, was plotted against *opacity* a continuous relationship was produced.

This appears to be an entirely credible approach to the measurement, that is, we perceive the degree of opacity by using the signal from the retinal cones having the greatest, therefore in colour terms, the most relevant response. If further work confirms this we can look forward to having a measure of translucency that is independent of colour.

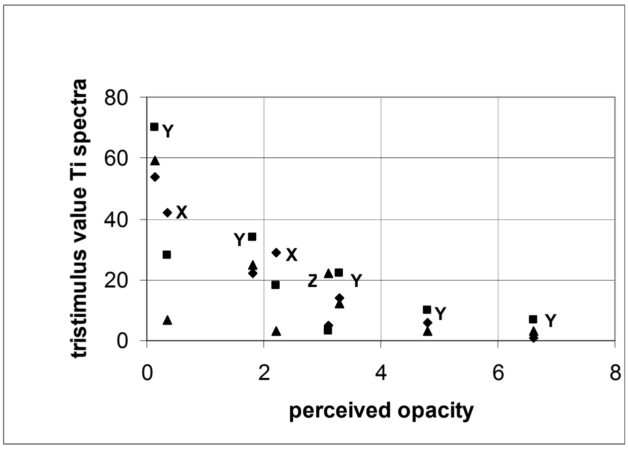

Figure 1. Perception of coloured translucency suspensions. Relationship between tristimulus values derived from internal transmittance spectra and the panel mean *opacity*[5]. A line can be drawn through the maximum tristimulus value of each sample.

The simple view of translucency occurring somewhere on a line joining transparent and opaque cannot be substantiated because absorption as well as scattering must be taken into account. We can postulate a slightly more complex model in which coloured suspensions are plotted on an intuitive diagram that has scattering and absorption as its axes – see Figure 2.

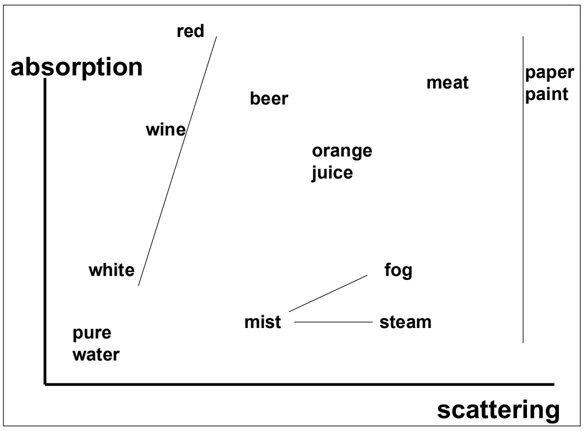

Figure 2. An intuitive model of translucent materials containing particle sizes greater than found in Rayleigh scattering in terms of light absorption and scattering.

The axes have yet to be defined in physics terms, but on this diagram we can imagine the world of translucent materials can be defined and plotted.

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