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Evaluation of turbidity: correlation between Kerstez turbidimeter and nephelometric turbidimeter

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Abstract

Turbidity is a quality parameter that has an important role in food liquid acceptance. Cloudiness of beverages and covering liquid are a consequence of manufacture processes and storage conditions. Spanish legislation defines the covering liquid turbidity in canning by Kerstez turbidimeter units (KTU), which is a sensorial measure. It is necessary to find a correlation between sensorial and instrumental measurements. This work studied the relationship between KTU and nephelometric turbidimeter units (NTU) and established a mathematical model, which allowed the expression of the turbidity of liquid products in KTU from measurements in nephelometric turbidimeter units. This mathematical model corresponds to a non-linear simple correlation model (KTU/NTU). The best adjustment was a Reciprocal-Y model.

Keywords: Beverages; Turbidity; Kerstez; Nephelometer

1. Introduction

Visual attributes play an important role in food acceptance. Among these, turbidity or cloudiness is often considered to be a specially important factor controlling quality of different food such as beverages (Dickinson, 1994) and canning brines (Martín Belloso, 1990). In addition, Spanish Food Legislation for Canned Food Products establishes different ranges of turbidity for the different quality classes of canned foods destined for direct consumption and commercialisation (BOE nos. 287, 288 and 289, 1984).

Turbidity depends essentially on the entities of colloidal size present in the liquid phase (Farinato & Rowell, 1983), on the difference in refractive index between the particles and the medium, and on the particle size distribution (Dickinson, 1992).

Cloudiness of beverages and covering liquid are a consequence of the manufacture process and the storage conditions. A typical covering liquid consists of a dilute aqueous phase containing various dissolved species, usually salt (commonly NaCl), some organic acid such as citric, acetic or/and ascorbic acids, or sugars. Spanish legislation defines the covering liquid turbidity as the degree of transparency of the covering liquid measured by the Kerstez turbidimeter. This is a sensorial measure (Calvo & Durán, 1980) which must be interpreted as a quality index since a more transparent covering liquid notes better canning elaboration and storage, and since the visual aspect of a covering liquid has a considerable influence on consumer acceptance.

In general, the turbidity of covering liquids depends on the size and proportion of the particles in suspension, and on the colorant material levels (Durán, Rodrigo & Alcedo, 1976). The causes which bring about an increase of covering liquid turbidity are diverse (Martínez Baigorri, 1984); although the most important could be: intensive blanching process which reduces firmness of product; high sterilising values (time and temperature) which cause a large dissolution of the components; and browning reactions which darkens the product and the covering liquid. On other hand, microbiological instability of the canned product quickly increases the cloudiness of the covering liquid.

Similar to covering liquid, juices and soft drinks are dilute aqueous phases containing various dissolved species, usually sugars, organic acid, and lipids, proteins,

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polysaccharides, polyphenols, etc., within which may be dispersed various colloidal species as well as microscopic particles such as cell-wall fragments. The wide variety of fruit derived beverages and soft drinks formulations mean that the sort of solids in suspension and their levels change notably from some products to others. (Primo Yúfera, 1987).

The turbidity of a juice could be measured using a Hunter Colorimeter (Durán et al., 1976), using spectrophotometer measurements at different wavelengths (Genovese, Elustondo & Lozano, 1997) and using a nephelometer or nephelometric turbidimeter (Ancín, Ayestarán, Corroza, Garrido & González, 1996; Markowski, 1998). Using spectrometric systems it is necessary to take into account that the optical density is not the only contribution to cloudiness. For a coloured beverage, there is a contribution also from light absorption, which must be taken into account. The nephelometer is the most used method in commercial measurements, due to the fact that it is a quick and sensitive method, and the turbidimeter measurement is carried out with a low quantity of sample.

This work presents a systematic attempt to establish a mathematical model, which allows calculation of Kerstez turbidity values from nephelometric values. In this way, with a simple, quick and economic (low quantity of the product) measurement one would be able to obtain both nephelometric and Kerstez turbidity data.

2. Materials and methods

2.1. Samples

A total of 135 samples (commercial products) were analysed: 53 of them were juices, 21 soft drinks, 11 fruits cocktails (syrup) and 50 vegetable canned products (brines). For the validation 20 samples from the total were used, 10 being juices and 10 vegetable canned products.

According to the recommendations of Kramer (1969), the turbidity values of analysed products cover the whole range of Kerstez turbidity, with a more or less uniform distribution.

The samples were evaluated by duplicate and measurements were carried out on two different bottles, tetra-packs or cans of each studied product.

2.2. Instrumental

2.2.1. Kerstez turbidimeter

The Kerstez turbidimeter (Lin Lab, Logroño, Spain) consists of two transparent plastic sheets of 16×16 cm joined diagonally by a black plastic sheet of 22×2 cm. This black plastic sheet is traced, or painted, with lines every 20 mm. These lines are the Kerstez scale. The system is closed on two parallel faces with a crystal sheet (Calvo & Morell, 1971) (Fig. 1).

To measure liquid turbidity, the covering liquid (brine or syrup) or the juice is introduced in the turbidimeter until it is complete full. Then, over the black sheet (scale) the number of visible lines is read. The number of visible lines corresponds to a qualification of the liquid with the turbidity, according to the following scale:

Visible lines	Qualification
8–9	Transparent
6–7	Bright
4–5	Slightly turbid
2–3	Turbid
0–1	Very turbid

2.2.2. Nephelometric turbidimeter

The nephelometric measurements were carried out with a Hach Turbidimeter Model 2100P (Loveland, CO, USA), which includes a tungsten-filament lamp, a 90° detector to monitor scattered light and a transmitted light detector. The instrument's microprocessor calculates the ratio of the signals from 90° and transmitted light detectors and compares the intensity of light scattered with those of a standard suspension. This microprocessor corrects for interference from colour and/or light absorbing materials and compensates for fluctuations in lamp intensity. The optical design also minimises stray light, increasing measurement accuracy.

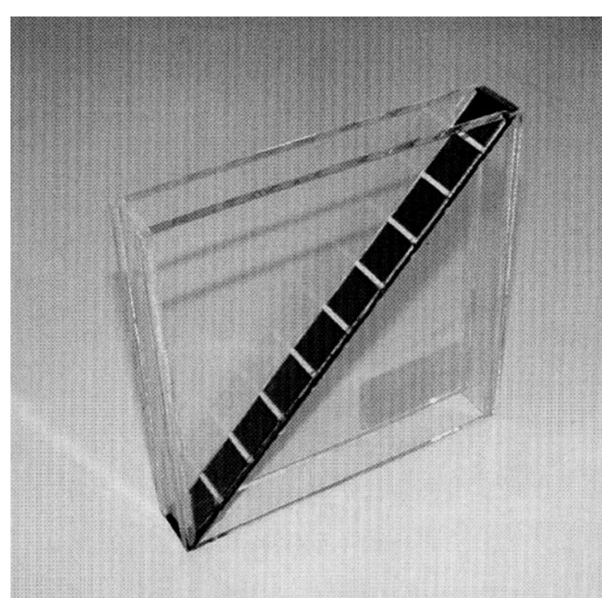

Fig. 1. Kerstez turbidimeter.

2.2.3. Mathematical models

Ten simple (linear and non-linear) regression models were assessed using STATGRAPHICS PLUS® software (Manugistics, Rockville, MD, USA). Nephelometric turbidity was the independent variable and Kerstez turbidity was the dependent variable.

Assessed models were: lineal ($Y = a + b \times X$), exponential [$Y = \exp(a + b \times X)$], reciprocal-*y* [$Y = 1/(a + b \times X)$], reciprocal-*x* ($Y = a + b/X$), double reciprocal [$Y = 1/(a + b/X)$], logarithmic-*x* [$Y = a + b \times \mathrm{Ln}(X)$], multiplicative ($Y = a \times X^{b}$), squared root-*x* [$Y = a + b\ \mathrm{sqrt}(X)$], squared root-*y* ($Y = (a + b \times X)^2$) and *s*-curve [$Y = \exp(a + b/X)$].

3. Results and discussion

In the first place, the 10 mathematical models cited were assessed with all of the experimental data, independently of the type of product. The results show that the reciprocal-*y* model gave the best adjustment, with a correlation coefficient value of 0.9686. The model explained 93.8% of total variability and the residuals showed an aleatory distribution. This result shows there is a relatively strong relationship between the two variables.

Fig. 2 shows the graphic representation of the reciprocal-*y* model, with experimental data, and prediction limits for new observations, which were calculated using the standard deviation of the residuals. The equation of the model is showed in Table 1, model 1.

After that, partial studies were carried out. In these studies, the 10 mathematical models were assessed grouping experimental data by type of products: juices, covering liquid (brines or syrup) and soft drinks.

The results noted that even when the data were grouped according to type of product, the reciprocal-*y* model was the best model for all of them. However, these new models gave satisfactory results only for juices and covering liquid, whiles the model for soft drinks explained a low percentage of the total variability (Table 1) and bigger prediction limits were obtained (Fig. 3). That result could be relation with previous works (Hernandez, Baker & Crandall, 1991) which showed that readings from the nephelometer may be distorted by small particles, giving high values for a fine suspension containing "invisible" haze or haze not really detected by the consumer's eyes.

From these results, we decided to assess the models without the soft drinks data. Then, a new general model was obtained (Table 1, model 5). Similar to the first results, this was a reciprocal-*y* model. This model showed the highest correlation coefficient $(r) = 0.9743$ of

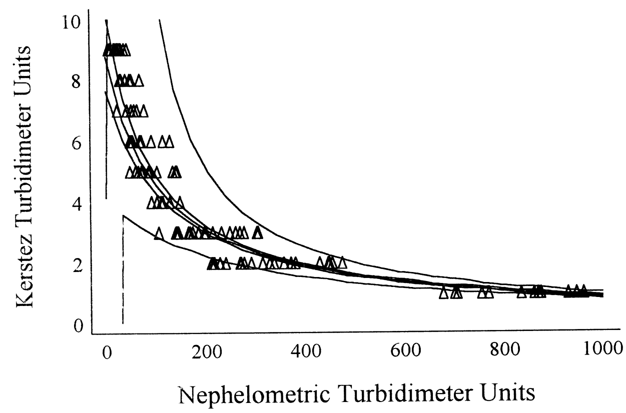

Fig. 2. Plot of fitted model corresponding to all the 115 samples (covering liquid, juices and soft drinks). The inner bounds show 95% confidence limits for the mean Kerstez turbidimeter units of many observations at given values of nephelometric turbidimeter units. The outer bounds show 95% prediction limits for new observations.

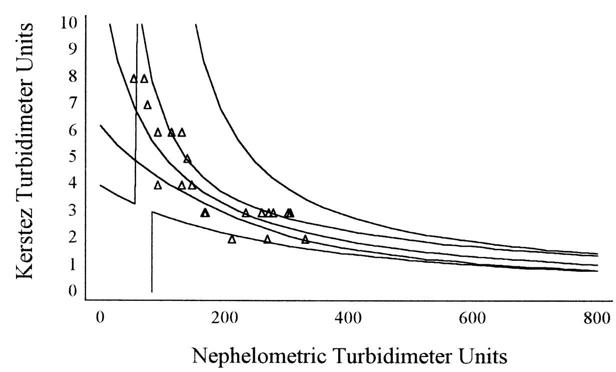

Fig. 3. Plot of fitted model corresponding to the soft drinks. The inner bounds show 95% confidence limits for the mean Kerstez turbidimeter units of many observations at given values of nephelometric turbidimeter units. The outer bounds show 95% prediction limits for new observations.

Table 1[a]

Kind of product	Equation	Variability explained	Correlation coefficient	Deviation of residual
All samples (model 1)	$KTU = 1/(0.11438 + 0.001055\ NTU)$	93.8	0.9686	0.0651
Covering liquid	$KTU = 1/(0.10981 + 0.001114\ NTU)$	91.6	0.9571	0.0601
Juices	$KTU = 1/(0.13210 + 0.001020\ NTU)$	95.5	0.9772	0.0673
Soft drink	$KTU = 1/(0.08599 + 0.001096\ NTU)$	66.5	0.8052	0.0705
Model 5	$KTU = 1/(0.12014 + 0.001050\ NTU)$	94.9	0.9743	0.0636

[a] The equations correspond to the different groups of products [all samples (model 1), covering liquid, juices, soft drinks and model 5 (covering liquid and juices)] where KTU = Kerstez turbimeter units; NTU = nephelometric turbidimeter units.

all obtained models, and it explained 94.9% of total variability, then it was the best model obtained.

Validation of the model was carried out by comparison between real and predicted data for 10 juices and 10 covering liquids, which were not used in the construction of the model. The global deviation between predicted and real data was lower than 4%, then model could be considered valid and adequate. No deviation between predicted and real data, in the range between 1 and 6, were detected. However, predicted values higher or equivalent to seven ($\geqslant 7$) showed sometimes significant deviation of the real data. In these cases, predicted values were always smaller than real data. Another time, these results are according to the fact that nephelometer detected haze not really detected by consumers' eyes.

Therefore, development of reliable correlation's between Kerstez (sensorial or visual observations) and nephelometric measurements of turbidity seems unavoidable in order to simulate consumer appreciation. This correlation could have a legal repercussion, especially on Spanish legislation, in order to adapt the law to new analytical technology.

4. Conclusions

It is possible to obtain simple mathematical model, reciprocal-y, which allow prediction of Kerstez turbidity from nephelometric data and vice versa. These results could be very interesting for juice and canning producers, especially if they are concerned with the Spanish market.

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