Measurement 63 (2015) 128–136

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Optoelectronic sensor device for monitoring the maceration of red wine: Design issues and validation

F. Jiménez-Márquez [1], J. Vázquez [*,1], J.L. Sánchez-Rojas

Microsystems, Actuators & Sensors Group, Escuela Técnica Superior de Ingenieros Industriales, Universidad de Castilla-La Mancha, Avenida Camilo José Cela s/n, 13071 Ciudad Real, Spain

ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form 31 October 2014
Accepted 2 December 2014
Available online 13 December 2014

Keywords:
Color
Absorbance
LED
Photodetector
Fermentation
Wine maceration

ABSTRACT

Enologists usually rely on spectrophotometers to perform the chromatic characterization of red wines. This work reports an optoelectronic instrument based on absorbance measurements aiming not only at the assessment of the chromatic characteristics of finished red wines, but at the supervision of the gradual maceration of fermenting grape musts as well. Maceration is a chemical process that takes place during the early stages of the fermentation that finally results in red wine. It is through maceration that wine acquires its distinctive chromatic features. Key issues related to the selection of optoelectronic components, the system design and its final validation using diluted wine samples are thoroughly discussed. Resolution figures lie in the range of one thousandth of an absorbance unit. Maceration has been successfully monitored with the proposed instrument using grape must samples extracted during the first three days from two different fermentations.

1. Introduction

The alcoholic fermentation that turns grape must into wine is a chemical process that remains active over a span of several days and is periodically supervised by winemakers. Although the time a wine fermentation is in progress depends on a number of factors, like the amount and type of yeast utilized, the sugar concentration of the grape must and the temperature of the tanks, it can be claimed that sugar content in the original grape must is virtually depleted in many cases after twelve days counting from the day when yeasts were inoculated [1]. During this time, the grape must undergoes changes that alter both its chemical composition and its appearance due to the consumption of sugars by yeast and the subsequent formation of ethanol. One of the factors that determine the color of a finished red wine is the maceration length; that is, the amount of time that grape skins are kept in the fermenting grape must once the fermentation has begun. Consequently, the possibility of monitoring the color evolution of grape musts, as a given fermentation is in progress, would provide enologists with valuable information as to when it is the right moment to remove the grape skins from the fermentation tanks. Unlike other parameters of relevance in winemaking, like the density, which is regularly monitored by enologists during the whole fermentation span, the chromatic characteristics are usually characterized once the fermentation is finished.

There is not a single method to characterize the color for a given application. Some of the available techniques rely either on RGB coordinates [2,3]; the CIELab color space [4,5]; or on measuring optical densities at multiple discrete wavelengths [6]. In the case of winemaking, the chromatic characteristics of a given wine are usually determined by enologists from absorbance measurements carried out at

* Corresponding author. Tel.: +34 926295300/3899.
E-mail addresses: k.jimenez.marquez@gmail.com (F. Jiménez-Márquez), javier.vazquez@uclm.es (J. Vázquez), joseluis.saldavero@uclm.es (J.L. Sánchez-Rojas).

[1] Both authors have contributed equally to this work.

http://dx.doi.org/10.1016/j.measurement.2014.12.009
0263-2241/

three wavelengths in the visible spectrum, using a spectrophotometer. Short macerations produce rosé wines, whereas longer maceration times are required for red wines [1].

The current design has been previously tested with actual grape must samples extracted periodically at different stages of a number of fermentations carried out at laboratory scale. Details relating to both the winemaking procedure and the analysis of the measurements carried out on the extracted samples, aiming at monitoring the evolution of the chromatic characteristics of grape musts during the maceration phase, can be found in a previous work [7]. The present work does not intend to focus on the chemical aspects of wine fermentations; it is rather devoted to cover in detail key issues related to the design, the selection of optoelectronic components and the subsequent validation of the developed sensor device. The system described in this work is part of a multi-purpose optoelectronic instrument initially conceived to obtain not only the chromatic characteristics of a fermenting grape must, but its refractive index at different stages of the fermentation too. Measuring the refractive index instead of the density represents an alternative method to follow the fermentation kinetics [7,8].

2. Chromatic characterization

The chromatic characteristics of fermenting grape musts are not gradually acquired during the whole fermentation, but mainly at its early stages instead, when the maceration occurs. Upon completion of the maceration process, the fermentation is still in progress and the fermenting grape must undergoes a slight but steady color loss [7]. The spectrum of red wines has a maximum at 520 nm, due to anthocyanins and their flavylium combinations, and a minimum in the region of 420 nm. The current approach to color analysis in winemaking requires absorbance measurements at 420 and 520 nm that take into account the contributions of red and yellow to overall color, with an additional measurement at 620 nm to include the blue component in young red wines [9]. This approach, known as Glories method, has previously been applied to finished red wines by other authors [10]. The chromatic parameters involved in the Glories method are three: color intensity (CI), hue (H) and brightness (dA (%)). The color intensity, of special relevance in enology, is a measure of the amount of color and may vary significantly among different grape types. Its evolution as a given fermentation progresses has been reported previously [1]. The hue is an indicator of color development toward orange, whereas the brightness is related to the shape of the spectrum, since a distinct absorbance peak at 520 nm is typical of bright red wines [9]. There is no target specification in terms of either expected values or validity ranges to apply the Glories method. This lack of strict specifications is a consequence of the fact that wine cellars follow their own protocols to produce a certain wine variety. Such protocols, it should be noted, are rather flexible, as they are influenced by factors like the sugar content of the harvested grapes, which may vary significantly from one season to the next.

Absorbance at a given wavelength A_λ is calculated using the Lambert–Beer law, which, as demonstrated in [11], holds for LED-based photometers applied to a wide range of sample thicknesses:

$$A_\lambda = \log\frac{I_0}{I} = alc \tag{1}$$

where I and I_0 are the radiation intensities after passing through the sample under test and through distilled water, respectively (see Fig. 1). a is the absorptivity, l is the path length of absorption and c is the concentration of the absorbing species [12].

Let A_{420}, A_{520} and A_{620} be the absorbances at 420, 520 and 620 nm using a 1-cm sample thickness, the common reference in colorimetry. The expressions (2)–(4) provide the color intensity, the hue and the brightness, respectively.

$$\mathrm{CI} = A_{420} + A_{520} + A_{620} \tag{2}$$

$$H = \frac{A_{420}}{A_{520}} \tag{3}$$

$$dA(\%) = A_{520} - \frac{(A_{420} + A_{620})}{2} \cdot \frac{100}{A_{520}} \tag{4}$$

Eqs. (2)–(4) represent an advance with respect to the pioneering technique proposed by Sudraud to describe wine color, where only absorbances at 420 and 520 nm were required in the calculations. In spite of this advance, the result of the analysis involving a third wavelength fails to reflect the overall visual perception of a wine's color and, although the application of the CIELab universal color appreciation system would represent an improvement compared to the Glories method, the results are difficult for winemakers to interpret [9].

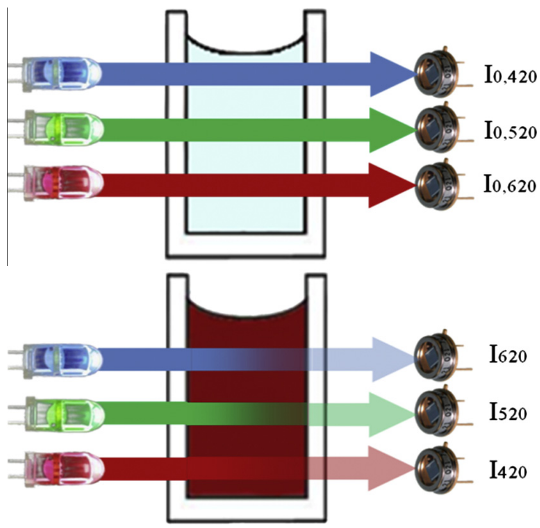

Fig. 1. Procedure for determining radiation intensities at 420, 520 and 620 nm using distilled water and a test sample from which absorbances can be determined.