CO$_2$ volume fluxes outgassing from champagne glasses: The impact of champagne ageing

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ABSTRACT

It was demonstrated that CO$_2$ volume fluxes outgassing from a flute poured with a young champagne (elaborated in 2007) are much higher than those outgassing from the same flute poured with an older champagne (elaborated in the early 1990s). The difference in dissolved-CO$_2$ concentrations between the two types of champagne samples was found to be a crucial parameter responsible for differences in CO$_2$ volume fluxes outgassing from one champagne to another. Nevertheless, it was shown that, for a given identical dissolved-CO$_2$ concentration in both champagne types, the CO$_2$ volume flux outgassing from the flute poured with the old champagne is, in average, significantly lower than that outgassing from the flute poured with the young one. Therefore, CO$_2$ seems to "escape" more easily from the young champagne than from the older one. The diffusion coefficient of CO$_2$ in both champagne types was pointed as a key parameter to thoroughly determine in the future, in order to unravel our experimental observation.

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1. Introduction

Champagne and sparkling wines elaborated according to the *méthode traditionnelle* typically hold 11–12 g L^{-1} of dissolved-CO$_2$ molecules [1,2]. As soon as a bottle of champagne or sparkling wine is uncorked, the liquid instantaneously becomes supersaturated with dissolved CO$_2$ (since ambient air contains only traces of gaseous CO$_2$). To reach a new stable thermodynamic state with regard to CO$_2$ molecules, champagne must therefore progressively degas. The progressive release of gaseous CO$_2$ from the liquid medium is responsible for bubble formation (the so-called effervescence process). It is worth noting that approximately 5 L of gaseous dissolved CO$_2$ must escape from a typical 0.75 L champagne bottle. Once champagne is poured into a flute, there are indeed two pathways for progressive CO$_2$ and potentially aromatic volatile organic compounds (VOC) losses. CO$_2$ and VOC escape (i) into the form of heterogeneously nucleated bubbles, the so-called effervescence, and (ii) by "invisible" diffusion through the free surface of the glass [1–3]. Glass shape is therefore also suspected to play an important role as concerns the kinetics of CO$_2$ and flavor release during champagne tasting [3].

From the consumer point of view, the role of bubbling is indeed essential in champagne, in sparkling wines and even in any other carbonated beverage. Without bubbles, champagne would be unrecognizable, beers and sodas would be flat [1–6]. However, the role of effervescence is suspected to go far beyond the solely aesthetical point of view. It was indeed recently demonstrated that the continuous flow of ascending bubbles strongly modifies the mixing and convection conditions of the liquid medium [7–10]. In turn, the CO$_2$ discharge by diffusion through the free air/champagne interface may be considerably accelerated, as well as the release of the numerous VOC, which both strongly depend on the mixing flow conditions of the liquid medium [11]. Suffice to say that a strong coupling therefore finally exists between rising bubbles, glass shape, CO$_2$ discharge and flavor release. Quite recently, glassmakers showed interest in proposing to consumers, a new generation of champagne tasting glasses, especially designed, with a well controlled CO$_2$ release all along tasting [7–10]. This is the reason why, in recent years, much interest has been devoted to depict each and every parameter involved in the release of gaseous CO$_2$ from glasses poured with champagne or sparkling wine. In a recent paper, the role of temperature on the kinetics of CO$_2$ fluxes outgassing from a champagne flute was investigated [12]. Moreover, kinetics of CO$_2$ fluxes were compared, whether champagne is served into a flute or into a coupe [13]. Very recently, also the development of a compact CO$_2$ sensor based on near-infrared laser technology for enological applications was reported [14].

Here, measurements of CO$_2$ fluxes outgassing from a flute poured with champagne are presented, in tasting conditions, all

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along the first 10 min following pouring. Two types of Champagne wines having experienced different periods of ageing were tested. In order to depict our experimental observations, the contribution of effervescence to the global kinetics of CO_2 release was discussed, and modeled by use of results developed over recent years.

2. Materials and methods

2.1. Some physicochemical parameters of both champagne samples

Two standard commercial Champagne wines were used for this set of experiments, namely a "young" one (vintage 2007, and referred to as YC in the following), and an "older" one, elaborated in the early 1990s (stored in a cool cellar since it was elaborated, and referred to as OC in the following). Some physicochemical parameters of champagne samples were determined, at 20 °C, with samples of champagne first degassed. The static surface tensions of both champagne type, γ, were found to be of order of 50 mN m^{-1}, and their density η were found to be close to 10^3 kg m^{-3}. Their dynamic viscosities were measured, at 20 °C, with a thermostated Ubelhode capillary viscosimeter, and found to be 1.55 mPa s for the YC, and 1.65 mPa s for the OC, respectively.

2.2. Measuring concentrations of dissolved CO_2 in both champagne samples

Concentrations of CO_2 molecules dissolved in both champagne samples were determined using carbonic anhydrase (labeled C2522 Carbonic Anhydrase Isozyme II from bovine erythrocytes, and provided from Sigma–Aldrich, US). This is the official method recommended by the OIV (namely the International Office of Vine and Wine) for measuring the CO_2 content in Champagne and sparkling wines [15]. This method is thoroughly detailed in two recent papers [12,16].

2.3. Glass washing protocol

In order to avoid the randomly located bubble nucleation inevitably provided in glasses showing natural effervescence, a single standard flute engraved at its bottom was used (thus providing a "standardized" artificial effervescence), as the one used in recent papers [12–14]. Between the successive pouring and time series data recordings, the flute was thoroughly washed in a dilute aqueous formic acid solution, rinsed using distilled water, and then compressed air dried. This drastic treatment forbids the formation of calcium carbonate crystals on the flute wall, as well as the adsorption of any dust particle acting as "natural" bubble nucleation sites. In such a flute, effervescence is therefore strictly restricted to the ring-shaped engravement, so that differences in CO_2 release from both champagne types are attributed only to physicochemical differences between champagne samples themselves.

2.4. Experimental set-up and procedure used to measure the flux of CO_2 desorbing from the flute poured with champagne

100 ± 4 mL of champagne were carefully poured into the flute previously level-marked with 100 mL of distilled water. Immediately after pouring, the flute was manually placed on the weighing chamber base plate of a precision weighing balance (Sartorius–Extend Series ED) with a total capacity of 220 g and a standard deviation of ±0.001 g. The Sartorius balance was interfaced with a laptop PC recording data every 5 s from the start signal, activated just before the flute was placed on the weighing chamber base plate. The total cumulative mass loss experienced by the flute
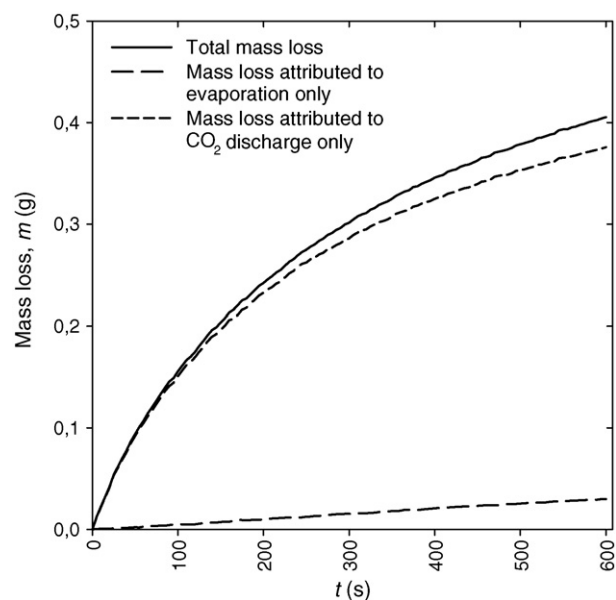
Fig. 1. Typical cumulative mass loss-time recordings (in g) from a 100 mL flute poured with a sample of YC, all along the first 10 min following the pouring process (at 20 °C); the mass loss data series attributed to CO_2 desorbing only is deduced by subtracting the data series attributed to evaporation only from the total mass loss data series; consequently, the CO_2 mass flux desorbing from the champagne surface is the slope of the short-dash curve (i.e., the first derivative of the cumulative mass loss data series attributed to CO_2 desorbing only).

poured with champagne was recorded during the first 10 min following the pouring process. The mass loss of the flute poured with champagne is the combination of both (i) champagne evaporation and (ii) CO_2 progressively desorbing from the supersaturated liquid. The mass loss attributed to champagne evaporation only was accessible by recording the mass loss of a flute poured with a sample of 100 mL of champagne first degassed under vacuum. Due to likely variations in hygrometric conditions from one day to another, champagne evaporation was thus systematically conducted just before series of mass loss recordings were done. The cumulative mass loss versus time attributed to CO_2 molecules progressively desorbing from champagne may therefore easily be accessed by subtracting the data series attributed to evaporation only from the total mass loss data series, as displayed in Fig. 1, for example. Moreover, from the cumulative CO_2 mass loss-time curve as that displayed in Fig. 1, the volume flux of CO_2 (in cm^3 s^{-1}), denoted F_T, may be deduced as follows, all along the degassing process:

$$F_T = 10^6 \left(\frac{RT}{MP} \right) \frac{\Delta m}{\Delta t} \tag{1}$$

with R being the ideal gas constant (equal to 8.31 J K^{-1} mol^{-1}), T being the champagne temperature (expressed in K), M being the molar mass of CO_2 (equal to 44 g mol^{-1}), P being the ambient pressure (close to 10^5 N m^{-2}), Δm being the mass loss between two successive data recordings (expressed in g), and Δt being the time interval between two successive data recordings (i.e., 5 s in the present case).

To enable a statistical treatment, six successive pouring and time series data records were done, for both champagne types (YC and OC). At each step of the time series (i.e., every 5 s), an arithmetic average of the six data provided by the six successive time series was done, to finally produce one single "average" mass loss-time series which is characteristic of a given champagne type (but with standard deviations corresponding to the root-mean-square deviations of the values provided by the six successive data recordings).