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Carbonation monitoring of beverage in a laboratory scale unit with on-line measurement of dissolved CO_2

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Abstract

The effervescence properties of carbonated drinks are subject to the concentration of carbon dioxide dissolved and its ability to be transferred from the liquid phase to the forming bubble. We report the construction of a small laboratory scale carbonation unit that allows the study of the solubility of carbon dioxide in various hydro-alcoholic media, differing in their compositions. This unit, which is a model of a real industrial one, measures the instant concentration of CO_2, during the carbonation process, by means of a thermal conductivity detector. The carbonation kinetics of various samples, containing water, alcohol, sugar, proteins and free amino-acids, were studied. While sugar diminishes CO_2 solubility and, consequently, carbonation kinetics, free amino-acids and proteins increase the concentration of carbon dioxide in the medium. A survey of the rheological properties of the samples showed that CO_2 solubility modifications are not correlated with changes in the viscosity of the medium. This equipment could be helpful for soft drink bottlers for measuring the changes that may affect effervescence and consequently the visual and gustative perception of the beverage after modification of its composition.

Keywords: Laboratory scale carbonation unit; Carbonation; Soft drinks; Quality control in sparkling beverage; Carbon dioxide solubility

1. Introduction

Beverages containing carbon dioxide are, nowadays, very popular products. Consumers enjoy their "pleasurable and sought after" sensation, despite the fact that they can be irritating, or even painful, for some people. The sensations elicited by carbonated drinks are either of mechanical origin, due to the bursting CO_2 bubbles stimulating mechanoreceptors on the tongue, or of chemogenic origin by formation of carbonic acid (H_2CO_3) in a reaction catalysed by carbonic anhydrase, which stimulates polymodal nociceptors in the oral cavity (Dessirier, Simons, Carstens, O'Mahony, & Carstens, 2000). Bubbles appear when concentration levels of CO_2 are 3–5 times higher than at the saturation equilibrium value and depend of the pre-existing gas–liquid interfaces (Lubetkin & Blackwell, 1988; Wilt, 1986). Numbers and sizes of these bubbles also have a sensory impact on the beverage, enhancing mass transport of CO_2 when the bubbles impinge upon the tongue and increasing the "tingling" sensation (Barker, Jefferson, & Judd, 2002a, 2002b). Those factors are very important in the case of Champagne wines where the ascending bubbles count in the sensory evaluation of the wine. Growth rate and ascending velocity of the bubbles are influenced by the concentration of carbon dioxide available in the liquid phase and by the presence of tensioactive molecules (proteins, sugar) in the solution and on the bubble wall, making it grow slower or faster (Jones, Evans, & Galvin, 1999; Odake, 2001). For example, in

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soft drinks, polysacharides or hydrocolloids are used as thickeners, stabilisers and gelling agents, as well as to improve ''mouthfeel'' and to aid in carbonation retention due to the augmentation of the tensio-active charge of the liquid. Modification of the composition of the liquid phase may dramatically affect the visual or taste perception of effervescence of a drink (Barker et al., 2002a, Barker, Jefferson, & Judd, 2002b).

Carbonation can be achieved by injecting the gas into a pressure-sealed vessel as with domestic carbonation units (Barker et al., 2002a, 2002b). As the system is pressure-sealed, gaseous injection increases the internal pressure, and thereby the CO_2 solubility. Up to 9 g/l of CO_2 can be dissolved, which is the limit for highly carbonated drinks such as tonic water. The success of the domestic system is largely dependent on its ease of use by the consumer and overall cost. Depressurising the system lowers the CO_2 concentration in the headspace, causing gas desorption. Gas can be injected continuously through a venturi in the liquid flow. Mixing is thus much more efficient and higher carbonation levels can be reached. The beverage is collected in pressurized tanks or directly in bottles. This is the process in use by the carbonated drinks industry.

Manufacturing carbonated soft drinks requires efficient monitoring of CO_2 concentration in the liquid during the carbonation process and evaluation of the influence of additives that could modify the absorption/desorption mechanisms. The two most common devices used for monitoring CO_2 concentration are the Severinghaus electrode (Severinghaus & Bradley, 1958) and the infrared detector (Munkolm, Walt, & Milanovich, 1988). The Severinghaus type CO_2 electrode comprises a pH electrode in contact with a thin layer of bicarbonate buffer solution with the whole system encapsulated by a thin, gas-permeable membrane. CO_2, in the sample under test, diffuses through the gas-permeable membrane and equilibrates with the internal aqueous solution, thereby altering its pH. The change in pH is monitored by the pH electrode. The electrode has a long response time, typically 5–15 min. The infrared absorption detector produces quick response times and the results are reliably quantitative, they are bulky and expensive, and only applicable to gaseous CO_2. Other devices for CO_2 measurements, include gas chromatography (GC) and mass spectrometry (MS). MS is capable of producing measurements in near real-time but its price is prohibitively high. GC, while less expensive, requires 10–20 min to complete an analysis of a sample and cannot be used for real-time measurements. Thermal conductivity detectors (Hale, Stehle, & Bals, 1992) record the difference in conductivity between a reference gas (N_2) and CO_2 after diffusion in a measurement chamber. The response time is quite convenient for following carbonation kinetics and the equipment can be easily mounted on liquid ducts after the mixing chamber. For a complete review of measuring techniques for the determination of CO_2 in beverages see Barker, Jefferson, and Judd (1999).

Real-time measurement of the CO_2 concentration during carbonation is a real challenge. This paper describes the construction and reliability of the system equipped with an on-line sensor, allowing continuous measurement of the concentration during carbonation and with a venturi for better gas–liquid mixing. The sensor is a thermal conductivity electrode incorporated in the unit. The unit built is a laboratory scale model of an existing carbonation unit used by a soft drink producer. The purpose of this paper is to gain a better understanding of the solubilisation kinetics of carbon dioxide in aqueous or hydro-alcoholic beverages as a function of the liquid composition. In this case, we assumed that the carbon dioxide concentration available for bubbling may not be affected by the way carbon dioxide is dissolved in the medium (by mechanical injection or natural fermentation).

Studies and modelling of effervescence properties of sparkling wines are numerous in the literature (Casey, 1988) but they do not focus on the chemical composition of wines or, more especially, the possible reactions of CO_2 with compounds such as nucleophiles. This class of molecules can be involved in reaction with gaseous carbon dioxide giving carbamates (see Fig. 1) as, e.g., ethanolamines (Danckwerts, 1979). For example, in still wines, the concentrations of free amino-acids, especially proline and arginine, increase with maturation time and are characteristics of some grapes. Proline is present in large amounts in Chardonnay and arginine in Pinot Noir. Serine with a chemical structure similar to ethanolamine and other free amino-acids is supposed to be involved in such reactions. We attempted to measure the influence of various solutes, such as alcohol, sugar, amino-acids (serine, arginine, proline) and proteins (BSA and colloidal extract of base wine) on the absorption kinetics of CO_2 in hydroalcoholic medium.

Rheological properties of the solution could also modify the rate transfer of gas from the liquid to the forming bubble, i.e. from a solvated form to a gaseous one. This will mechanically influence the bubbling of the liquid when served. A study of the viscosities of the samples and carbonation levels will show whether the variations of the carbonation levels are due to a mechanical barrier to the diffusion of gas or whether there are other relationships between carbon dioxide and the molecules dissolved.

2. Materials and methods

2.1. Carbonation unit

The unit (Fig. 2), is composed of a laboratory-designed venturi, two stainless steel tanks (one can be re-

$$2\ \text{R-NH}_2 + \text{CO}_2 \leftrightarrow \text{RNHCOO}^- + \text{RNH}_3^+$$

$$\text{RNH}_3^+ \leftrightarrow \text{RNH}_2 + \text{H}^+$$

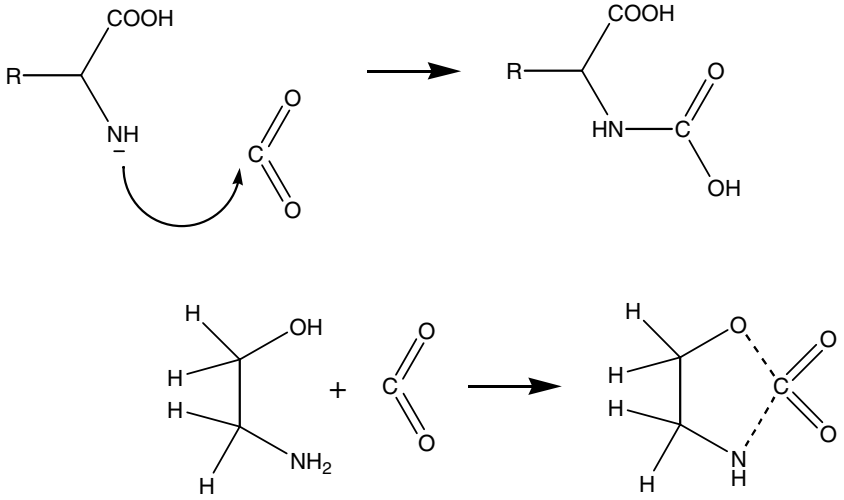

Fig. 1. Equilibrium of carbon dioxide with alkyl amines and formation of carbamate. Supposed reaction mechanisms of carbon dioxide with amino acids and mono ethanolamine.

moved from the system and used for tasting the carbonated drink), a pump (FM 1.30, KNF Floods), a refrigerated bath and a sensor Model 3621 from Orbisphere Laboratories for monitoring the dissolved CO_2. All gas and liquid ducts are made with Rilsan tubing (4/6 mm, Legris, France). All couplings use the Swagelok connection system. The maximum injection pressure is given as 10 bars, following the safety sheets of the equipment.

The venturi is made of a stainless steel tube (80 mm long, 2 mm thickness). The gas and liquid inlets are tubes of 8/10 mm. They end in a nozzle with a 2 mm diameter. As the carbon dioxide pressure increases in the system, a spray is formed, ensuring an intimate mixing of the gas/liquid phases.

The intermediary tank (3 in Fig. 2) is made with a stainless steel tube of 95 mm (diameter), 250 mm (height) with 3 mm thickness walls. It is equipped with two inlets of 6/8 mm and a control valve in the upper part to allow a depressurisation of the system, providing a variable gas stream in the venturi.

This removable tank (5) has the same dimensions as the previous one. It is equipped with two inlets of 6/8 mm, each one fitted with a valve and a Swagelok quick-connecting system. The outlet has a bottle-neck form which can be closed by a capsule, as used in the Champagne region for wine making. An electropolishing (40 μm metal removal) was done inside and outside the tank to ensure removal of all the crevices that could initiate nucleation.

2.2. Chemicals

Carbon dioxide, used in the carbonation experiments, was food grade and was provided by Messer Gmbh. Amino-acids (serine, proline and arginine), bovine serum albumin (BSA) and L-(+)-tartaric acid (purity 99%) were from Sigma–Aldrich chemicals and were used without purification. Sugar, of beet origin, was commercial grade. Alcohol, of agricultural origin (99.9%) was obtained from Charbonneaux–Brabant (Reims, France).

2.3. Wines

Still wines were furnished by a Champagne winery. It is a blend of different wines from Pinot Noir, Pinot Meunier and Chardonay grapes in equal proportions. Base wines were centrifuged, earth-filtered on Kieselghur and sulphated after malo-lactic fermentation (*Oenococcus oeni*) was completed. All wines were racked in individual bottles until opened. Composition was: alcohol (11.06°), sugars (1.2 g/l), SO_2 (42 mg/l), total acidity (4.6 g eq. H_2SO_4/l). Typically, for all these wines, pH is around 3.2 and ionic strength is 0.02 M.

2.4. Colloids from base wine

Wine colloids were prepared from 60 l of still wine. They were ultrafiltered on a molecular weight cut off membrane at 10 kDa. The retentate was freeze-dried.

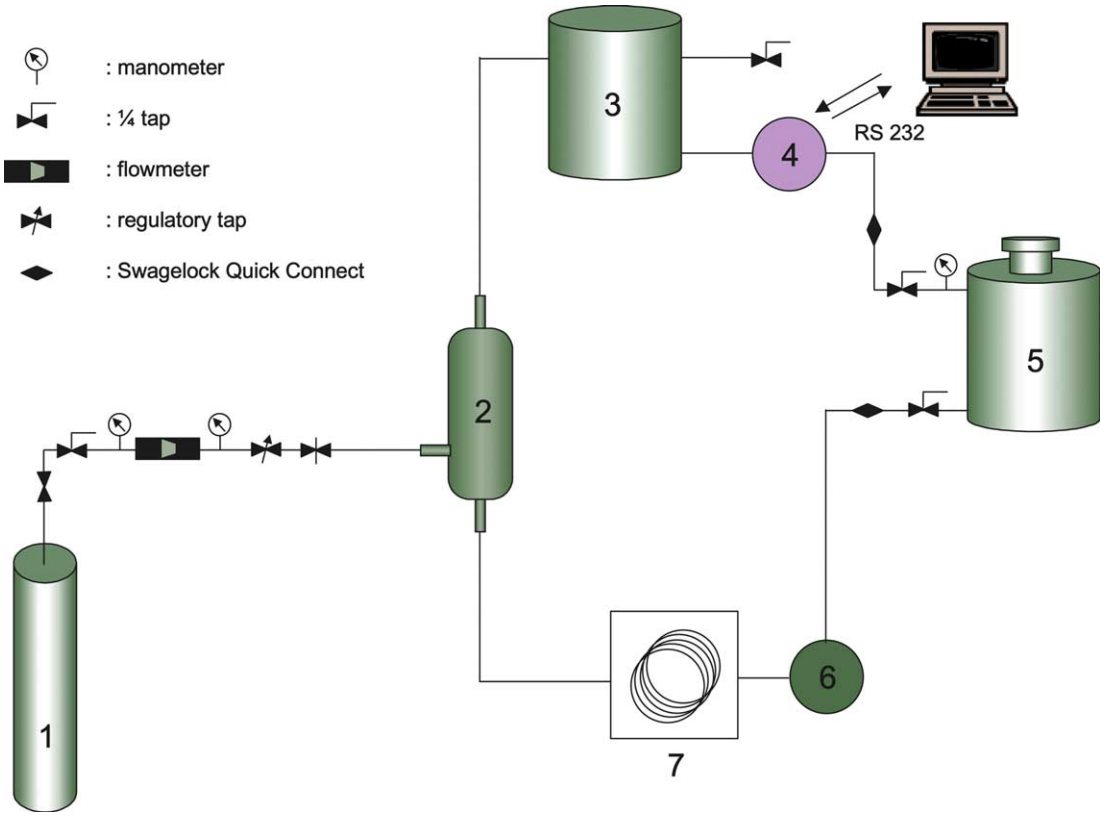

Fig. 2. Overall view of the carbonation unit: (1) CO_2 delivery; (2) venturi; (3) intermediary tank with gas outlet; (4) dissolved CO_2 sensor; (5) removable tank; (6) pump; (7) refrigerated bath.

Evaluation of the protein concentration was done by measurement of the nitrogen content.

2.5. Sample preparation and carbonation

2.5.1. Sample preparation

Hydro-alcoholic solutions were made of water plus alcohol (alcoholic degree: 11°), and tartaric acid to give pH 3.2. The compound to be tested was added and the sample directly used for carbonation. A waiting period of 24 h is needed if the solution contained free amino-acids, BSA, β-casein or colloids from the base wine.

2.5.2. Carbonation

One half-litre of solution was introduced to the intermediary tank. The pump was set to function, causing liquid flow in the system. Temperature of the liquid was lowered to 11 °C by means of a refrigerated bath. Opening of the inlet gas valve increased the internal pressure up to 6 bars. The exhaust valve was slowly opened, causing a weak depressurisation of the system and consequently a gas stream in the venturi. As carbonation began ($t = 0$), partial pressure of carbon dioxide was recorded simultaneously, every 20 s, by the computer. The liquid passed through the mixing chamber several times until it reached saturation. Carbonation was stopped by the operator when the recorded values were stable during 10 min. Each curve presented is the average of four experiments.

2.6. Measurement of the carbon dioxide concentration

The Orbisphere® Laboratories device (model 3621) uses a membrane covered dynamic thermal conductivity (MDTC) sensor operating in a cyclic mode. It works by measurement of the rate of diffusion of the gas through a semi-permeable membrane isolating the fluid from the receiving chamber which is periodically flushed with a purge gas (N_2). After each purge cycle, the thermal conductivity reading changes from the value of the purge gas at a rate which is proportional to the CO_2 concentration in the sample. A suitable electronic circuit amplifies the signal from the sensor and calculates the concentration of the gas in the fluid medium. The values can be recorded during the experiment on a computer through a RS 232 interface.

2.7. Viscosity measurements

Dynamic viscosities (Pas) at 11 °C were determined using an ARES Rheometer from Rheometrics Scientific. ARES is a controlled strain rheometer for evaluating the storage and loss moduli (G' and G'') (viscoelastic properties) of the samples. The controlled strain rheometer

ARES employs a dynamic actuator to apply a deforming strain to the sample and a separate transducer to measure the resultant stress developed within the sample. This system provides a wider frequency range at high sensitivity, and achieves smaller dynamic strains than does a controlled stress rheometer. All measurements were done using the cone/plate modulus (cone angle: 0.04 rad; plate diameter: 50 mm; spacing: 0.5 mm).

3. Results and discussion

3.1. Operating range

Carbonation of tap water was repeated at various temperatures and pressures (from 1 to 6 bars) and partial pressure of carbon dioxide was recorded and converted to concentration (g/l) using the Henry's law coefficient. As temperature decreased from 27 to 7 °C, the concentration of dissolved CO_2 increased. Results were compared with a compilation of data from the literature (Sanders, 1999) and are plotted in Fig. 3. The correlation with data from the literature is quite good. By combination of temperature and pressure settings, we can reach saturation levels (from 2 to 15 g/l of dissolved carbon dioxide) covering a wide range of sparkling beverages from tonic water to sparkling wines (Champagne wines contain 12 g/l of dissolved carbon dioxide).

3.2. Carbonation time

The carbonation unit is equipped with an exhaust valve in the intermediary tank. Modifications in the setting allow increases of gas flow in the system and commencement carbonation. We have recorded various carbonation kinetics of tap water using various gas flows (7, 15, 30 g/min) (Fig. 4). When the gas flow is increased, the time needed to reach saturation is decreased. In further experiments, the flow will be set at 15 g/min, which is a good mean between gas consumption and carbonation kinetics.

3.3. Influence of pH on carbonation monitoring

In aqueous solutions, carbon dioxide concentration, as solvated CO_2, is modified by the pH of the solution and the dissociation equilibrium involved in reaction of CO_2 with water (Scarano & Calcagno, 1975)

$$CO_2(\text{gas}) \leftrightarrow CO_2(\text{aq})$$

$$CO_2(\text{aq}) + H_2O \leftrightarrow H_2CO_3 \quad K = 1.6 \times 10^{-3}$$

$$H_2CO_3(\text{aq}) + H_2O \leftrightarrow HCO_3^-(\text{aq}) + H_3O^+(\text{aq})$$
$$pK_a = 6.35$$

$$HCO_3^-(\text{aq}) + H_2O \rightarrow CO_3^{2-} + \underline{H_3O^+} \quad pK_a = 10.33$$

Carbonations of tap water were repeated three times under the same conditions (temperature, carbonation pressure and gas flow rate). CO_2 partial pressure values were recorded during carbonation until equilibrium was reached at various pH values. Results are presented in Fig. 5. As the sensor measures the amount of carbon dioxide passing through the selective membrane during a short period of time, the precision of the measurements is influenced by the quantity of free CO_2 in the liquid and, consequently its pH. Better results are obtained for acid solutions where carbon dioxide is mainly in its solvated form. For pH > 7, the formation of carbonates modifies the reliability of the measurements. In our studies, pH was set at approximately 3.1. This is the value observed for sparkling wines and for some soda.

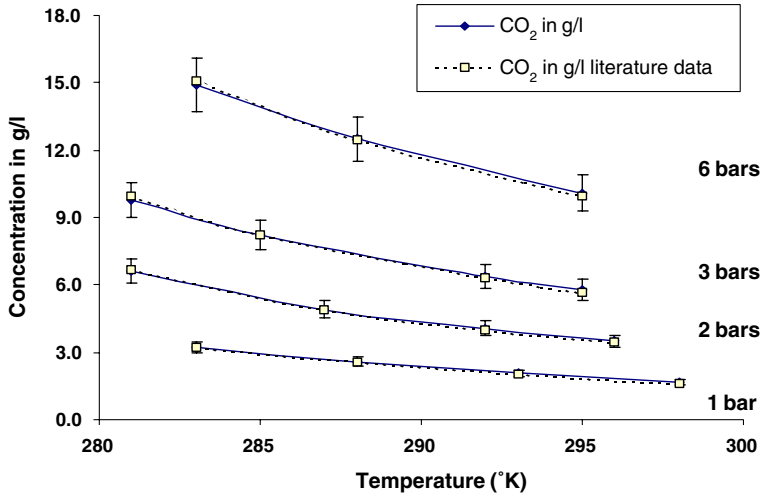

Fig. 3. System range: carbonation of water at various pressures (bars) and temperatures (K). pH is set to 7. Values measured by the sensor are compared with literature data. Each point is the meaning of four experiments.

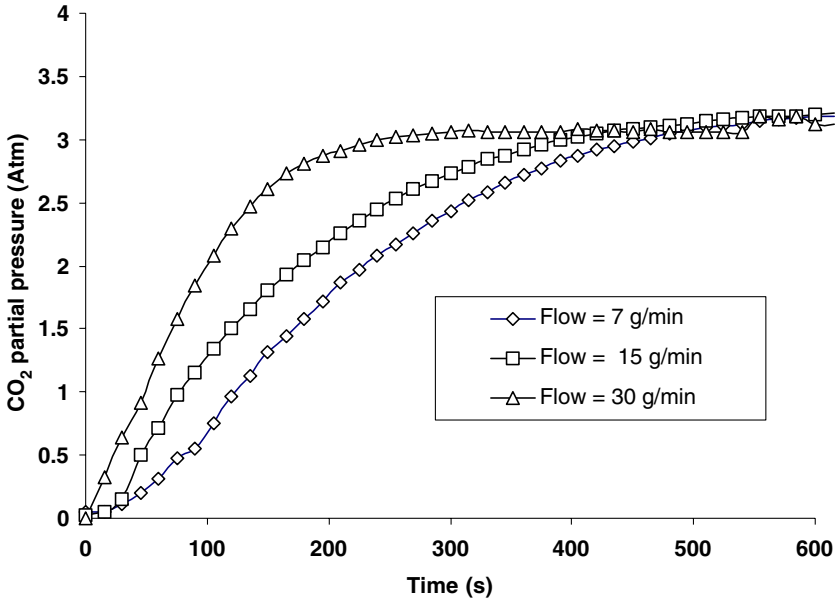

Fig. 4. Carbonation kinetics of tap water recorded at various gas stream and for a CO_2 pressure of 3 bars and at pH 3.1. Each curve is the meaning of four experiments. Carbonation time is shortened as gas flow increases.

3.4. Carbonation of hydro-alcoholic samples

3.4.1. General

Alcohol, sugar, free amino-acids and proteins are the major constituents of wines. Initially, we have measured the effects of alcoholic degree and sugar concentration on carbonation, by comparison with pure water. Then, using a liquid containing 10 g/l of sugar and 11% alcohol, we recorded the carbonation kinetics in the presence of free amino-acids, proteins (BSA and casein) and colloids from base wine (see Table 1).

3.4.2. Effect of alcohol

Fig. 6 shows the carbonation of two samples containing different amount of alcohol (11% or 40%). An average value 11°, observed for the alcoholic degree in wines before the second fermentation takes place in bottles in the champenoise method. The same conditions were used for the two samples and there is no difference in the absorption kinetics of carbon dioxide in the liquid.

3.4.3. Effect of sugar

Fig. 7 shows the results obtained with two different samples of the same alcoholic degree (11°) but differing in their sugar contents (10 or 40 g/l). Carbonation kinetics differ between the samples. Increasing concentration of sugar yields a decrease of the average level of dissolved carbon dioxide.

3.4.4. Effect of free amino-acids

Three amino-acids (proline, serine and arginine) were dissolved at a concentration of 200 mg/l in a hydro-alcoholic medium (11°) containing 10 g/l of sugar. The carbonation kinetics are shown Fig. 8. The differences from the other carbonation kinetics are obvious. As addition of sugar decreases the solubility of carbon dioxide, free amino-acids added to the medium produce a slight increase in the amount of carbon dioxide dissolved. They facilitate the solubilisation of the gas and the polar amino-acids (serine or proline) have a greater effect than arginine.

3.4.5. Effect of proteins

Two standard proteins (BSA and β-casein at a concentration of 50 mg/l) were used in this test and were dissolved in the standard hydro-alcoholic medium (11°) containing 10 g/l of sugar. The carbonation kinetic is very different (Fig. 9) from that observed for the reference medium. As for free amino-acids, absorption of carbon dioxide is faster in the presence of proteins but there is no difference between the two molecules.

3.4.6. Effect of a colloidal extract from base wine

A colloidal extract from Champagne base wine (13% eq. protein) was added to the reference medium at a concentration of 100 mg/l and carbonated under the usual conditions (Fig. 10). As for free amino-acids and proteins, the carbonation kinetics were faster in the presence of the colloids. This was then compared with a carbonation of a sample containing the same amount of protein (10 mg of BSA). The kinetics showed the same profile, and solubilisation of carbon dioxide was faster than in the reference medium.

3.5. Carbonation of natural wines

Fig. 11 shows the carbonation kinetics of a natural wine sample. The profile obtained is similar to that

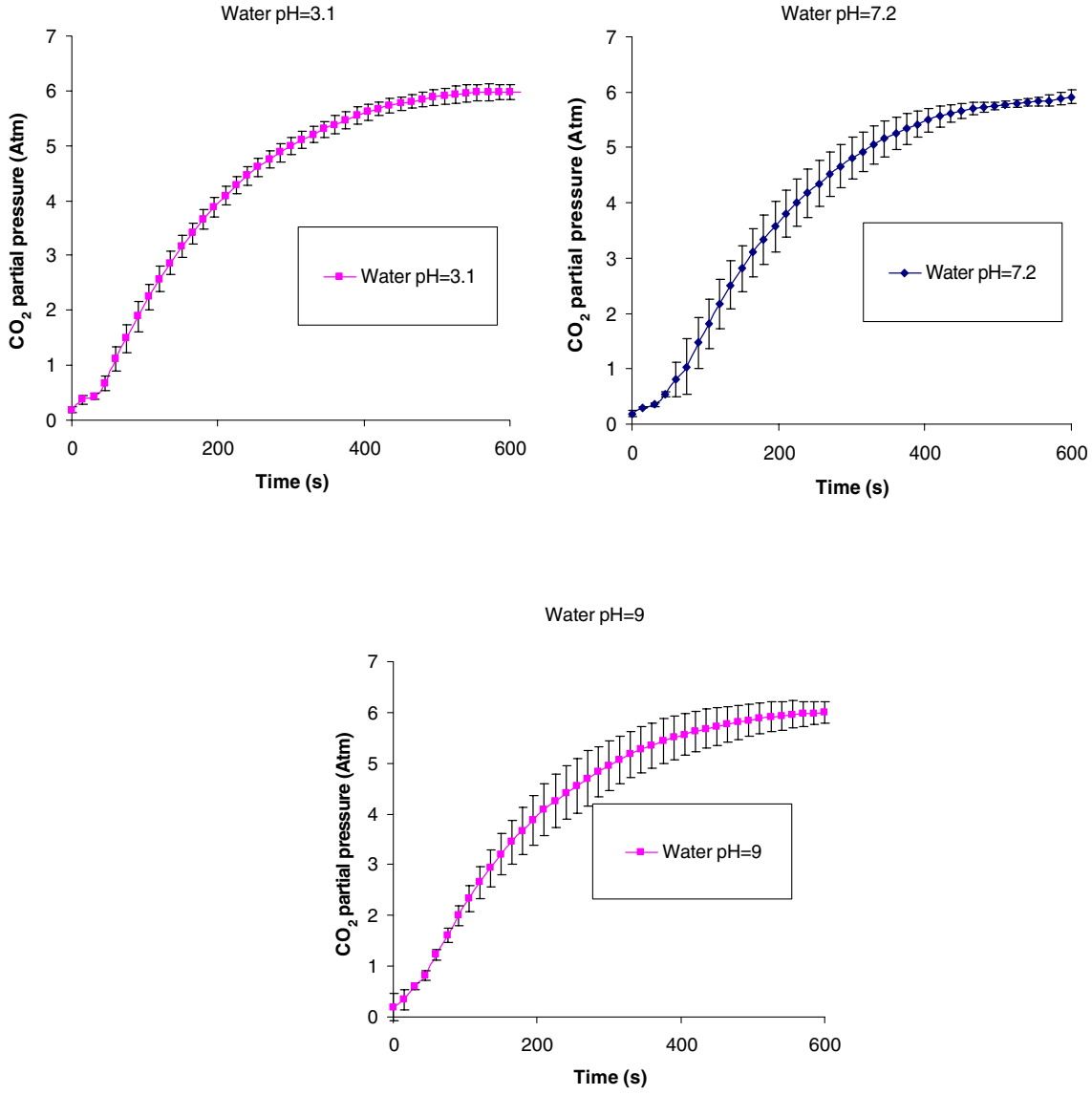

Fig. 5. Carbonation of water at different pH values. Gas flow is set at 15 g/l and CO_2 pressure at 6 bars. Precision of the measurements is due to the equilibrium involved in the solubilisation of carbon dioxide in water.

Table 1
Concentrations of the various compounds added to the standard medium made of water and alcohol (11°)

Compound added to the base medium: water and alcohol (11°)	Concentration
Sucrose	10 or 40 g/l
Proteins: BSA or β-casein	50 or 10 mg/l
Colloids (13% eq. proteins)	100 mg/l
Free amino-acids	
Serine	200 mg/l
Proline	200 mg/l
Arginine	200 mg/l

obtained with the reference medium. An ultrafiltration (>10 kDa) was done on this wine and the filtrate was dissolved in 500 ml of natural wine and carbonated. The profile obtained was similar to the kinetics recorded with the carbonation of the reference medium containing 100 mg/l of colloidal extract. A carbonation of the reference medium plus 10 mg/l of BSA gave the same profile. In both cases, addition of proteins to the medium increased the solubility of carbon dioxide in the wines, as in the reference medium.

For a better understanding of the results, carbon dioxide concentrations measured at $t = 300$ s are plotted in Fig. 12. Increasing the concentration of sugar, lowered the concentration of carbon dioxide; alcohol had no effects and free amino-acids, proteins and colloids increased the concentration of CO_2.

3.6. Rheology of the samples

We first determined the viscoelastic properties of samples of Champagne still wine which differs in sugar

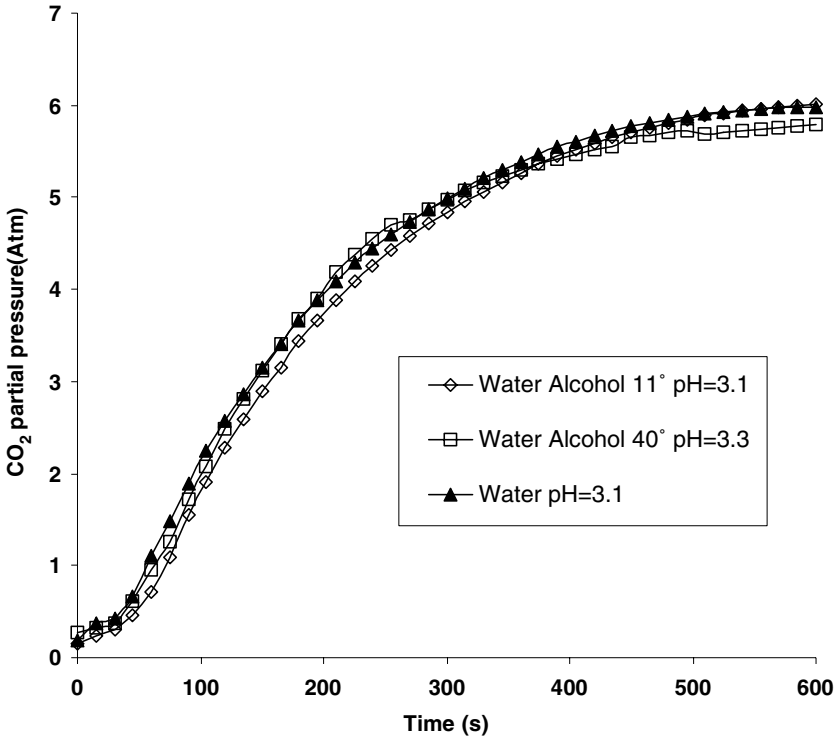

Fig. 6. Effect of the alcoholic degree: carbonation under 6 atm and 15 g/l of CO_2 of two samples of 11% and 40% alcohol. pH is set at 3.1. The full line indicates the carbonation kinetic of pure water.

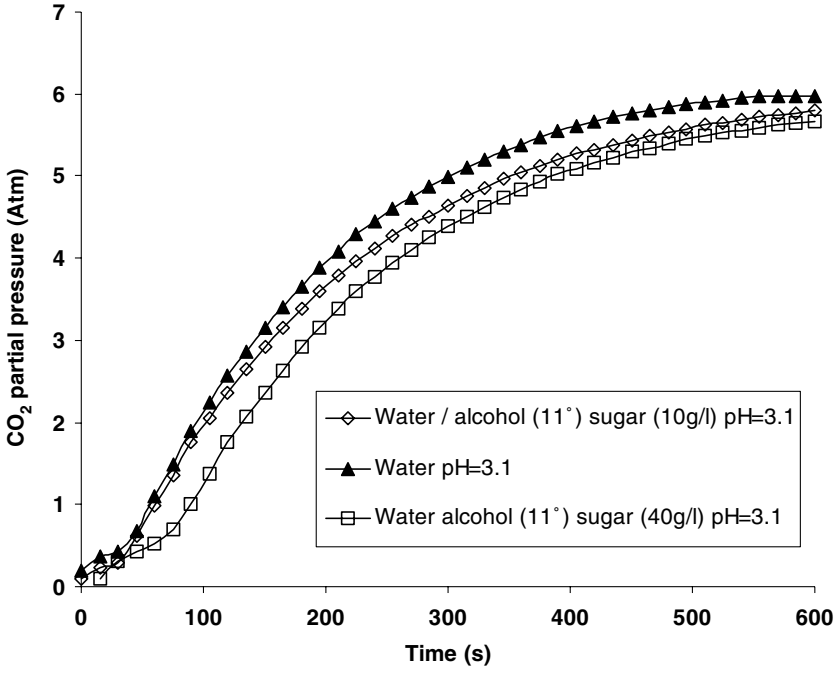

Fig. 7. Effect of the sugar concentration. Carbonation under 6 atm of two samples containing 10 or 40 g/l of sugar. pH is set at 3.1. The full line indicates the carbonation kinetic of pure water.

concentrations at different temperatures (Fig. 13). Storage modulus did not seem to change as temperature, or sugar concentration were varied, which is consistent with the negligible amount of wine constituents having noticeable elasticity values. On the other hand, the viscous modulus, G'', greatly depended on these two parameters. The variation of sample viscosity was mainly due to this modulus.

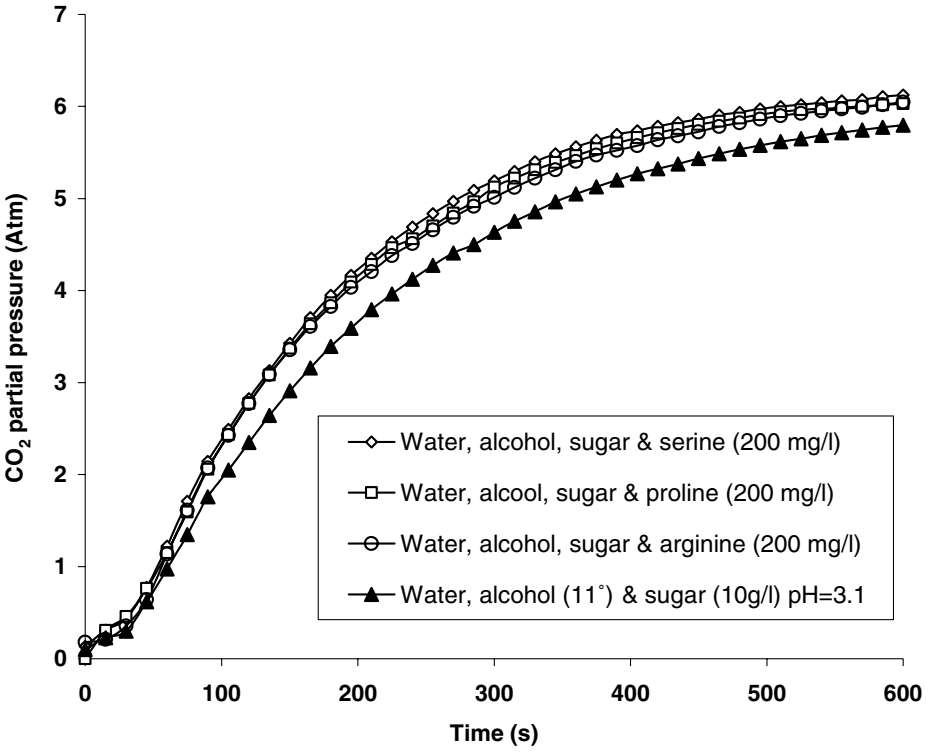

Fig. 8. Effect of free amino-acids: carbonation under 6 atm of three samples containing different amino-acids: serine, arginine and proline at 200 mg/l. Concentration of sugar is 10 g/l and pH is set at 3.1 for all the samples. The full line indicates the carbonation kinetic of the reference sample: water, alcohol (11°) and sugar (10 g/l).

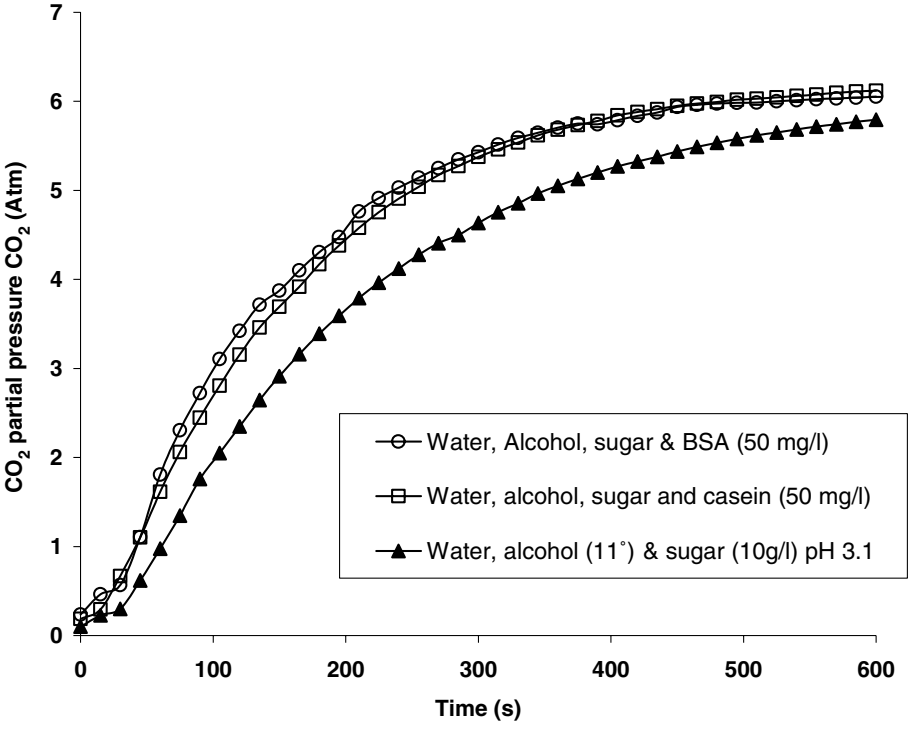

Fig. 9. Effect of proteins: Carbonation under 6 atm of two samples containing 50 mg/l of standard proteins (BSA and β-casein) at a concentration of 50 mg/l. The full line indicates the carbonation kinetic of the reference sample: water, alcohol (11°) and sugar (10 g/l).

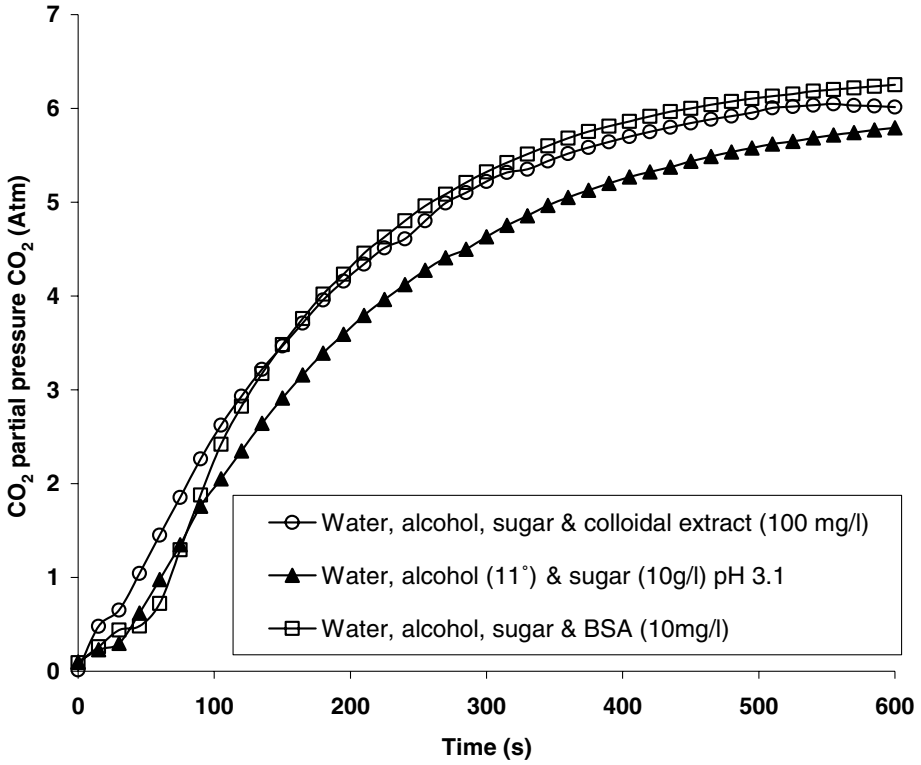

Fig. 10. Effect of a colloidal extract: carbonation under 6 atm of a sample (500 ml) containing 100 mg of a lyophilizated colloidal extract (>10 kDa) from of a base wine. The extract contains 13% eq. protein. It is compared with a sample containing 10 mg/l of BSA The full line indicates the carbonation of the reference sample: water, alcohol (11°) and sugar (10 g/l).

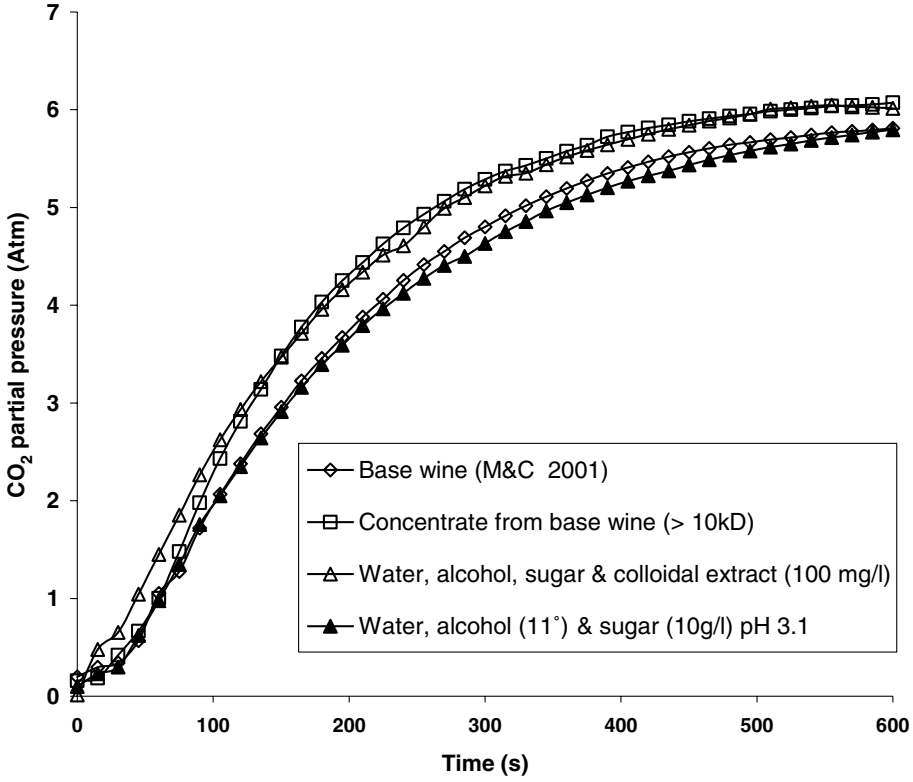

Fig. 11. Carbonation under 6 atm of a wine sample (vintage 2001) and a concentrate obtained by ultrafiltration of the same base wine and compared to the carbonation kinetic of the reference sample plus 100 mg of lyophylizated colloidal extract. The full line indicates the reference sample: water, alcohol (11°) and sugar (10 g/l).

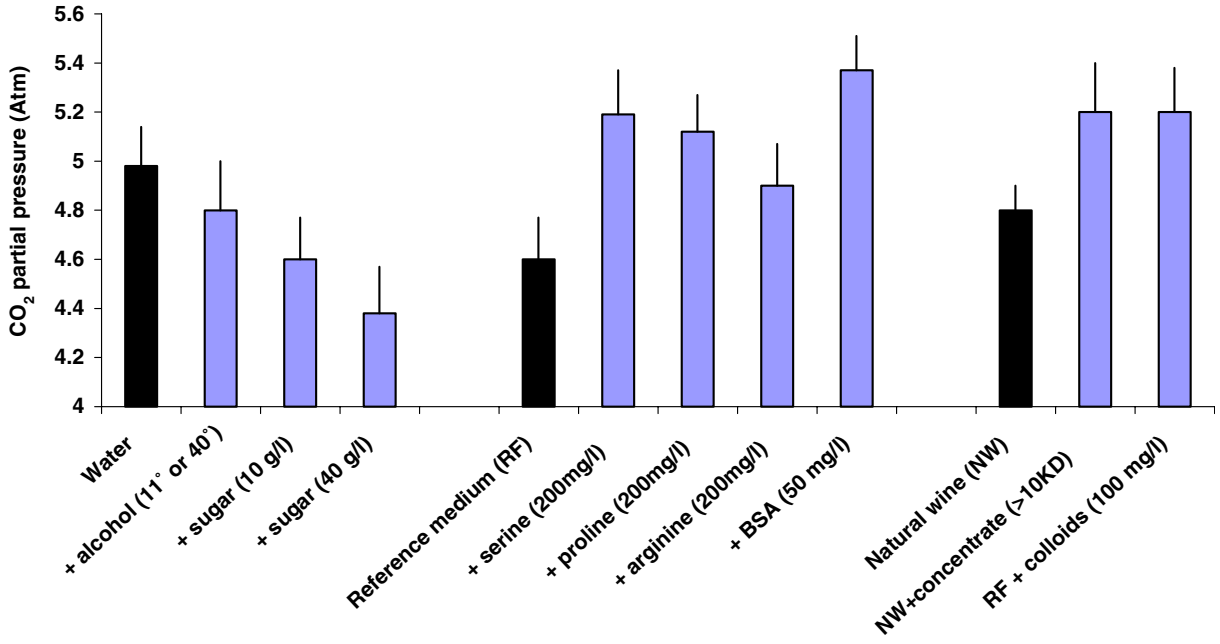

Fig. 12. Partial pressures of carbon dioxide in samples during carbonation (t = 300 s) in the following conditions: pH 3.1; gas flow = 15 g/l and carbonation pressure is 6 bars. Reference medium is water, alcohol (11°) and sugar (10 g/l).

A survey of the viscoelastic values of the different media was done at 11 °C and the values measured are shown in Fig. 14. Addition of sugar or alcohol increased the viscosity of the sample. The modification of the rheological properties, due to the addition of alcohol, was greater than that obtained with sugar (almost no change for sugar concentration between 10 and 40 g/l).

Addition of proteins to the reference medium (water, alcohol (11°) and sugar at 10 g/l) increases the viscosity. Addition of amino-acids modified the rheological properties of the samples by lowering viscosity.

Viscosity of natural wine is similar to the sample reference containing water, alcohol and sugar at 10 g/l. The retentate from the ultrafiltrated base wine had a viscosity similar to a reference sample containing 50 mg/l of BSA or β-casein and the filtrate, which contains sugar and other small molecules, had a viscosity similar to the reference medium.

We attempted to establish relationships between the rheological properties of the samples and the ability of the liquid to trap carbon dioxide. For the sugar-containing samples, viscosity increased with sugar concentration while the concentration of carbon dioxide in the solution was decreased. Surprisingly, alcohol which is a compound that greatly modifies the viscosity of the samples, had no effect on carbonation level. When the reference medium (water, alcohol (11°) and sugar at 10 g/l) contained free amino-acids, viscosity was not greatly modified but there was an increase in the carbon dioxide concentration, as for addition of proteins. Viscosity of the sample and its ability to dissolve carbon dioxide are not related. The solubility of carbon dioxide seems to be more sensitive to the change in mass concentration of solution constituents than to their physical properties.

4. Conclusion

The versatility of our laboratory unit allows carbonation of various samples, ranging from soda to alcoholic beverages. The use of a venturi provides a better mixing of the gas with the liquid than is achieved by dissolving the gas in a pressurized vessel. The system can be used, either for producing a carbonated drink and collecting it in the removable tank for sensory evaluation purposes or for studying the carbonation kinetics. The TCD device, thanks to its conception, can record small differences in carbonation kinetics that are due to modifications in the composition of the medium.

Effects of alcohol, sugar, free amino-acids and proteins on the carbonation of a hydro-alcoholic medium were investigated and the results compared with the dynamic viscosity data. Addition of increasing amounts of sugar (10–40 g/l) to a hydro-alcoholic medium modifies the viscosity of the sample and lowers the amount of carbon dioxide dissolved. Changing the concentration of alcohol (11% or 40%) greatly modifies the viscosity but the solvation of carbon dioxide is not affected. If the sample contains proteins or free amino-acids, an increase in carbon dioxide concentration is observed despite modification of the rheological properties of the

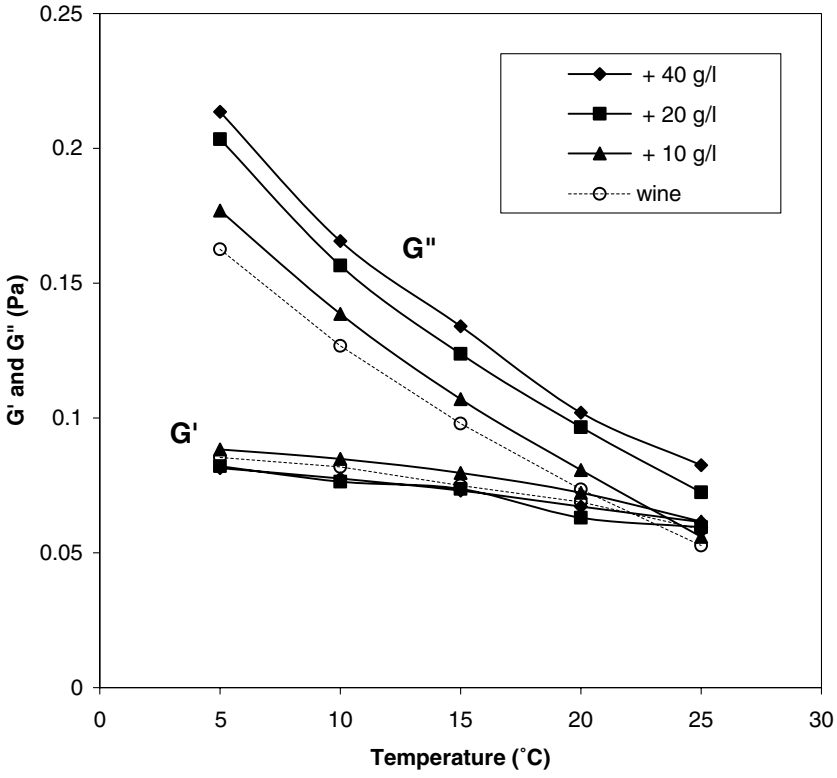

Fig. 13. Loss and storage modules measured at different temperatures on samples of Champagne wines differing by their sugar content (cone/plate module).

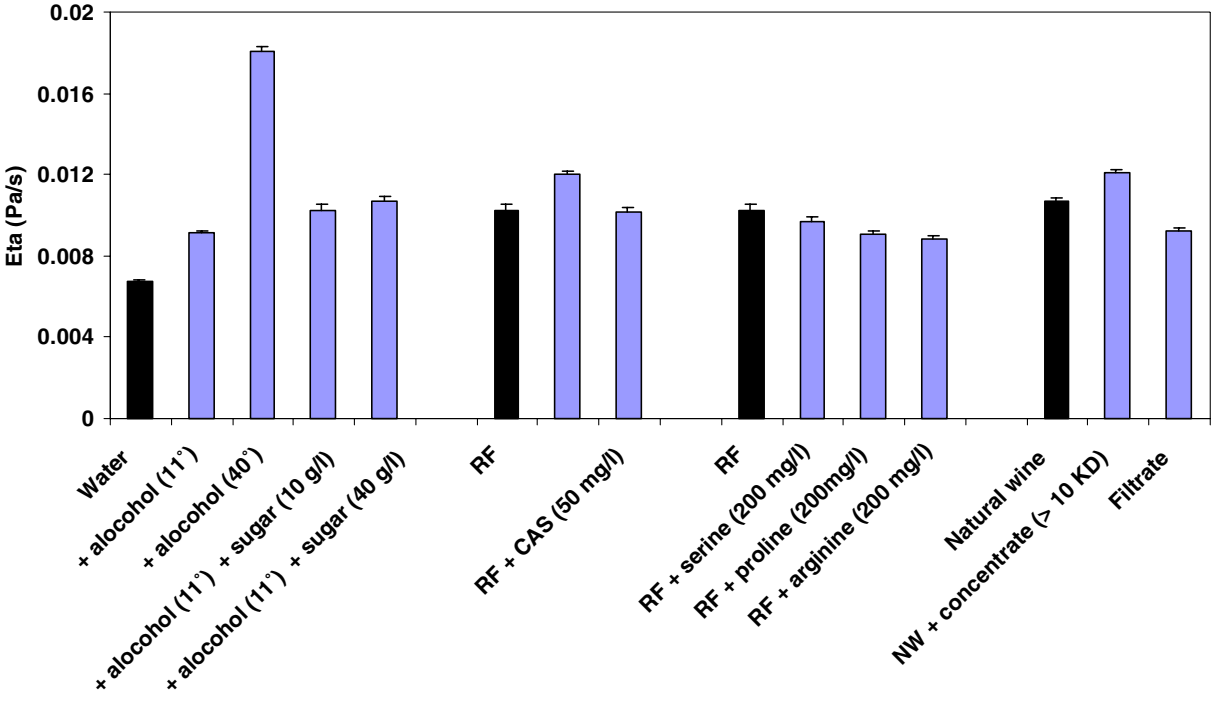

Fig. 14. Viscosity values of studied samples. RF is reference medium: water, alcohol (11°) and sugar (10 g/l).

liquid. There is no correlation between the viscosity of the solution (i.e. its physical properties) and its ability to dissolve carbon dioxide.

With this study, we have underlined the importance of proteins and free amino acids in the solubilisation of carbon dioxide. Proteins, by their tertiary structure, form

cavities that could trap carbon dioxide and facilitate its solvation. Amino-acids, with their polarity, can be involved in weak interaction with carbon dioxide. Checking the formation of pseudo-carbamate (as is reported for ethanolamine) will be the next step in our studies.

In carbonated beverage, the transfer rate of dissolved carbon dioxide from the liquid phase to the gas pocket acts directly on the visual aspect of the beverage through bubble trains. It depends on the gas solubility and also on the concentration of surface-active molecules (proteins, sugar) adsorbed on the bubble wall, making it grow slower or faster. Wines, during elaboration processes, are subject to various enological treatments, such as precipitation of proteins or filtration on membranes, that clarify the wine but diminish the concentration of colloidal material. Our equipment could be a helpful tool for studying the modifications of sparkling and foaming behaviour of wines after such treatments.

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