A method for measuring gas solubility

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Vigneault, C., Panneton, B. and Raghavan, G.S.V. 1993. **A method for measuring gas solubility**. Can. Agric. Eng. **35**:199-206. A simple method for measuring the solubility of pure gases in liquid was developed. The results obtained using this method for CO_2, O_2, and N_2 solubility in distilled water were compared to published data to assess the accuracy of the method. The differences between the measured and published data did not exceed 3% in all cases and the mean difference for each gas did not exceed 0.6%. An error analysis permitted optimization of the testing conditions to increase the precision of the method. The method was used to measure the CO_2, O_2, and N_2 solubility in water of varying quality used in the development of a high pressure water scrubber for controlled atmosphere storage of fruits and vegetables.

Une méthode simple de mesure de la solubilité d'un gaz pur dans l'eau a été mise au point. Les résultats obtenus en utilisant cette méthode pour mesurer la solubilité du CO_2, du O_2, et du N_2 dans l'eau distillée ont été comparés avec ceux cités dans la littérature pour déterminer la précision de cette méthode. Les différences obtenues n'ont pas excédé 3% dans tous les cas. La moyenne des différences des résultats pour chaque gaz n'a pas dépassé 0.6%. Une analyse d'erreur a permis d'optimiser les conditions expérimentales à utiliser pour accroître la précision de cette méthode. Cette méthode a été utilisée pour mesurer la solubilité du CO_2, O_2, et N_2 dans différentes qualités d'eau utilisée dans le développement d'un séparateur de gaz à haute pression pour l'entreposage des fruits et légumes sous atmosphère contrôlée.

INTRODUCTION

Accurate knowledge of equilibrium air-liquid partitioning coefficients, or gas solubility, is essential to a variety of applications such as the design of air stripping towers or water aeration processes involved in environment control processes. The development of a high pressure water scrubber (HPWS) used to modify and control the gas composition in a fruit or vegetable storage room (Vigneault and Raghavan 1991) required the measurement of the solubility of CO_2 , O_2 and N_2 in water.

Current methods for measuring gas solubility usually involve batch air stripping in a bubble column as proposed by Mackay et al. (1979). This technique is popular because it only requires the measurement of relative concentrations so that the preparation of standard curves for determining exact concentrations is unnecessary. This technique is limited since the equilibrium is assumed to be reached between the gas concentration in the liquid and in the bubbles, and the time available for reaching equilibrium is a function of the height of the column.

An EPICS technique (Equilibrium Partitioning in Closed Systems) was developed by Lincoff and Gossett (1984) for gas mixtures. This technique requires the measurement only of relative concentrations of the gas in one phase (gas or liquid). Since this technique uses closed systems which may be allowed an indefinite time to reach equilibrium, it is free of mass transfer rate limitations.

These two techniques require a gas chromatograph or other gas analysis methods to determine the relative gas concentrations in either or both the gas and the liquid phases. The standard method described in ASTM (1990) has the advantage of avoiding utilisation of a gas analysis method but involves hazardous operations, equipment and materials such as mercury. This method is also fairly tedious and requires expensive equipment.

The objectives of this work were: first, to develop a simple and inexpensive method of measurement of pure gas solubility in various water qualities; second, to estimate the precision of this method by comparing the results obtained for the pure gas solubility in distilled water to published data; and finally, to present results obtained when using the new method for measuring the gas solubility of the water used in the development of the HPWS.

THEORY

Gas solubility

In 1803, William Henry observed that the amount of gas that dissolves in liquid at a given temperature is directly proportional to its partial pressure (Gerrard 1980). Henry's Law is expressed by:

$$C_l = \frac{P_{eq}}{H} \qquad (1)$$

where:

C_l = liquid phase solute concentration at equilibrium (mole of gas•L^{-1} of liquid),

H = Henry's constant of the solute (L of liquid•kPa•$mole^{-1}$ of gas), and

P_{eq} = partial pressure of the gas at equilibrium (kPa).

There are theoretical reasons for employing mole fraction, but there are no universally accepted units for expressing the solubility of a gas and this unit is not convenient for general use. Since the solubility of a gas is usually determined by measuring the dissolved volume, rather than the dissolved mass, units of volume of gas per volume of liquid are more frequently used (Glasstone 1946). Equation 2 can be used to transform the C_l to solubility expressed in terms of volume of gas per unit of volume of liquid.

$$S = 22.4\, C_l \qquad (2)$$

where: S = gas solubility ($L_s \bullet L^{-1}$ of liquid).

The unit L_s is the standardized litre of gas, that is the volume occupied by the mass of gas at 0°C (273.15 K) and 101.3 kPa absolute pressure. The conversion from L to L_s is performed using the perfect gas law.

The solubility of gas in liquid is inversely proportional to the temperature. Published data of gas solubility in distilled water (Weast and Astle 1979) for the three gases involved in the separation process of the HPWS are presented as a function of the temperature in Fig. 1. The van't Hoff equation describes the effect of temperature on the gas solubility and shows that the natural logarithm of S varies linearly with the reciprocal of the absolute temperature (Glasstone 1946). Equations 3, 4, and 5 can be used to compute solubilities at various temperatures between 0°C and 30°C and were obtained by applying linear regression to the data in Fig. 1.

$$S_{O_2} = \exp\left[-9.3633 + \frac{1728.7}{T}\right] \qquad R^2 = 0.999 \qquad (3)$$

$$S_{CO_2} = \exp\left[-9.0254 + \frac{2608.8}{T}\right] \qquad R^2 = 0.997 \qquad (4)$$

$$S_{N_2} = \exp\left[-9.4479 + \frac{1550.7}{T}\right] \qquad R^2 = 0.995 \qquad (5)$$

where:

$S_{O_2}, S_{CO_2}, S_{N_2}$ = solubilities of O_2, CO_2, and N_2 respectively ($L_s \bullet L^{-1}$ of liquid),

T = temperature of the liquid (K), and

R = correlation coefficient.

Heat of solution

When a gas dissolves in a liquid, heat may be released or absorbed in the process (Glasstone 1946). The magnitude of this heat exchange per unit mass of gas dissolved varies with the gas concentration in the liquid; it is larger at low gas concentrations. For distilled water at zero gas concentration, 8.94 kJ per gram of gas dissolved is released for CO_2 while solubilization of O_2 and N_2 is done without any heat exchange (Weast and Astle 1979). For CO_2, the significant amount of heat released during solubilization may affect the experimental conditions by varying the system temperature.

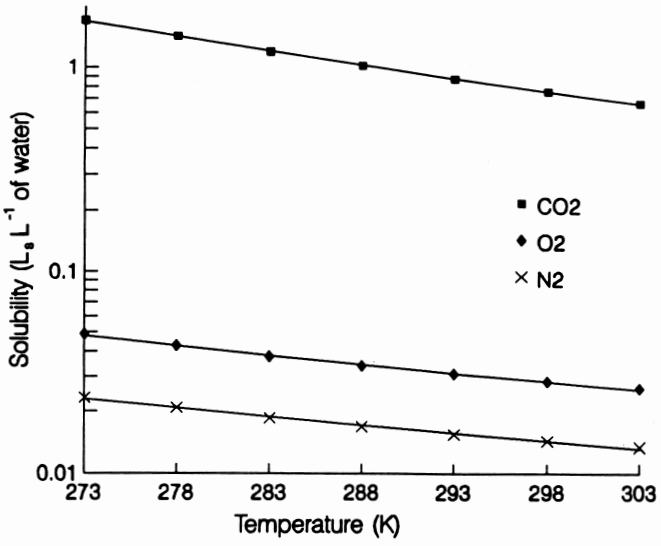

Fig. 1. Gas solubilities of O_2, CO_2 and N_2 in water under standard pressure (101.3 kPa) as a function of temperature (Weast and Astle 1979).

Basic principle

Theoretically, the solubility of a pure gas may be indirectly obtained by measuring the pressure drop caused by gas solubilization in a pressurized closed container. A gas solubility measuring method was developed based on this principle. Initially, the container is filled with a known quantity of degasified liquid and pure gas. While temperature is kept constant, the system evolves to an equilibrium state where the system pressure is recorded. The difference between the initial and equilibrium pressures is used to calculate the mass of gas dissolved using the perfect gas law.

MATERIAL AND METHODS

Experimental apparatus

The apparatus developed consisted of an airtight cylindrical container made from a PVC tube, 700 mm long, 100 mm inside diameter and having a net volumetric capacity of 5600 mL (Fig. 2). A thermocouple having a 0.5°C precision was installed to measure the temperature of the gas approximately 25 mm below the top of the cylinder. A 0 to 1400 ± 3.5 kPa pressure gauge and a self shut-off coupling valve were installed at the same end of the cylinder to allow gas purging and pressure measurement. Two valves (A and B in Fig. 3) isolated the pressure gauge and the coupling valve when necessary. At the opposite end of the cylinder, two valves (C and D) were installed to fill and empty the cylinder with water. An S-shape water trap was installed at the bottom of the valve D to avoid any air infiltration while emptying the

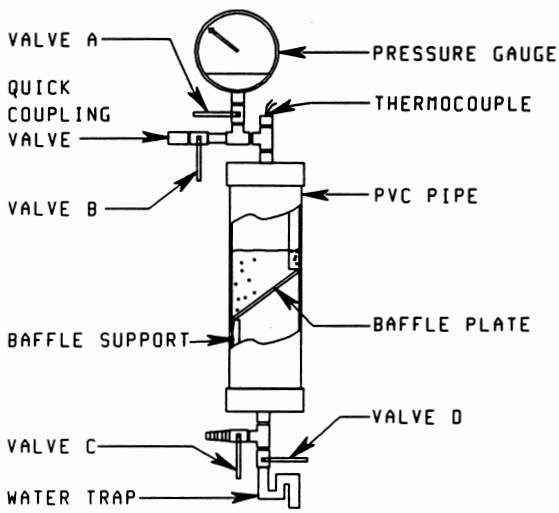

Fig. 2. Schematic for the pressurized vessel used for the measurement of the gas solubility in water.

cylinder. A baffle plate was installed in the centre of the cylinder. The baffle plate was maintained in a 45° position by two supports. This baffle forced a better mixing of water and air when reversing the cylinder top and bottom. The 180° rotation of the cylinder was allowed by mounting the apparatus on an horizontal shaft positioned at the centre of gravity of the apparatus.

Structural resistance test procedure

A pressure test was conducted to determine the volumetric deformation of the apparatus due to the internal pressure. This test consisted in lowering the apparatus into a water container 150 mm in diameter and 1250 mm high. The apparatus was firmly held in place leaving only the top part of the apparatus exposed to air, i.e. the pressure gauge and the two valves A and B. The water level was precisely marked using a needle tip touching the water surface. The apparatus was pressurized at five different levels varying from 200 kPa to 1050 kPa. Some water was removed to readjust the water level to the needle tip level. The volume of water removed was measured using a 10 ± 0.1 mL syringe. This volume of water corresponded to the increase in the volume of the apparatus when submitted to pressure. The series of tests were replicated three times. At the end of each series of tests the pressure was released and the decrease in the volume of the apparatus was measured to detect any permanent volumetric deformation.

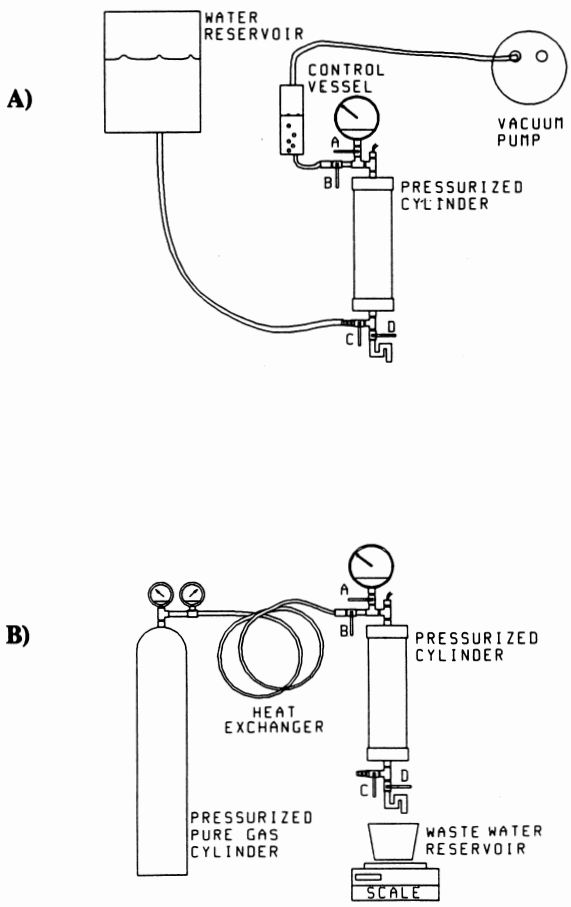

Fig. 3. Schematic view of the gas solubility measurement system; a) filling and degasification procedures, b) pressurization procedure.

Solubility test procedure

The procedure established for the measurement of the gas solubility in distilled water may be divided into two phases. First, a water reservoir was positioned at a higher level than the apparatus (Fig. 3). This reservoir was connected to the valve C to fill the cylinder by gravity exhausting the air by the valve B. Water was added until the control vessel connected to the valve B and positioned at a higher level than the apparatus was half filled (Fig. 3A). After filling the apparatus, the water was degasified using a vacuum pump operated for 4 minutes at an absolute pressure of 11 kPa. Then, the apparatus was partially emptied. The water removed was weighed using a 0 to 60 kg scale with ±1.0 g. The water was replaced by the pure gas to be tested by connecting the valve B to a 7 MPa pressurized gas cylinder (Fig. 3B). A pressure regulator installed on the pure gas cylinder was used to ensure the gas pressure in the apparatus does not exceed 1 MPa. A heat exchanger consisting of a 2.5 m long copper tube of 6.4 mm O.D. was installed between the pressure regulator and the valve B to allow the gas to equilibrate with the ambient temperature before entering the apparatus. The volume of water replaced by pure gas was approximately 2500, 600, and 600 mL while testing respectively the CO_2, O_2, and N_2.

After the water was replaced by gas, the pressure regulator on the pressurized pure gas cylinder was rapidly adjusted to approximately 775 kPa to force more gas to enter into the cylinder. The valve B was then closed and the time, the temperature and the pressure inside the cylinder were measured to establish the initial condition of the solubilization process. It was very important that gas filling was rapid to minimize the gas solubilization and gas temperature variations before reading the initial pressure and temperature.

The second phase of the test consisted of forcing the solubilization process by rotating the apparatus every minute, forcing the gas and water to mix together. The pressure was monitored every two minutes. When the pressure had remained the same for three consecutive readings, the gas and water were considered at equilibrium and the test was terminated. The cylinder was emptied and the water it contained was weighed. The temperature of the water was measured using a thermometer having a ±0.5°C precision before filling the apparatus and immediately after the test. Since there was very little variation in the water temperature through the duration of the test, the mean of these two temperatures was used as the temperature of the test.

The relative solubility of the gas was defined as the ratio between the measured solubility and the published solubility of the gas for the temperature of the test. It was calculated using Eqs. 6 and 7.

$$S_r = \frac{V_{gs}}{V_l S_{pub}} \qquad (6)$$

$$V_{gs} = V_{is} - V_{es} \quad (7)$$

where:

S_r = relative solubility of the gas at the temperature of the liquid,

S_{pub} = published solubility of the gas at the temperature of the test ($L_s \bullet L^{-1}$ of liquid) (Eqs. 3, 4 and 5),

V_l = volume of liquid contained in the apparatus during the test (L),

V_{gs} = volume of gas solubilized in the liquid (L_s),

V_{is} = initial volume of gas (L_s), and

V_{es} = volume of the gas remaining in the apparatus when equilibrium had been reached (L_s).

The solubility tests were conducted with both distilled water and "system" water which had passed through the HPWS system several times. The system water samples were collected during a series of experiments on the HPWS. During these experiments, samples were collected periodically and each sample was analyzed separately. These analyses were used to monitor the variability in the solubility of system water. The quality of the system water was quite variable since some tap water had to be added to compensate for water losses during the test of the HPWS. The tests using the system water were conducted at ambient temperature which varied from 22°C to 24°C. The tests using distilled water were conducted at both ambient temperature and at cold temperature which varied from 2°C to 6°C. The cold temperature tests were conducted by relocating the entire system into a controlled temperature room maintained at about 4°C. Each test was replicated four times.

Temperature test procedure

Since compressed gases are used in the gas solubility measuring method, the impact of system cooling due to gas expansion must be considered. When decompressing a gas, a cooling effect is produced (H) due to a gas expanding to equilibrate with its new conditions. This H may produce a significant decrease in temperature. Using the mean conditions for the test, which are initial pressure of 6.65 MPa, release pressure of 0.86 MPa and constant temperature of 295 K; the theoretical H of CO_2, O_2, and N_2 were evaluated at 220 $J \bullet g^{-1}$, 15 $J \bullet g^{-1}$, 16 $J \bullet g^{-1}$, respectively (ASHRAE 1981).

A temperature test was conducted to evaluate the efficiency of the heat exchanger (Fig. 3B) in supplying the heat to compensate for the cooling due to gas expansion and to evaluate the importance of the temperature increase due to gas solubilization at the beginning of the test. The test consisted of filling the apparatus the same way as the solubility test using approximately 600 mL, 2600 mL and 5600 mL (5600 mL is the total volume of the apparatus) of CO_2 at 775 kPa and monitoring the temperature of the gas inside the apparatus at 5 s intervals. Tests using O_2 or N_2 were not conducted since preliminary trials with these gases showed no detectable temperature variation, and the temperature decrease for O_2 and N_2 should be only about 7% of that for CO_2.

Error analysis

An error analysis is presented to assess the relative importance of the accuracy in the measurements of pressure, volume, and temperature on the resulting solubility determination. Further, the results of the error analysis will be used to specify a ratio of the volume of liquid to the volume of the apparatus where the error is minimized.

From the basic measurements, the solubility is computed as:

$$S = \frac{(V_a - V_l)}{V_l} \frac{T_s}{T} \frac{(P_o - P_{eq})}{P_s} \quad (8)$$

where:

V_a = volume of the apparatus (corrected for expansion) (L),

V_l = volume of liquid in the apparatus (L),

T_s = standard temperature (273 K),

T = test temperature (K),

P_o = initial pressure (kPa),

P_{eq} = equilibrium pressure at the end of the test (kPa), and

P_s = standard pressure (101.3 kPa).

To first order, the maximum absolute error $|\Delta S|$ on S is obtained using:

$$|\Delta S| = |\Delta S_v| + |\Delta S_p| + |\Delta S_t| \quad (9a)$$

$$|\Delta S_v| = \frac{\partial S}{\partial V_a}\bigg|_{S_o} |\Delta V_a| + \frac{\partial S}{\partial V_l}\bigg|_{S_o} |\Delta V_l| \quad (9b)$$

$$|\Delta S_p| = \frac{\partial S}{\partial P_o}\bigg|_{S_o} |\Delta P_o| + \frac{\partial S}{\partial P_{eq}}\bigg|_{S_o} |\Delta P_{eq}| \quad (9c)$$

$$|\Delta S_t| = \frac{\partial S}{\partial T}\bigg|_{S_o} |\Delta T| \quad (9d)$$

where:

ΔS_v = maximum absolute error due to volume error,

ΔS_p = maximum absolute error due to pressure error,

ΔS_t = maximum absolute error due to temperature error, and

S_0 = true solubility (L_s of gas$\bullet L^{-1}$ of water).

Expanding Eq. 9b gives:

$$\frac{|\Delta S_v|}{S} = \frac{1}{1-\alpha}\left[\frac{|\Delta V_a|}{V_a} + \frac{|\Delta V_l|}{V_a}\frac{1}{\alpha}\right] \quad (10)$$

where: $\alpha = \frac{V_l}{V_a}$

Noting that V_a and V_l are measured by the same method, it follows that $|\Delta V_a| = |\Delta V_l|$, and

$$\frac{|\Delta S_v|}{S} = \frac{1}{1-\alpha}\left[1 + \frac{1}{\alpha}\right]\frac{|\Delta V|}{V_a} = \frac{|\Delta V|}{V_a} f_v(\alpha) \quad (11)$$

Taking the derivative in Eq. 9c yields:

$$\frac{|\Delta S_p|}{S} = \frac{2|\Delta P|}{(P_o - P_{eq})}$$

$$= 2\frac{T_s}{T}\frac{|\Delta P|}{P_s}\frac{1}{S}\left[\frac{1-\alpha}{\alpha}\right]$$

$$= K\frac{|\Delta P|}{P_s} f_p(\alpha) \qquad (12)$$

where: $|\Delta P_o| = |\Delta P_{eq}|$ has been assumed by the same argument as for the equality of volume errors. Finally, the error on S due to temperature is:

$$\frac{|\Delta S_t|}{S} = \frac{|\Delta T|}{T} \qquad (13)$$

Assembling Eqs. 11, 12, and 13 gives:

$$\frac{|\Delta S|}{S} = \frac{|\Delta V|}{V_a} f_v(\alpha) + K\frac{|\Delta P|}{P_s} f_p(\alpha) + \frac{|\Delta T|}{T} \qquad (14)$$

In Eq. 14, ΔV, V_a, and P_s are fixed by design and convention, K and T vary from test to test, while α can be chosen to suit any particular test. For the test conditions used here, the fixed terms in Eq. 14 are: $\frac{|\Delta V|}{V_a} = 0.00071$ and $\frac{|\Delta P|}{P_s} = 0.035$; and for T = 20 °C: $K = \frac{1.86}{S}$ and $\frac{|\Delta T|}{T} = 0.0017$. Inserting these values in Eq. 14 and taking S = 6.9 $L_s \bullet L^{-1}$, typical of CO_2 solubility at 770 kPa yields:

$$\frac{|\Delta S|}{S} = 0.00071 f_v(\alpha) + 0.0094 f_p(\alpha) + 0.0017 \qquad (15)$$

Equation 15 is plotted in Fig. 4, which shows the relative contribution of the various terms to the total error. The contribution of the error on temperature is small and constant. At low α, the error on pressure dominates. The pressure error decreases with increasing α, and is smaller than the error on volume at high values of α. The total error has a minimum at α = 0.73, which means that the test should be performed using 1680 mL of CO_2 in the present test apparatus to maximize the precision of the results.

Taking the derivative of Eq. 14, the minimum in the curve is found to be:

$$\alpha_{min} = -\frac{a_1 S + a_2}{a_1 S - a_2} + \frac{\sqrt{2}}{a_1 S - a_2}\sqrt{a_1^2 S^2 + a_1 a_2 S} \qquad (16)$$

where: $a_1 = \frac{|\Delta V|}{V_a}$ and $a_2 = 2\frac{T_r}{T}\frac{|\Delta P|}{P_s}$

Equation 16 is plotted on Fig. 5 for the same conditions as Fig. 4. Also shown on Fig. 5 is the error associated with α_{min} for solubilities varying from 0 to 10. Figure 5 can be used to optimize α. It shows that increasing solubility reduces the error. Henry's law states that solubility increases with pressure. Therefore, increasing pressure reduces the error.

RESULTS AND DISCUSSION

Structural resistance

The volumetric deformation caused by internal pressure is presented in Fig. 6. The volumetric deformation followed a straight line when plotted against the applied pressure. This means that the deformation occurred in the elastic range of the material used. Furthermore, the water added to adjust the water level when the pressure was released at the end of each series of test was equal to the sum of the volume of water removed at each increase of the pressure. This means that the apparatus returned to its initial volume when the pressure was removed.

Equation 17 represents the volumetric deformation of the

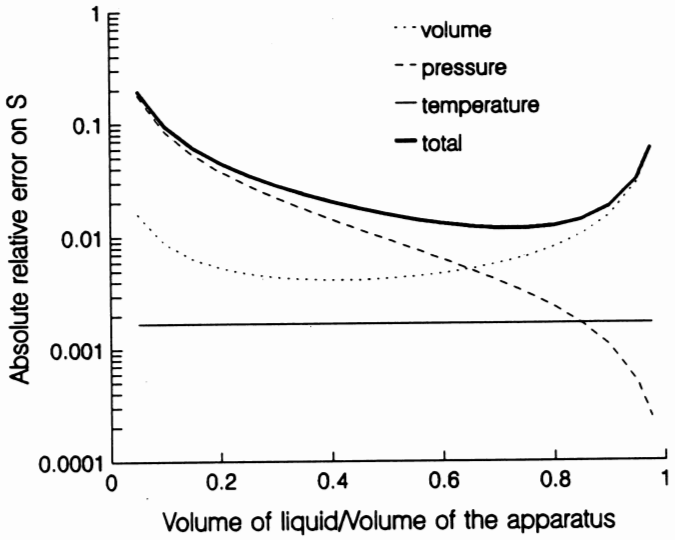

Fig. 4. Relative contribution of the various terms to the total error.

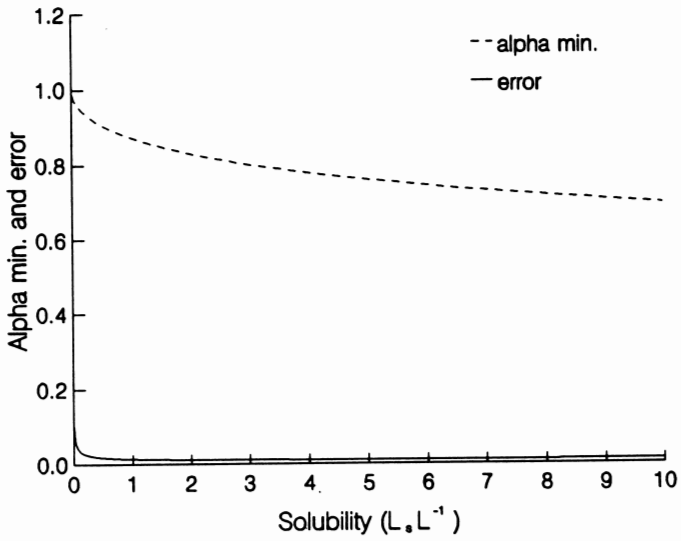

Fig. 5. Error associated with α_{min} for solubilities.

apparatus as a function of the pressure applied.

$$\Delta V = 0.0373\,P \qquad R^2 = 0.997 \qquad (17)$$

where:

P = pressure applied (kPa), and

ΔV = volume increase (mL).

The water was introduced while no pressure was applied. Assuming the compressibility of water is negligible, the volume increase caused by the pressure was added to the volume of the gas contained in the apparatus in the calculation of the solubility of the gas.

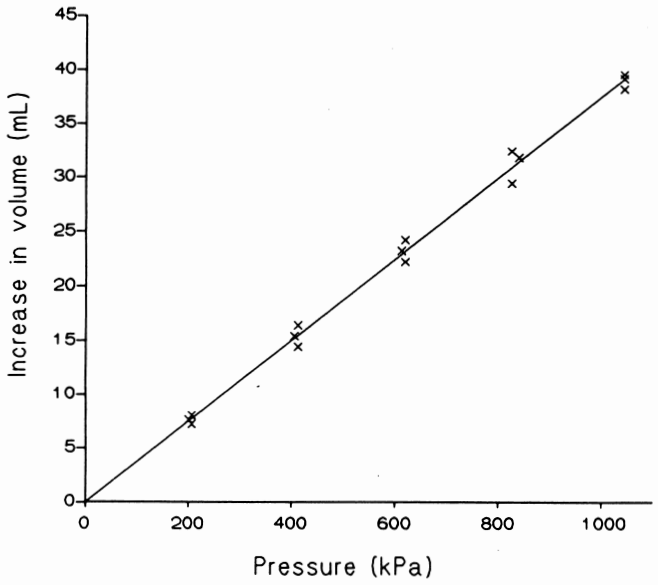

Fig. 6. Increase in the volume of the apparatus with increasing pressure.

Temperature history

The variation of the gas temperature in time is shown on Fig. 7 for each of the three volumes of gas tested. As it can be seen, the temperature decreases very quickly when the gas is introduced to pressurize the apparatus. As expected, the cooling effect increased as the volume of gas increased. The temperature decrease was fairly small (0.3°C) when using 600 mL of gas and would result in an error of 0.1% in the calculation of the initial volume of gas if neglected. The temperature decrease of 1.4°C when using 2600 mL of gas was much more important but still represents an error of 0.5% in the calculation of the initial volume of gas if neglected.

The gas temperature increase due to gas solubilization was 1.7°C and 2.9°C when using 600 mL and 2600 mL of CO_2, respectively. To avoid any error in the calculation of the initial volume of gas, it is clear that the initial condition should be measured within about 5 s after the pressurization of the apparatus. For a 600 mL gas sample, using the water temperature instead of the actual gas temperature would result in an error in the calculation of the gas solubility of

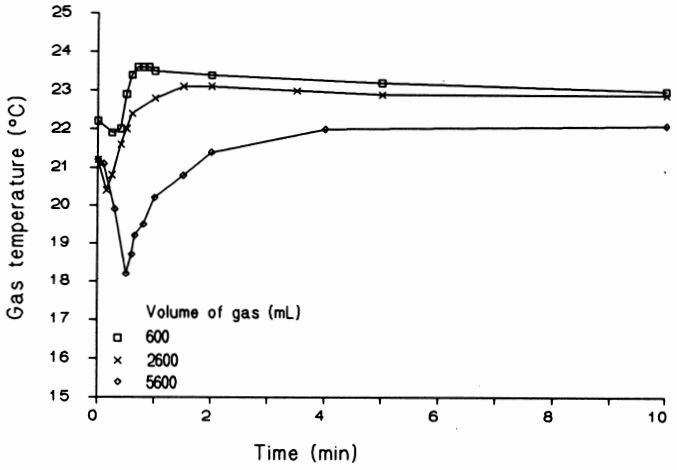

Fig. 7. General variation of temperature inside the apparatus over time.

approximately of 0.1%. It is important that pressure is measured very quickly (within 5 s) after the apparatus is pressurized.

Rapid temperature increase was not encountered when using 5600 mL of gas. This is explained by the absence of water in the apparatus, and thus there was no solubilization. The slow temperature increase was due to heat exchange through the apparatus wall.

Solubility

The pressure variation in time is shown in Fig. 8. The test duration did not exceed 30 min in all cases. The precision in reading the initial pressure had a large impact on the solubility measurement accuracy. Experience demonstrated that the difficulty of getting good readings was due to the rapid drop in pressure immediately after closing the valve B after gas pressurization as can be seen in Fig. 8. After a few tests, operators had no problem obtaining good readings within the

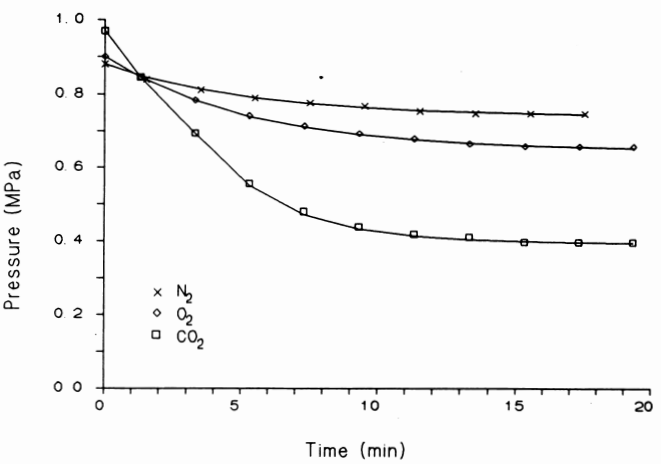

Fig. 8. General variation of pressure inside the apparatus over time.

5 s that followed the closure of the valve B, resulting in the precision shown here.

The relative solubility presented in Table I varied between 0.977 and 1.030. The mean and the standard deviation were 1.004 ± 0.004 for CO_2, 1.006 ± 0.012 for O_2 and 0.997 ± 0.016 for N_2. The lower value obtained with the N_2 solubility was expected since the tests were begun by degasifying the water at an absolute pressure of 11 kPa. At this pressure, some gases are still dissolved. At 23 °C, the mean temperature at which the tests were conducted, the vapour pressure of water is 2.8 kPa (ASHRAE 1981). The gas dissolved in distilled water should equilibrate with the remaining pressure, 8.2 kPa. This should result in a systematic underestimation of the CO_2 , O_2 and N_2 solubilities of 0%, 0.2%, 0.8% corresponding to the equilibrium pressure of 400 kPa, 690 kPa, and 750 kPa, respectively. The variability in the result was higher for the O_2 and N_2 compared to the CO_2 result. This is explained by the error analysis results. The pressure drop for the test done using O_2 and N_2 was much smaller even if the volume of gas was about one quarter. The precision of the reading was about 2.3% of the pressure drop for the O_2 and N_2 while it was about 0.8% in the case of the CO_2. However the precision obtained was sufficient to evaluate the solubilities for the HPWS assessment.

Table II shows the relative solubility for the system water at ambient temperature. As can be seen, the relative gas solubilities are smaller than 1. This reduction of the solubilities was expected since the solubility of gases decreases with increasing contaminants in the water. The larger variability of these results is likely due to the variability of the quality of the system water. In fact, it was suggested that the quality of the system water continuously changed with the time. It was, indeed, the reason why the monitoring of the solubility of the gas was recommended for the development of the HPWS.

CONCLUSION

A simple measurement method of the solubility of pure gases in water was developed. The importance of the rapidity in the reading of the pressure at the initial conditions was demonstrated. The temperature monitoring during the test may be neglected since the variations were not important and did not affect significantly the precision in the calculation of the initial volume of gas. The results obtained using this method to measure the solubility of the CO_2, O_2 and N_2 in distilled water were compared to published data. Measured and published data agreed within 3% in all cases and the mean of the deviation for each gas did not exceed 0.6%. A more precise pressure gauge may be used when greater precision in the gas

Table I: Comparison between the measured values of the solubility of distilled water at both ambient and cold temperatures with the solubility published in the literature

Temperature	Run #	Relative gas solubilities (measured/published)		
		CO_2	O_2	N_2
Ambient	1	1.006	1.005	1.002
	2	0.996	1.030	1.017
	3	1.004	0.998	0.979
	4	1.006	1.007	0.999
Cold	1	1.006	0.999	1.002
	2	1.010	0.987	0.977
	3	1.003	1.011	1.012
	4	1.004	1.017	0.973
Average ± σ		1.004 ± 0.004	1.006 ± 0.012	0.997 ± 0.016

Table II: Comparison between the measured values of the solubility of used water at ambient temperature and the values published in the literature for the solubility of distilled water

Run #	Relative gas solubilities (measured/published)		
	CO_2	O_2	N_2
1	0.881	0.829	0.929
2	0.930	0.840	0.921
3	0.870	0.893	0.842
4	0.878	0.888	0.921
Average ± σ	0.890 ± 0.024	0.863 ± 0.028	0.903 ± 0.036

solubility measurement is required. The volume of gas may also be optimized to increase the precision in the measurement of gas solubility. This simple method permitted the measurement of the solubility of the CO_2, O_2, and N_2 in water of various purities used in the development of a high pressure water scrubber for controlled atmosphere storage of fruits and vegetables.

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