KVASNÝ PRŮMYSL

Kvasny prumysl (2023) 69: 771–776
https://doi.org/10.18832/kp2023.69.771

Detection of the internal pressure in beer cans by measuring the force-displacement curves

Petr Gabriel[1*], Robert Král[1], Roman Beneš[2]

[1] *Faculty of Mathematics and Physics, Charles University in Prague, Ke Karlovu 3, 121 16 Prague, Czech Republic*

2 *Research Institute of Brewing and Malting, Lípová 511/15, 120 00 Prague, Czech Republic*

* *corresponding author: petr.gabriel@matfyz.cuni.cz*

Abstract

Microbiological contamination of beer is in many cases manifested by the production of CO_2 and its increase in the concentration. An increase in the concentration of CO_2 in a closed package leads to an increase of internal pressure, which can cause destruction of a package with dangerous consequences. This case study aimed to verify the applicability of force-displacement measurement for non-destructive monitoring of the internal pressure in beer cans.

Keywords: beer; can; microbial contamination; force-displacement curve

1 Introduction

Microbiological contamination of beer can be not only a health risk for consumers, but also a frequent cause of deterioration of its sensory properties. Contamination is normally verified by standard microbiological methods after opening the packaging and taking a sample (Matoulkova and Kubizniakova, 2014). When the sample is taken, the package is broken and the sample is thus invalidated. Non-destructive optical methods can also be used to detect contamination of beer in transparent packaging, the increase in microorganism concentration can be detected, for example, by elastic light scattering (turbidity measurement). Optical methods are non-destructive and enable long-term monitoring of the sample without its destruction.

Cans are one of the most commonly used beer packaging. In contrast to transparent packaging, in the case of cans, it is not possible to use optical measurement to continuously detect microbiological contamination without opening the sample. Microbiological contamination of beer is manifested in the majority of cases by the production of CO_2 or another gas, e.g. H_2S by the genus *Pectinatus* (Matoulkova and Kubizniakova, 2014), and an increase in its concentration in packaging (Štulíková et al., 2021). An increase in the CO_2 concentration is associated with a pressure increase according to Henry's law (Henry, 1803) which can cause destruction of the package (Meier-Dörnberg et al., 2017). The destruction of the package can be dangerous for customers. Hence the main focus of this paper is to non-destructively measure the internal pressure in beer cans.

Pressure increase in beer in general can cause an increase of internal pressure on the wall of the can. If external pressure is applied to the wall of the can, its displacement occurs, the size of which depends not only on the properties of the wall but also on the internal pressure imposed on the wall. By measuring the dependence of the displacement of the can wall on the developed force (force-displacement curve), we are able to collect information about the internal pressure of the can. We used standard equipment to measure force-displacement curves. The aim of the presented case study is to verify the applicability of force-displacement curves to monitoring the internal pressure in beer cans.

Research Institute of Brewing and Malting
Published online: 15 August 2023

2 Materials and methods

Materials

Sodium bicarbonate NaH_2CO_3 (bioreagent) and citric acid monohydrate for analysis (99%) were purchase from Sigma-Aldrich (Germany), deionized water was prepared using Aqual 35 apparatus (Aqual, s.r.o., Czech Republic) with conductivity less than 0.2 µS/cm. Kegl and 500ml B64 cans 500ml wide mouth (full aperture) silver aluminium disposable cans were purchased from Kegland (Austria) (Kegland, 2023).

Solution with defined CO_2 concentration

Solution with defined CO_2 concentration was prepared according to the following reaction

$$2\ NaHCO_3 + C_6H_8O_7 = 2\ CO_2 + 2\ H_2O + Na_2HC_6H_5O_7$$

Molecular weight of sodium bicarbonate is 84 g/mol, molecular weight of CO_2 is 44 g/mol, molecular weight of citric acid is 192 g/mol. One molecule of sodium bicarbonate creates one molecule of CO_2 after the release of sodium and water. Citric acid is able to bind up to 3 sodium atoms depending on the pH of the solution. It is obvious that to create 1 g of CO_2, it was necessary to use 1.90 g of sodium bicarbonate which reacted with less than 2.18 g of citric acid. In order to have an excess of citric acid during the reaction, we prepared a citric acid solution with a concentration of 21.8 g/l for all the samples. This solution contains enough acid to generate CO_2 up to the concentration of 10 g/l CO_2.

Preparation of beer cans with a defined CO_2 concentration

Cannular Compact semi-auto canning machine KL15769 was used for sample cans preparation. Aluminium cans intended for use on KL15769 (Kegland, 2023) were used to prepare the samples. The cans were filled with 0.5 l of citric acid solution with a concentration of 21.8 g/l. A defined amount of sodium bicarbonate was weighed in a plastic weighing bowl. The bowl was placed on the surface of the solution in the can so that the citric acid did not come into contact with the sodium bicarbonate. The can was then closed with a cap in the Cannular Compact semi-auto canning machine KL15769. After closing the can, the can was turned upside down, sodium bicarbonate came into contact with citric acid and the required amount of CO_2 was produced.

0.95 g of sodium bicarbonate was weighed into 0.5 l solution to obtain a final concentration of 1 g/l of CO_2 in the can. This corresponds to the amount of 1.90 g of sodium bicarbonate per 1 liter of solution. For higher CO_2 concentrations, the corresponding amount of sodium bicarbonate was used. Cans with CO_2 concentrations from 0 g/l to 7 g/l with a step of 1 g/l CO_2 were prepared.

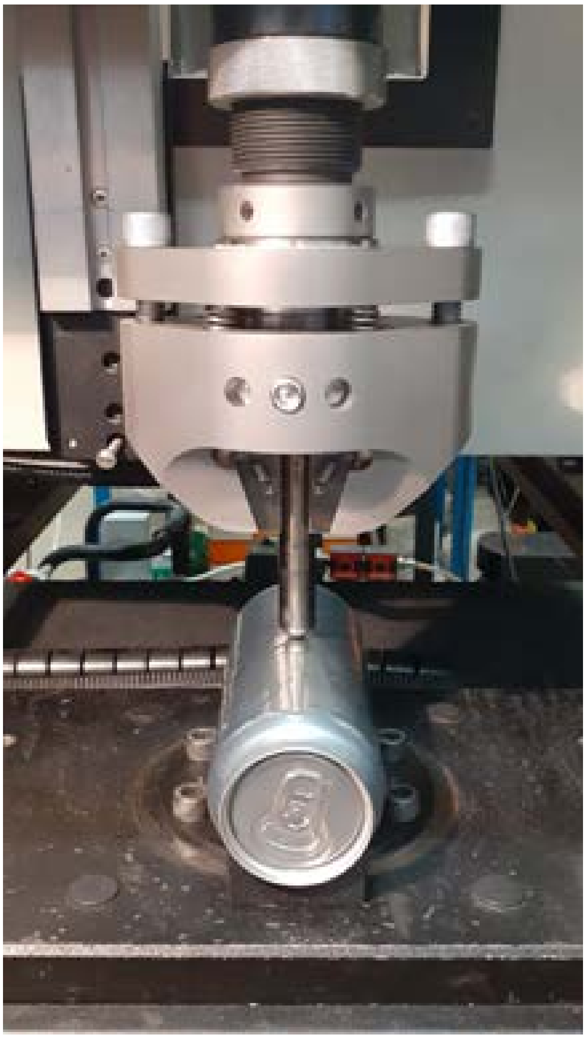

Figure 1 *Instron apparatus with sample can*

Measurement of CO_2 concentration in prepared cans

After measuring the force-displacement curves, the CO_2 concentration in the cans was measured on the Carbo QC apparatus from Anton Paar Austria according to the MEBAK 2.26.1.5 methodology (MEBAK, 2023). The measurement on the Carbo QL apparatus is contact and is associated with opening and subsequent deterioration of the sample. For all samples, the correctness of the prepared CO_2 concentration was verified with an accuracy higher than 1% of the value.

Measurement of force-displacement curves

Instron universal testing machine 5882 was used for the measurement of force-displacement curves. A pad, in which the can was placed, was fixed to the frame of the apparatus with four screws. The pad was specially designed for the measurement and printed on a 3D printer. The can was placed on the base in a horizontal position (the axis of the can is horizontal) and rested on the bed with a cylindrical surface in the entire length (see Figure 1). The crosshead of the apparatus, which exerts pressure on the sample at a defined displacement, was equipped with a hemispherical punch with a diameter of 15.5 mm. The punch deflected the can in half of its length perpendicular to the axis and to the surface of the can. The diameter of the punch is large enough to prevent the wall of the can from being destroyed when the force on the can increases. The measurement of the force-displacement curves was carried out with a strain rate of 0.1 mm/min. The force applied to the sample and the displacement of the punch were recorded at a time interval of 0.1 s. The measurement was ceased when the force of 10 N was applied or the can was bent by 0.6 mm, whichever occurred first. The measurement time was from 4 minutes for a can with the highest pressure to 10 minutes for a can without pressure. To verify the repeatability of the measurement, cans with a CO_2 concentration of 1 g/l and 5 g/l were measured three times with the same position of the can (the punch pressed the can in the same spot). In order to find out the effect of the can wall on the measurement, all the cans were measured three times, between the measurements the can was rotated around the axis by 120 ° so that the punch deformed the can in a different place during each measurement.

3 Results and discussion

Samples with a CO_2 concentration from 0 g/l to 7 g/l were prepared according to the instructions in the methods. Used aluminium cans have declared maximum safe pressure of 690 kPa (6.9 atm) (Kegland, 2023). Cans pressurized with dissolved CO_2 were used for the measurements, as this was the simplest way to create samples with defined internal pressure.

At room temperature of around 25 °C, with a CO_2 content of 7 g/l, the pressure in a can reaches 450 kPa (4.5 atm). With increasing temperature, the pressure in a closed can increases rapidly and the maximum safe pressure of 690 kPa is reached already at 39 °C. The standard CO_2 concentration in beer is in the range of 4.5 g/l to 5.5 g/l. Therefore, from the safety point of view, during preparation, measurement and storage of the sample, the maximum CO_2 concentration of 7 g/l was chosen, which is higher than the maximum concentration used in the carbonation of beers.

Force-displacement curves were measured on prepared cans with a CO_2 concentration from 0 g/l to 7 g/l on the Instron apparatus. Before the measurement, the cans were left to equilibrate for 24 hours at room temperature of 22±1 °C. Figure 2 shows the measured force-displacement curves.

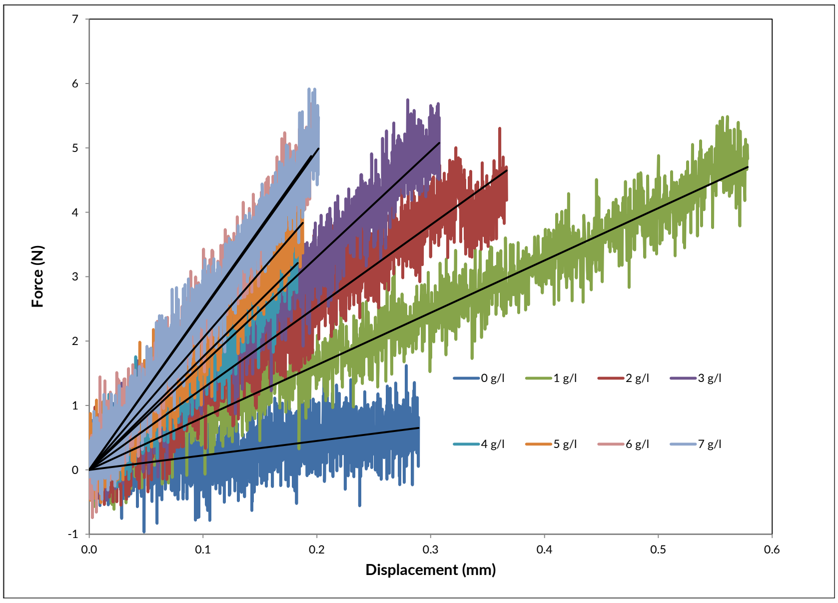

Figure 2 *Force-displacement curves measured on cans with CO_2 concentration from 0 g/l to 7 g/l*

In all the curves, there is an obvious linear increase in force associated with the displacement of the can wall, the curves can be fitted with linear dependencies with great accuracy. The slope of measured curves corresponds to the internal pressure in the can. As the concentration of CO_2 increases and the corresponding pressure in the can increases, the slope of the interpolated line of the dependence of force on the displacement (dForce/dDisplacement (N/mm)) increases. The higher the internal pressure in the can, the more force must be applied to carry out the same displacement of the can wall. For each measured displacement curve, the slope of the dependence of force on displacement dForce/dDisplacement (N/mm) was calculated by the method of least squares.

Cans with concentrations of CO_2 1 g/l and 5 g/l were measured three times with the same position of a can. The mean value and standard deviation were calculated of the slopes of the measured curves (dForce/dDisplacement (N/mm). Results of dForce/dDisplacement values were 8.13±0.40 N/mm for the can with a CO_2 concentration of 1 g/l and 20.44±0.65 N/mm for the can with a CO_2 concentration of 5 g/l. Repeatability of a dForce/dDisplacement (N/mm) measurement is 3–5%. When using maximum force of 10 N at a maximum deflection of the can wall of 0.6 mm and when using a punch with a diameter of 15.5 mm, the can wall does not deform irreversibly and the measurements are repeatable.

Comparing the standard error of dForce/dDisplacement (N/mm) values obtained by a repeated measurement at the same position of the can (3–5%) with the standard error of values measured when turning the can (8–10%) shows great influence of the can wall on the measurement results.

The force-displacement test responds to internal pressure in the can. The pressure in the can depends on the concentration of dissolved CO_2 and increases significantly with increasing temperature (Speers and MacIntosh, 2013). At the usual concentration of CO_2 in pilsner-type beer of 5 g/l (Kosin et al., 2018), the pressure in the can increases from 56 kPa (0.56 atm) at 0 °C to 209 kPa (2.09 atm) at 20 °C, thus more than four times. It is therefore important to maintain defined and constant temperature of the sample during the measurement. A change in temperature by 1 °C causes a change in the internal pressure in the can from 3 to 5%. dForce/dDisplacement (N/mm) results obtained from the force-displacement curves are more suitable to be displayed as a function of the internal pressure in the can rather than the CO_2 concentration. For all samples, the internal pressure in the can was calculated from the CO_2 concentration and the temperature of the can during the measurement (22±1 °C). The pressure was calculated according to Henry's law with the parameters determined by the National Institute for Standards and Technology of U.S. Department of Commerce (NIST) for aqueous solutions of CO_2 (NIST, 2023). The effect of acid was negligible.

Figure 3 shows the dependence of the dForce/dDisplacement values determined from the force-displacement tests as a function of the internal pressure in the can. Mean values and standard deviations were calculated from three measurements performed on each can (between the measurements the can was rotated around the axis by 120°).

A dForce/dDisplacement value (N/mm) increases with the pressure in the sample. When the pressure in the can increases from 0 kPa, there is a rapid increase in the value of dForce/dDisplacement (N/mm). From the pressure of 120 kPa, the increase of dForce/dDisplacement (N/mm) value is more gradual up to the maximum measured pressure of 440 kPa (4.4 atm). The standard deviation of dForce/dDisplacement (N/mm) values is in the range of 8–10% of the value for all measured samples, with the exception of the can with a CO_2 concentration of 0 g/l and pressure of 0 kPa, where the dForce/dDisplacement value is low and standard deviation is 22%. The value dForce/dDisplacement (N/mm) is non-zero even if the internal pressure of the can is zero. This effect is caused by the resistance of the can wall, which depends on the material of the can and the thickness of its wall. For the can without CO_2, the value of dForce/dDisplacement is 2.24±0.49 N/mm. The resistance of the can wall affects the measurement results of all other cans with non-zero CO_2 concentration.

Starting from 120 kPa (corresponds to 2 g/l of dissolved CO_2), the effect of the wall resistance is constant and the dependence between the dForce/dDisplacement and pressure can be fitted to a linear model. The correlation coefficient is R = 0.983 and slope 0.0394 N/mm/kPa. The measurement points scatter within the repeatability of the measurement. To ensure there are no additional effects causing a deviation from the linear model, the measurement must be done with higher repeat-

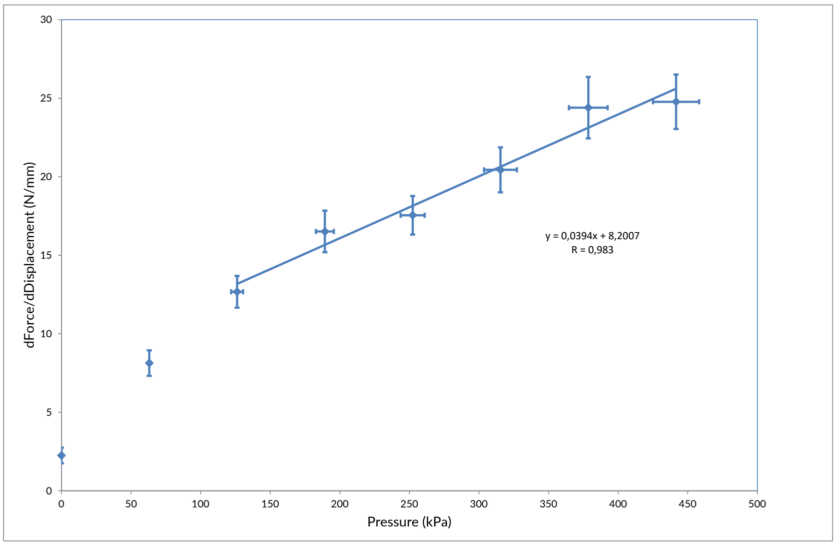

Figure 3 *Dependence of the slope of the force-displacement curve (dForce/dDisplacement(N/mm)) on the pressure in the can.*

ability. For this reason, new measurement apparatus should be used. The standard error of the pressure value on the x axis is around 5% and is mainly due to the error of the sample temperature 1 °C.

Figure 4 shows the dependence of dForce/dDisplacement values (N/mm) on the concentration of CO_2 in the can. The curve has a similar course as in Figure 3. The dependence in Figure 4 changes significantly depending on the temperature of the sample, as the temperature of the sample increases, the internal pressure in the can increases according to Van't Hoff expression (Speers and MacIntosh, 2013) and values of dForce/dDisplacement (N/mm) increase.

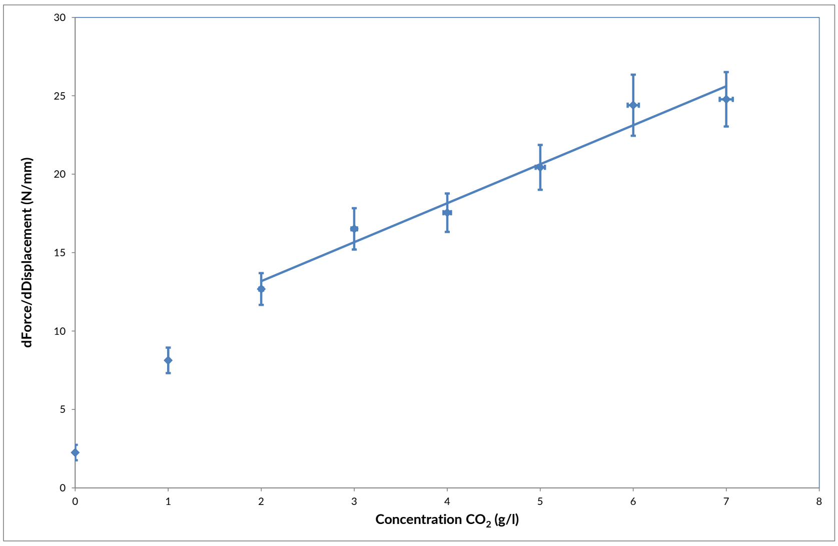

Figure 4 *Dependence of the slope of the force-displacement curve (dForce/dDisplacement (N/mm)) on the concentration of CO_2 in the can at temperature 22±1 °C*

Our measurement verifies the possibility of using the force-displacement test to determine the pressure in a beer can. The measurement is mainly affected by a large error of the equipment used and the influence of the can wall. The Instron 5882 apparatus, on which the force-displacement curves were measured, is intended for measuring tensile and compressive tests of various materials (including metal) and enables the use of forces up to 100 kN. We measured the curves only up to a maximum force value of 10 N, thus up to 0.01% of the measuring range of the force detector. When using equipment with a detector with greater sensitivity, it would be possible to increase the signal to noise ratio and reduce the error of the measured values. The slopes of force-displacement curves (dForce/dDisplacement) are influenced by the material and thickness of the can wall. In addition, the influence of the can wall is not the same at the whole surface of the can.

The force-displacement test has been shown to be a promising non-destructive method for the detection of the internal pressure in beer cans. In order to be able to use the method for monitoring pressure changes in cans, for example during storage, it is necessary to improve the repeatability of the apparatus and to verify and eliminate the influence of the can wall on the measurement results. Based on this case study, a prototype of the apparatus for measuring force-displacement curves directly on beer cans will be developed. The prototype will be equipped with a more sensitive detector, which enables the measurement of force-displacement curves with better repeatability.

4 Conclusion

The applicability of force-displacement measurement on samples of beer cans with a defined CO_2 concentration for non-destructive monitoring of the internal pressure in the beer can was tested. The measured force-displacement curves were linear. The linear coefficient of the dependence of force on displacement (dForce/dDisplacement (N/mm)) increased with increasing pressure in the can. In the range of 120 kPa to 440 kPa, the dependence between the pressure in the can and the dForce/dDisplacement value was linear. Force-displacement measurement proved itself to be a promising non-destructive method for the detection of the internal pressure in beer cans.

5 Acknowledgement

This study was supported by the Ministry of Agriculture of the Czech Republic within the institutional support No. MZE-RO1923.

6 References

Henry, W. (1803). III. Experiments on the quantity of gases absorbed by water, at different temperatures, and under different pressures. *Philosophical Transactions of the Royal Society of London*, *93*, 29–274. https://doi.org/10.1098/rstl.1803.0004

Kegland (2023). Pro Canning Gear – Canning Machines – Oktober Canner – Bulk buy Empty Aluminium Beer Cans, Crowlers. Retrieved from www.kegland.com.au

Kosin, P., Branyik, T., Savel, J., Ulmann, F., Vlcek, J. (2018). Use of sorbents to increase beer foam stability. *Journal of the American Society of*

Brewing Chemists, *76*(1), 58–61. https://doi.org/10.1080/03610470.2017.1398565

Matoulkova, D., Kubizniakova, P. (2014). Microbiology of brewing – strictly anaerobic bacteria *Megasphaera*, *Pectinatus*, *Zymophilus* and *Selenomonas* and methods for their detection. *Kvasny Prumysl*, *60* (11–12), 285–294. https://doi.org/10.18832/kp2014028

MEBAK (2023). Kohlendioxid im Gebinde oder At-Iine mit CarboQC der Firma Anton Paar. Method 2.26.1.5. Retrieved from https://www.mebak.org

Meier-Dörnberg, T., Jacob, F., Michel, M., Hutzler, M. (2017). Incidence of *Saccharomyces cerevisiae* var. *diastaticus* in the beverage industry: Cases of contamination, 2008–2017. *MBAA Technical Quarterly*, *54*(4), 149–156. http://dx.doi.org/10.1094/TQ-54-4-1130-01

NIST (2023). NIST WebBook Chemie – NIST Standard Reference Database Number 69. Retrieved from https://webbook.nist.gov/chemistry/

Speers, R. A., MacIntosh, A. J. (2013). Carbon Dioxide Solubility in Beer. *Journal of the American Society of Brewing Chemists*, *71*(4), 242–247. https://doi.org/10.1094/ASBCJ-2013-1008-01

Štulíková, K., Vrzal, T., Kubizniaková, P., Enge, J., Matoulková, D., Brányik, T. (2021). Spoilage of bottled lager beer contaminated with *Saccharomyces cerevisiae* var. *diastaticus. Journal of the Institute of Brewing*, *127*(3), 256–261. https://doi.org/10.1002/jib.653