A Continuation of Research on the Effect of CO_2 PMV on Fill Volumes

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Relevance

Consistency of volume in packaged products is very important in the brewing industry. A popular method in the determination of the volume of packaged beer involves collecting a mass of the contents and using the density of the liquid to convert this mass to volume (ASBC Methods). Most equipment is unable to calculate the density of packaged beer under the pressure of CO_2; therefore, ASBC suggests a standard Partial Molal Volume (PMV) of .80 ml/g of CO_2 to be used for most beers to account for the swelling effect of CO_2(ASBC Methods). In addition, this PMV value does not represent many craft beers that have either a higher alcohol or higher residual extract content.

The purpose of this study was to determine if the true PMV of CO_2 for any given beer can be substituted with this standard number, or if the resulting density calculated from this standard is significantly different from that of the true density. This was performed by applying known analytical methods from past literature and running an experiment to observe the effect of varying CO_2 concentrations on the density of beers of different compositions.

Calculations

Using previously recorded experimental PMV values from the 1991 ASBC report and their associated alcohol and real extract concentrations, the following equation was developed through linear regression for calculation of PMV (Patino et al., 1991):

$$\boldsymbol{PMV} = 0.8922 - 0.0283 * (\boldsymbol{EOH}) - 0.0026 * (\boldsymbol{RE})^2$$

This equation verified the empirical formula from the 1992 ASBC article (Patino et al., 1992).To determine the density without the effect of CO_2(corrected density), the following equation was used where **d** is the corrected beer density at 20˚C (g/mL) and R is the density of the dealcolized beer @ 20˚C (g/ml):

$$\boldsymbol{d} = \frac{0.8(\boldsymbol{EOH})}{100} + \frac{\boldsymbol{R}(100 - (\boldsymbol{EOH}))}{100}$$

To uncorrected beer density is simply the corrected density with the addition of a CO_2 correction. This correction was calculated using standard values as well as previously calculated values in the following equation:

$$\boldsymbol{D} = \frac{(1 - (\boldsymbol{P} * \boldsymbol{d}) * \left(\boldsymbol{V} - \boldsymbol{W} - \frac{\boldsymbol{V} * \boldsymbol{W}}{\boldsymbol{k} * \boldsymbol{d}}\right))}{\boldsymbol{k} - (\boldsymbol{P} * \boldsymbol{W})} + \boldsymbol{d}$$

Where **P** is the PMV of CO_2 , **d** is the uncorrected density, **V** is the CO2 by volume, **W** is the residual CO2 by volume, and **K** is the conversion constant for CO2 (506.07) (ASBC Method).

Experimental Methods

For the experimental portion of this study, 3 beers with different compositions were analyzed using an Anton Paar ME with a Cbox QC attachment. This device allowed for the necessary measurements of both corrected and uncorrected densities at varying carbonation levels. The starting ABW and RE values of these beers are represented in the chart below:

	RE (%w/w)	ABW (%w/w)
Beer 1	7.54	4.39
Beer 2	7.76	7.16
Beer 3	4.24	7.58

Results

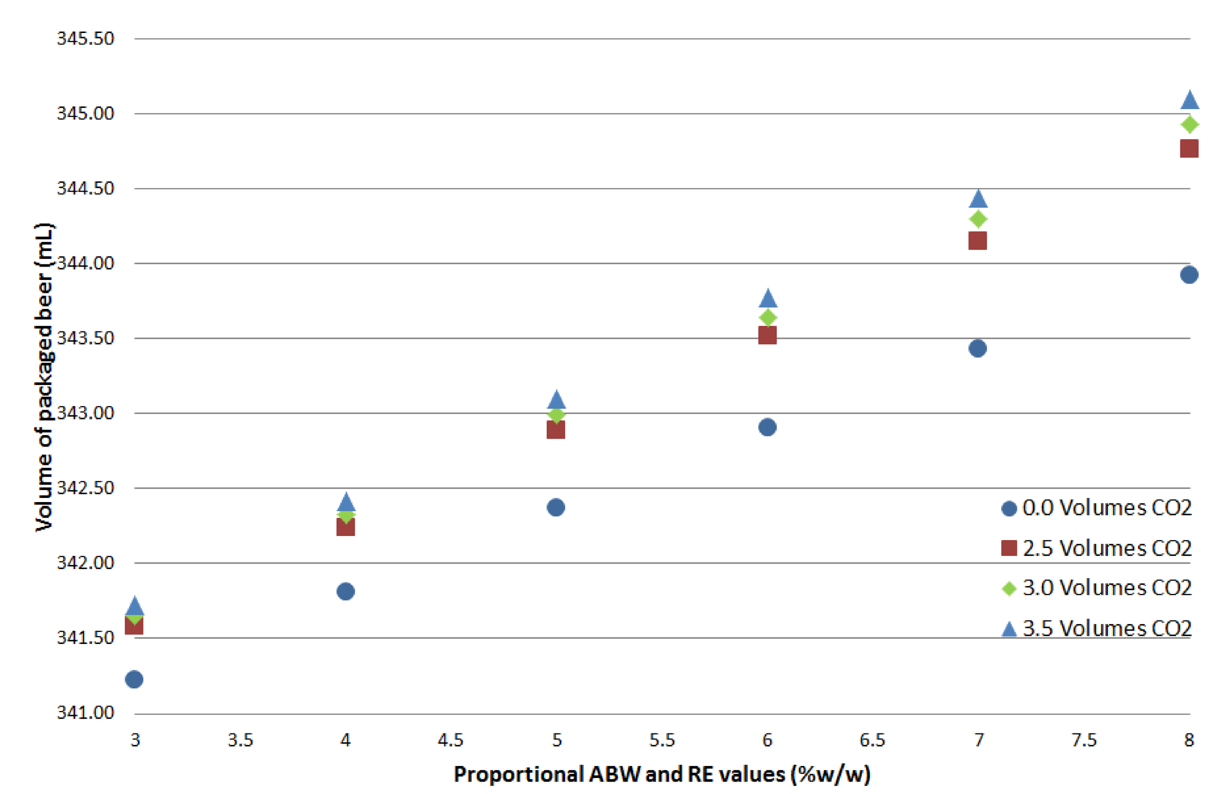
Fig 1. helps distinguishes between weight changes from CO_2 additions and changes due to beer composition. As can be seen, the differences due to varying CO_2 concentrations are very minimal.

The differences are higher in cases with higher concentrations of alcohol and residual extract, but excluding the lack of oxygen, these differences are less than 1.50 mL.

The predicted densities in *Fig 2*. have a trend of being consistently smaller than the densities determined experimentally although this difference never exceeds more than .005 g /cm^3.

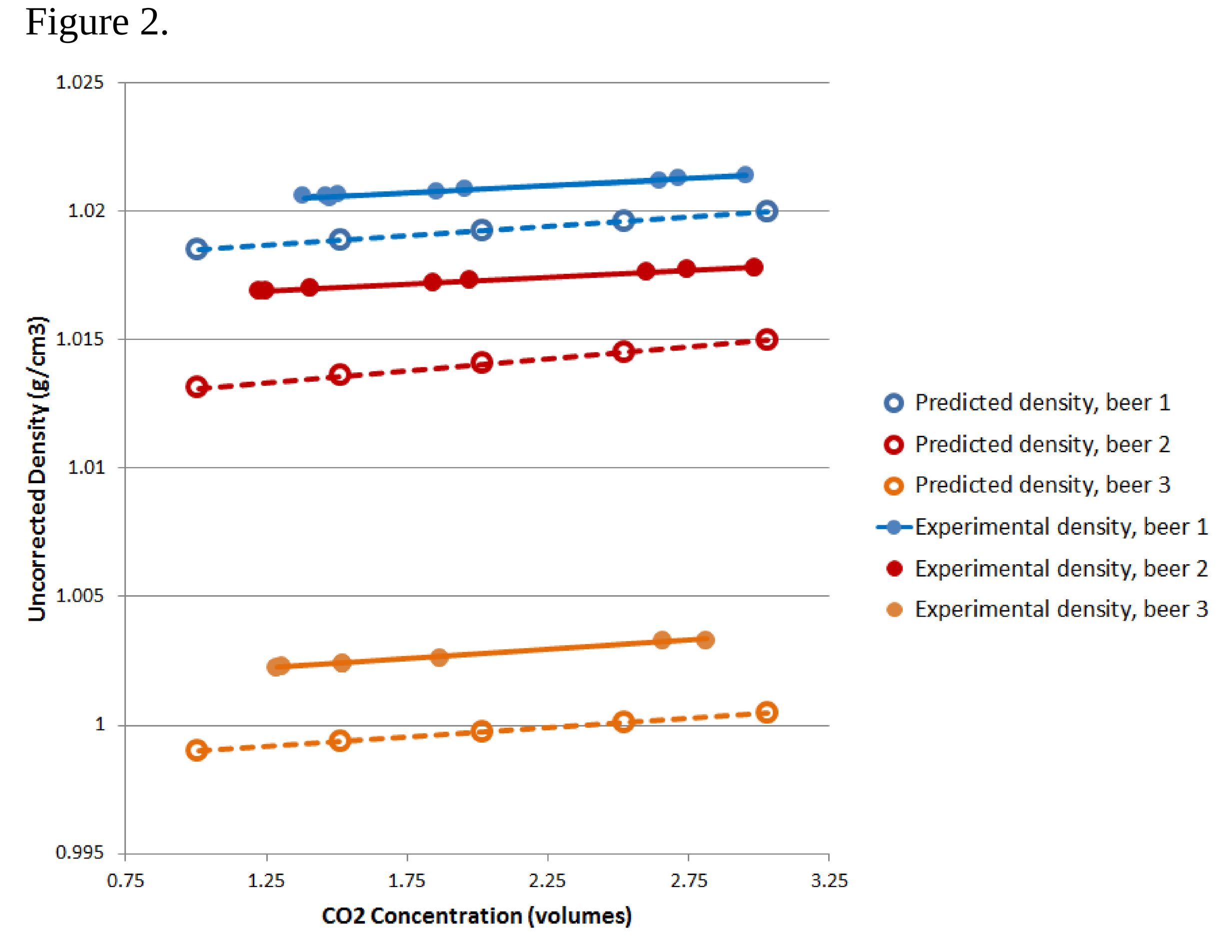
The corrected densities determined experimentally in *Fig. 3* demonstrate a very minimal slope as expected with an average of .00004. Uncorrected densities were only slightly more with an average of .00033. Although this difference is slight, it is consistent. As expected, the increase in concentration of CO_2 causes an increase in the density of the beer.

Figure 1.



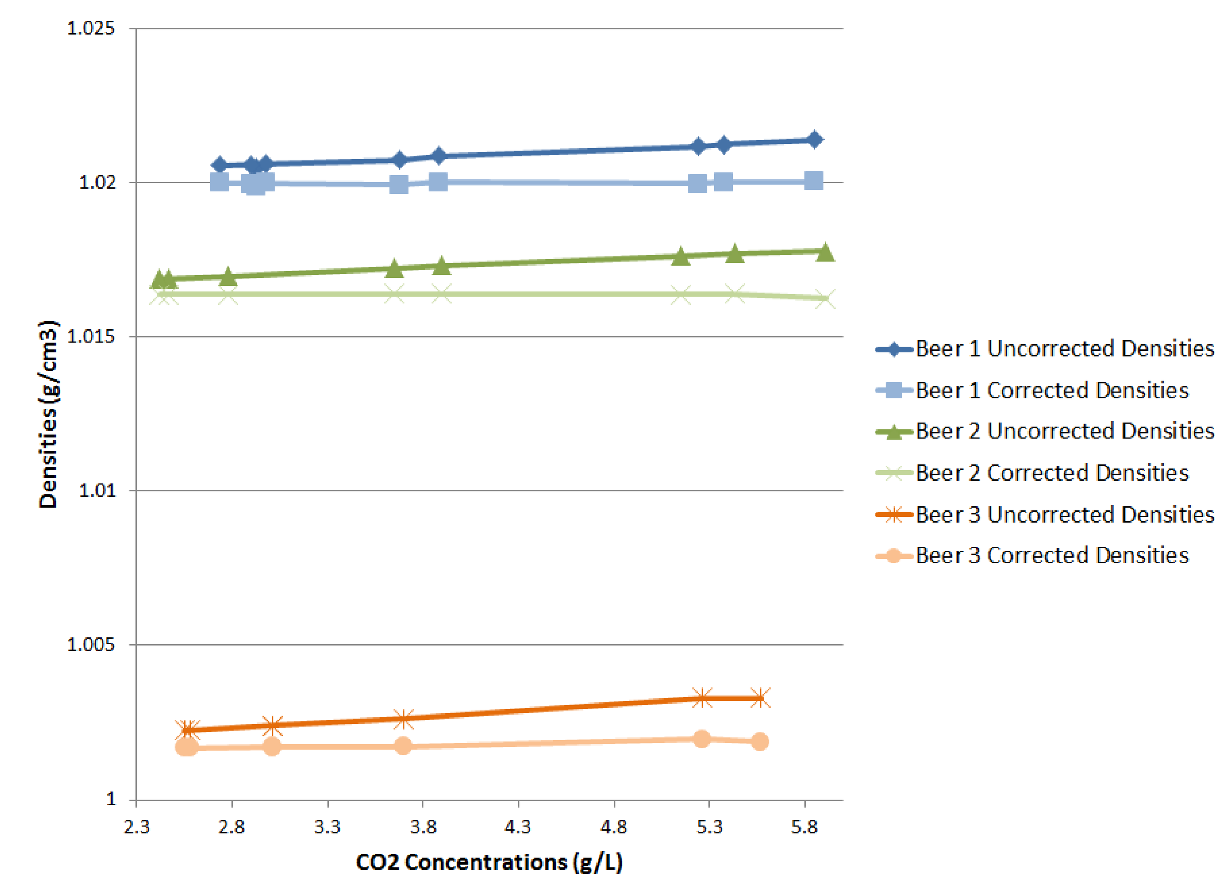
Change in volume of packaged beer (g) due to CO_2 concentrations at 6 Different ABW:RE (3:3, 4:4, 5:5, 6:6, 7:7, 8:8). Volume calculations based on a desired can weight of 340 g. CO_2 concentrations of 0.0, 2.5, 3.0, and 3.5 volumes of CO_2 were used.

Figure 2.



The change in predicted and experimental Uncorrected beer densities over CO2 concentration. Predicted densities were determined using previously recorded equations for PMV and uncorrected density. Experimental densities were taken from readings on the Anton Paar ME.

Figure 3.



The change in both CO_2 -uncorrected and CO_2 -corrected densities of Beer 1, Beer 2, and Beer 3 (g/cm3) due to changes in CO_2 concentrations (g/L).

Conclusion

The results collected from this study support results from previous literature. The main conclusion is that the PMV of CO_2 does have an effect on the weight of a packaged beer, but that these differences are minimal enough to allow for use of the standard PMV value of .80 ml/g as accepted by ASBC. This was shown by the initial calculations portion in which variance in volume due to CO_2 adjustments was less than 1.5 mL with can volumes ranging from 340 to 345 mL. It was also shown in the experimental portion where the difference between both the corrected and uncorrected densities of various beers was not a significant percentage of the uncorrected beer density. Comparison between experimental values and predicted values were also extremely similar which supports current equations for density calculations. Overall, the accepted method using a standard PMV for all beers will yield results very similar to the actual values with insignificant variance from the true value.

List of References

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2. Torrent, J. CO_2 correction factor for the net contents of Containers, *J. Inst. Brewing*. 2006, Vol. 112, No 4.
3. Patino, H., Kemper, E. A., Lincoln, R., and Michener, W. L. Adjustments to beer density for carbon dioxide partial molal volume and residual carbonation after degassing.. *J. Am. Soc. Brew. Chem.* 49:23-27, 1991.
4. Patino H., Kemper, E. A., Lincoln, R., and Michener, W. L. The effect of carbon dioxide partial molal volume on beer density. *J. Am. Soc. Brew. Chem.* 49:23-27, 1991.

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