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Development of a Practical Tool for Estimating Risk of Can Pressure Failures during Tunnel Pasteurization

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ABSTRACT

With the growing popularity of canned alternative beverages (such as hard seltzer) requiring tunnel pasteurization, many breweries and co-packers have discovered the hard way that the combination of higher CO_2 specifications and higher pasteurization temperature requirements frequently exceed the design pressure limits of beverage cans, often resulting in pressure failures of the can. There were no specific references or tools that could determine the risk of can failure under current conditions, so one was developed. The data collection consisted of a heated water bath that simulated tunnel pasteurizers. The data collected provided for the creation of temperature and pressure charts that could be used by packaging departments to greatly reduce the risk of pressure-related can failures for their products.

Introduction

In recent years many new alternative beverages have entered the market that compete for the attention and dollars of the consumer. For the sake of creativity, variety, or functional advantages, many of these alternative beverages include ingredients and/or processes that pose a higher risk of spoilage than is traditionally found in the beer space or the beer-like sister space of flavored malt beverages and the like.

A new group of co-packing facilities has sprung up to meet the production needs of these alternative beverages—both alcoholic and non-alcoholic. Additionally, many breweries have entered the co-packing arena, having found themselves with excess capacity. Although this surge in co-packing capacity has mostly met the rise of beverage start-ups and existing brand growth, many co-packers have found themselves facing production challenges they are unfamiliar with or unable to handle.

Additionally, the spike in beverage entrepreneurs entering the market has greatly expanded the options for consumers, but occasionally, due to a lack of beverage industry experience, the entrepreneur's vision for their products do not line up with the practical considerations of producing a high-quality, safe, and cost-effective product. The issues of contamination and food safety have been known to collide with these visions and become practical problems for new products.

Whether the spoilage risk is simply a flavor quality issue or a more serious health risk, preservation methods are required that don't damage the intended quality of the product in turn. Preservation methods compatible with carbonated beverages include chemical preservation and heat pasteurization. Chemical preservation generally is frowned upon due to the common desire to maintain a "clean label" and a healthy image for the brand. With that background in place, the logical alternative is heat treatment via pasteurization.

One such heat treatment option is flash pasteurization. This method is very effective at reducing any microbial load in a bulk liquid, but its downside is that it happens prior to the filling step, and the beverage may be exposed to subsequent contaminants from the environment, packaging equipment, or associated materials. Therefore, the rest of this paper will focus on post-filling-and-sealing pasteurization, in what I will generically refer to as tunnel pasteurization. However, the same issues are present in any post-filling and -sealing heating process, including purpose-built batch pasteurizers or other bulk package heating methods.

Basis for Pasteurization

According to *Food Processing Technology Principles and Practice*, Second Edition, "Pasteurisation (pasteurization) is a relatively mild heat treatment, in which food is heated to below 100°C…. In acidic foods (pH 4.5, for example bottled fruit) it is used to extend the shelf life for several months by destruction of spoilage micro-organisms (yeasts or moulds) and/or enzyme inactivation." Generally, a pasteurization specification is given as either a length of time at a defined temperature, or a pasteurization unit (PU) total, or both.

One PU is defined as 1 min at 140°F (60°C). There are many publications and tools available to calculate the time and temperature needed to achieve a specific PU target or to accumulate a total PU value estimated to achieve the shelf stability required, so I will not go into that in this paper. The best practice is to utilize the services of a processing authority to define the required pasteurization needs of any new alternative beverage. Per the FDA website, "A processing authority is a person who has expert knowledge of thermal processing requirements for low-acid foods packaged in hermetically sealed containers, or has expert knowledge in the acidification and processing of

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acidified foods." Typically, processing authority letters will define a PU total target and a range of time and temperature combinations that will achieve that PU total target.

Expectations

Beverage brand owners and entrepreneurs bring wonderful variation, complexity, and innovation to our industry. As you would expect, they enter the development phase of their new product and are hit with many decisions needed to successfully bring their new product to market in a cost effective, efficient, and safe way that delivers their dream to the target consumer. One of the decisions that I have found to be the hardest to explain, and reach agreement on, is the carbonation level and the pressure limits of beverage containers, be they cans or bottles. Generally speaking, brand owners often want high carbonation levels, approaching those that normal seltzer water might have, of 3.0–4.0 vol. Additionally, I have found there is often some misunderstanding at packaging facilities, or at least extreme conservatism, regarding the carbonation levels that can be achieved with a tunnel pasteurized product.

So, I set out to find a resource that would help us explain this concept. Unfortunately, I could not find a resource that accomplished this in a simple, easy to understand way. Therefore, I decided to produce one myself—one that considers the published pressure limits of the package and the practical experiences that packaging professionals have confronted in real life.

A Little Background

For this paper, I looked at three common beverage cans in the North American market: 12-oz standard, 16-oz standard, and 12-oz sleek. These cans all utilize a 202 lid and are each rated to withstand 90 psi of internal pressure.

To eliminate the tedious math involved with the gas laws—remember those?—I utilized on-line forced-carbonation calculators to estimate the pressure in cans from a known carbonation level as I increased temperature.

In this practical application, the gas laws can be applied simply because in a fixed volume (sealed can) the pressure increases in a predictable way as temperature increases. For instance, we know from standard carbonation charts that 2.75 vol of CO_2 will generate about 12 psig in a sealed container at 34°F. On the other temperature extreme, at a standard beer pasteurization temperature of 140°F, that same CO_2 level will generate over 82 psig, and this safe combination has served us well for many years in the beer industry. The highest pasteurization temperature I have ever seen specified for a standard beer was 145°F, which would put us at 87 psig in the container, still below the 90 psig rating of the can.

However, the introduction of alternative beverages with a wider variety of ingredients has introduced a new set of microbiological challenges. Processing authorities often prescribe pasteurization temperatures in the mid 150 degrees Fahrenheit and sometimes as high as 160°F. Following the previous example, at 150°F our 2.75-vol product would exceed the 90 psig rating of the can, and at 160°F we would hit nearly 99 psi (assuming the can held together). These are hard and fast facts of nature that we can do nothing about—or can we? Well, there is an additional factor, the fill level, which we will go into later, but for now we are assuming the products are filled to the designed volume of the can and properly labeled as such.

To get started, I decided to lay out a chart covering the common ranges of carbonation levels and tunnel pasteurization levels, 2.0–3.2 vol of CO_2 and 140 to 160°F. I then used common on-line forced-carbonation calculators to populate each cell with a pressure calculated to the given combination of CO_2 and temperature. The result is shown in Figure 1.

To make visualization easier, I then formatted the cells to call out when the pressure exceeded 90 psi (Fig. 2). Anyone who has spent any time in a production facility knows that there are few black and white lines—or green to red lines, in this case. There are many contributing factors that affect the point at which an individual can will fail. Additionally, few of us would recommend running at the knife's edge. Therefore, I decided to include a marginal area where the risk increases, but with eyes wide open, a decision could be made to produce product that falls within that margin. A 10-psi margin was chosen as a reasonable range. Coincidentally, this lined up well with information provided by some can manufacturers. This information was published in a different format that was less visual and less accessible to the target audience. This resulted in the chart shown in Figure 3.

Because the chart was intended to be a quick reference guide for brand owners and formulators, as well as packaging professionals, looking for a quick guide, I felt that having the pressure calculations shown in each cell added unneeded complexity. I ended up with the final chart shown in Figure 4. A full-page, printable version of Figure 4 is included as an Appendix on the last page of this article for readers to print out and use on the packaging floor or add to their SOP manuals.

Getting Comfortable

That was the easy part. Next I wanted to verify that this chart represented reality. Initially, I spoke to several packaging man-

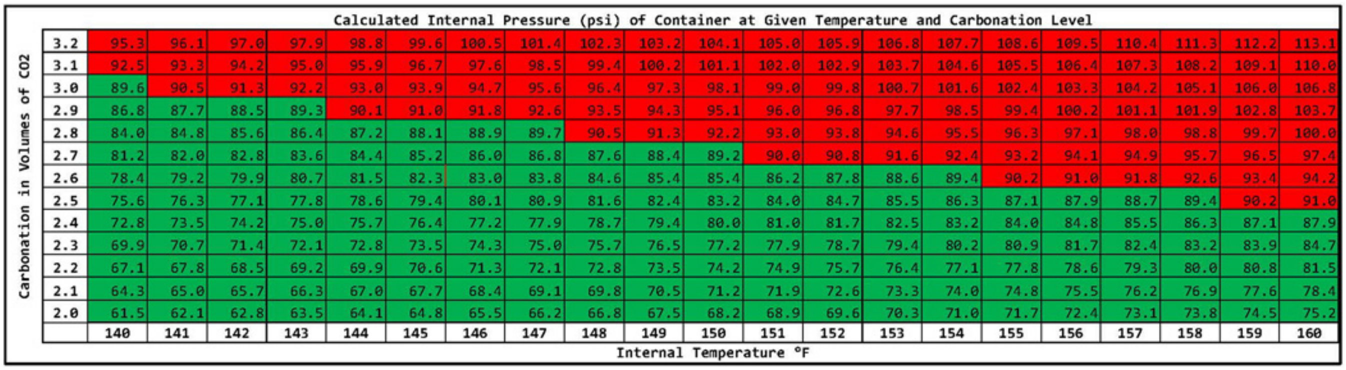
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	**141**	**142**	**143**	**144**	**145**	**146**	**147**	**148**	**149**	**150**	**151**	**152**	**153**	**154**	**155**	**156**	**157**	**158**	**159**	**160**

Internal Temperature °F

Figure 1. Pressure calculated for specific combinations of CO_2 and temperature using common on-line forced-carbonation calculators.



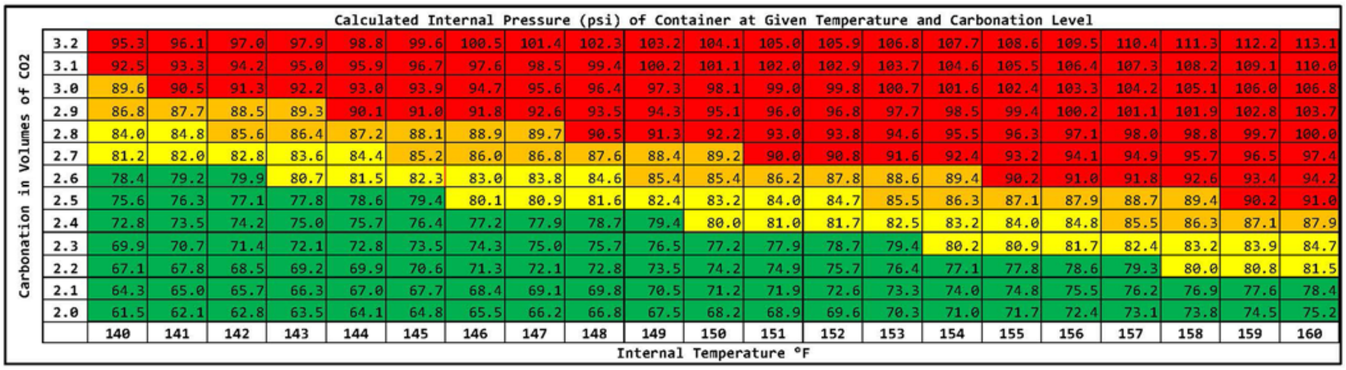
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 2. Cells formatted to show when the calculated pressure exceeds 90 psi based on the combination of CO_2 volume and temperature.



Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

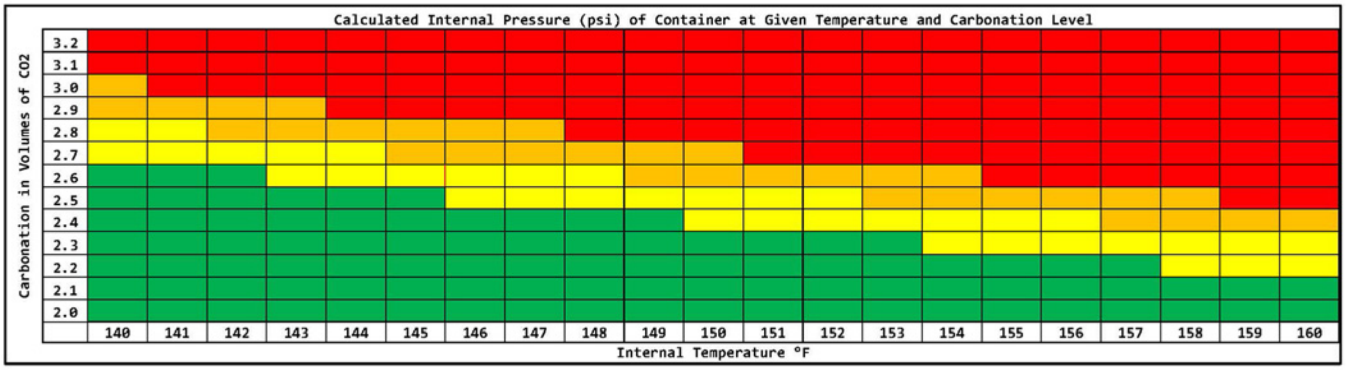
3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 3. Cells formatted to show when calculated pressure exceeds 90 psi and the marginal area in which risk of can failure increases based on the combination of CO_2 volume and temperature.

Legend

🟥	Above Design Spec of Package
🟧	On the high end of the range of possible failure
🟨	On the low end of the range of possible failure
🟩	Safe level of pressure



Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
3.1	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
3.0	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.9	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.8	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.7	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.6	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥
2.5	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥
2.4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧
2.3	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨
2.2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨
2.1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2.0	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 4. Cells color coded to provide a guide showing when calculated pressure exceeds 90 psi and the marginal area in which risk of can failure increases based on the combination of CO_2 volume and temperature.

agers and co-packers who have experience running carbonated cans at higher temperatures through their tunnel pasteurizers and have good process control on their CO_2 levels and pasteurizer temperatures. These conversations gave me confidence that I was in the ballpark.

To get even more comfortable, I wanted to test commercially available products under controlled circumstances. Samples from national brands with well-established quality programs were purchased off the shelf to reduce the variations in CO_2 and fill height that are sometimes found with smaller brands. As such, all fills were assumed to be at the stated volume on the can.

A water bath consisting of a cooler and sous vide device worked well as a stand-in for small-batch pasteurizers (Fig. 5).

I proceeded to test six lots of cans using the following procedure. The test samples consisted of two examples of 12-oz standard cans, two examples of 12-oz sleek cans, one example of a 16-oz standard can, and one example of a 12-oz proprietary can.

Method

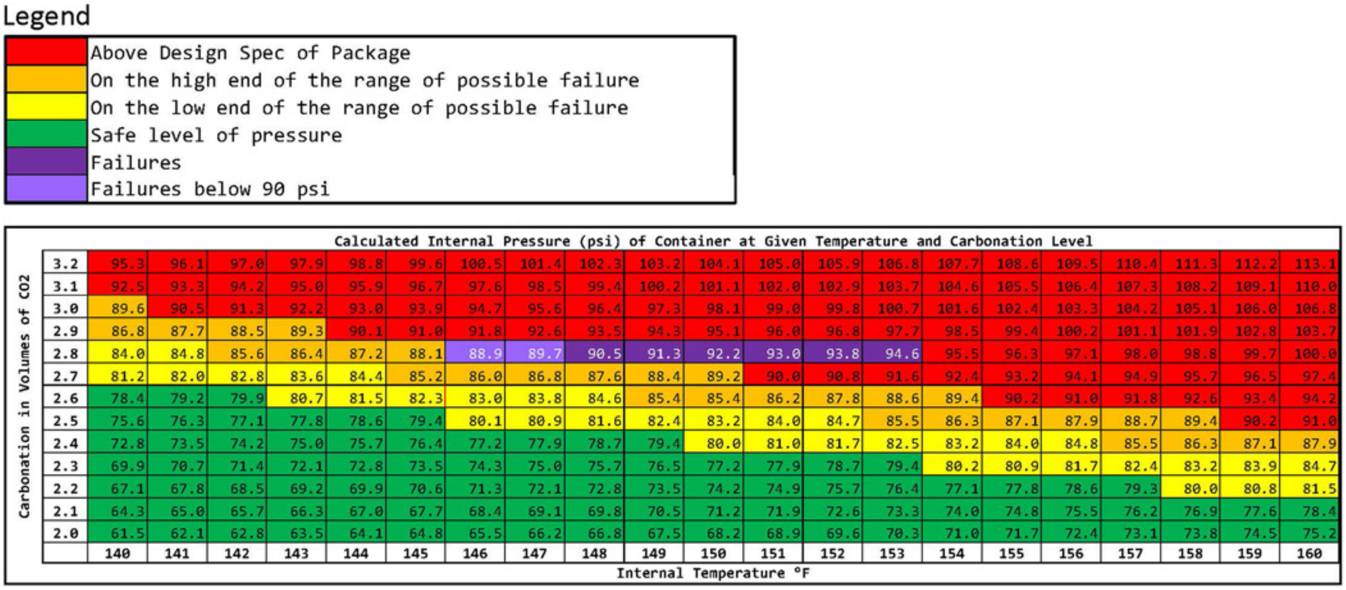
1. Purchase a typical 12 pack of cans produced by a national brand.
2. Test 2 cans from each 12 pack for carbonation using standard methods and record the average results. The average carbonation level (volumes of CO_2) was used to determine the temperature/pressure relationship for water bath testing of the can lot.
3. Submerge the remaining 10 room-temperature cans into a bath of room-temperature water.
4. Raise the temperature to 140°F and hold for 10 min.
5. Can failure was defined as any visual deformation (buckling) of the lid or dome (Fig. 6A and B, respectively).
6. Count the number of failed tabs and domes.
7. Raise the water temperature to 141°F and hold for 10 min.
8. Count the number of failed tabs and domes.
9. Repeat, incrementally raising the water temperature by one degree at a time for 10 min each, through 160°F or until all cans have failed.
10. Record the number of failures, by type, at the end of each temperature hold.

During the initial batch, a control can with an internal temperature probe confirmed that the internal temperature of the can reached the water bath set temperature within 2 min after the bath itself.

The test results were surprising and are listed in Figures 7–12. In most cases, there was a broad range of failure temperatures. However, the goal of the test was to confirm that the

Figure 5. A water bath consisting of a cooler and sous vide device worked used as a stand-in for small-batch pasteurizers.

Figure 6. Visual deformation (buckling) of the can lid (**A**) or dome (**B**).



Legend

🟥	Above Design Spec of Package
🟧	On the high end of the range of possible failure
🟨	On the low end of the range of possible failure
🟩	Safe level of pressure
🟪	Failures
🟪	Failures below 90 psi

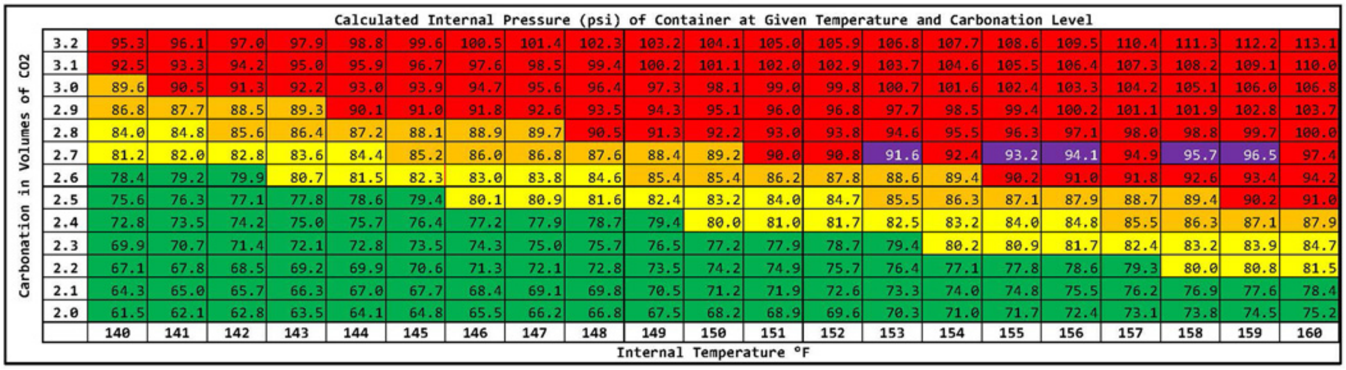
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2																					
3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
Internal Temperature °F	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Figure 7. Test of can failure for a national light beer in 12-oz standard cans based on the combination of CO_2 volume and temperature.

Legend

🟥	Above Design Spec of Package
🟧	On the high end of the range of possible failure
🟨	On the low end of the range of possible failure
🟩	Safe level of pressure
🟪	Failures
🟪	Failures below 90 psi



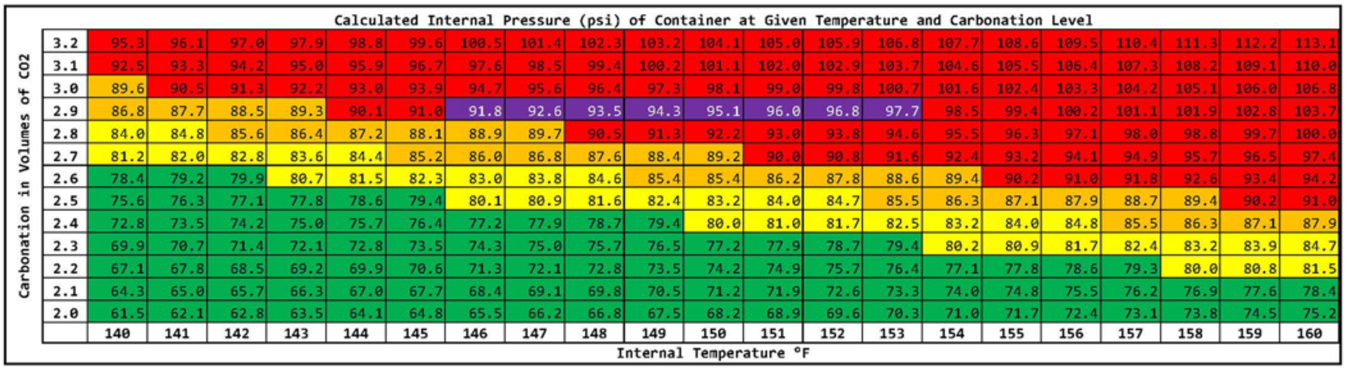
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 8. Test of can failure for a national craft ale in12-oz standard cans based on the combination of CO_2 volume and temperature.



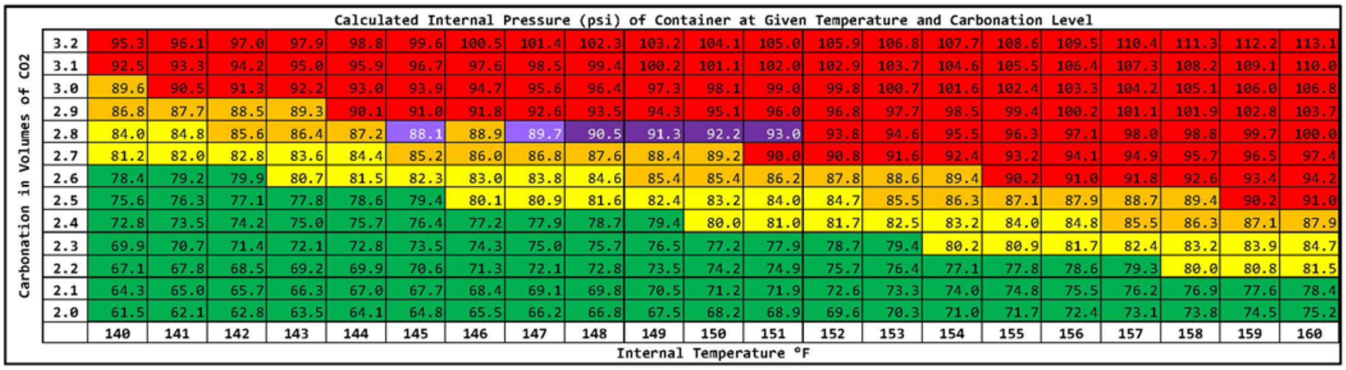
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 9. Test of can failure for a national seltzer in 12-oz sleek cans based on the combination of CO_2 volume and temperature.



Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

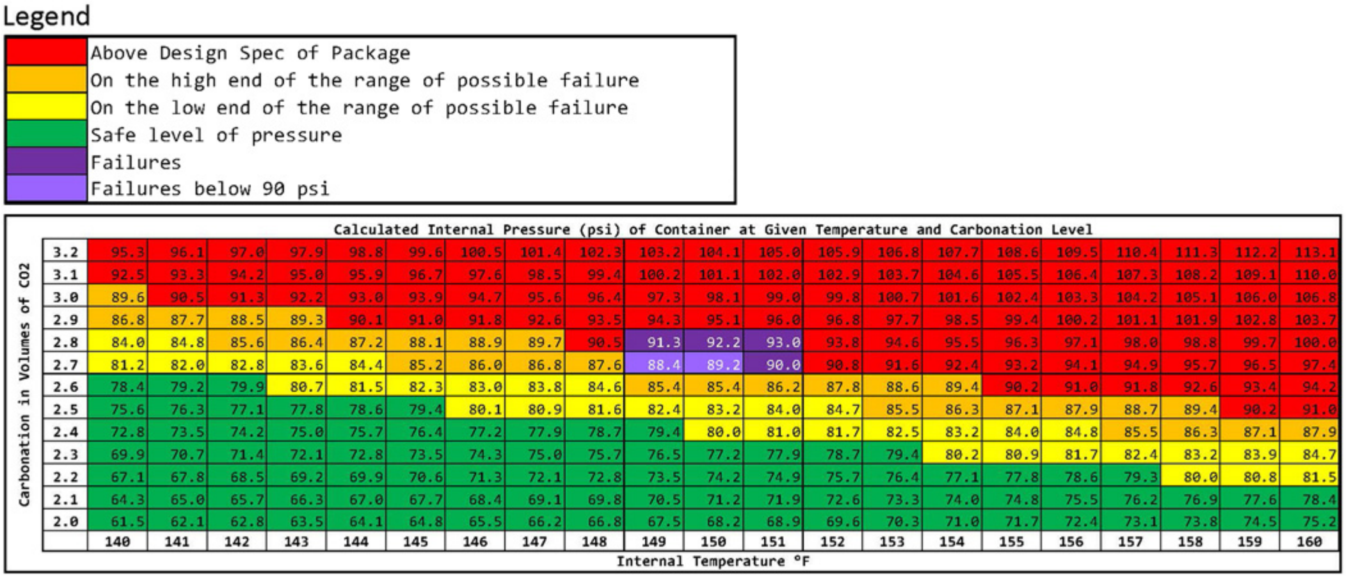
Figure 10. Test of can failure for a national seltzer in 12-oz sleek cans based on the combination of CO_2 volume and temperature.

ranges outlined for relative risk of can failure were in line with practical experience.

The first test of a 12-oz standard can from a national brand resulted in failures across an eight degree band, from just below 90 psig to nearly 95 psig (Fig. 7). Most of the failures were lid buckles, with only two dome failures.

The second test of a 12-oz standard can from a national craft ale also resulted in a broad range of temperature failures (Fig. 8). All of these failures were lid buckles.

Both tests of 12-oz sleek cans from a national seltzer had a wide range of temperature failures (Figs. 9 and 10). All failures were lid buckles.



Legend

🟥 Above Design Spec of Package
🟧 On the high end of the range of possible failure
🟨 On the low end of the range of possible failure
🟩 Safe level of pressure
🟪 Failures
▨ Failures below 90 psi

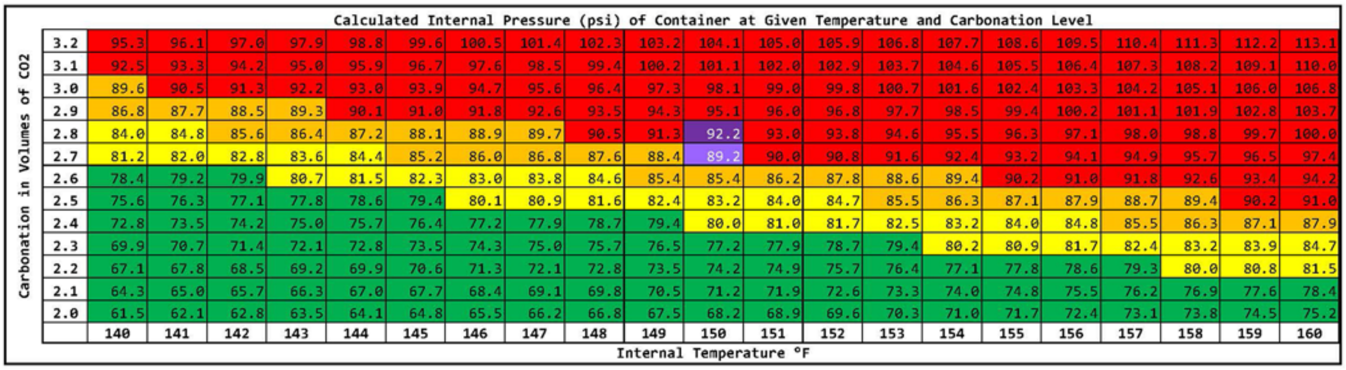
Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 11. Test of can failure for a national light beer in 16-oz standard cans based on the combination of CO_2 volume and temperature.



Calculated Internal Pressure (psi) of Container at Given Temperature and Carbonation Level

Carbonation in Volumes of CO2

3.2	95.3	96.1	97.0	97.9	98.8	99.6	100.5	101.4	102.3	103.2	104.1	105.0	105.9	106.8	107.7	108.6	109.5	110.4	111.3	112.2	113.1
3.1	92.5	93.3	94.2	95.0	95.9	96.7	97.6	98.5	99.4	100.2	101.1	102.0	102.9	103.7	104.6	105.5	106.4	107.3	108.2	109.1	110.0
3.0	89.6	90.5	91.3	92.2	93.0	93.9	94.7	95.6	96.4	97.3	98.1	99.0	99.8	100.7	101.6	102.4	103.3	104.2	105.1	106.0	106.8
2.9	86.8	87.7	88.5	89.3	90.1	91.0	91.8	92.6	93.5	94.3	95.1	96.0	96.8	97.7	98.5	99.4	100.2	101.1	101.9	102.8	103.7
2.8	84.0	84.8	85.6	86.4	87.2	88.1	88.9	89.7	90.5	91.3	92.2	93.0	93.8	94.6	95.5	96.3	97.1	98.0	98.8	99.7	100.0
2.7	81.2	82.0	82.8	83.6	84.4	85.2	86.0	86.8	87.6	88.4	89.2	90.0	90.8	91.6	92.4	93.2	94.1	94.9	95.7	96.5	97.4
2.6	78.4	79.2	79.9	80.7	81.5	82.3	83.0	83.8	84.6	85.4	85.4	86.2	87.8	88.6	89.4	90.2	91.0	91.8	92.6	93.4	94.2
2.5	75.6	76.3	77.1	77.8	78.6	79.4	80.1	80.9	81.6	82.4	83.2	84.0	84.7	85.5	86.3	87.1	87.9	88.7	89.4	90.2	91.0
2.4	72.8	73.5	74.2	75.0	75.7	76.4	77.2	77.9	78.7	79.4	80.0	81.0	81.7	82.5	83.2	84.0	84.8	85.5	86.3	87.1	87.9
2.3	69.9	70.7	71.4	72.1	72.8	73.5	74.3	75.0	75.7	76.5	77.2	77.9	78.7	79.4	80.2	80.9	81.7	82.4	83.2	83.9	84.7
2.2	67.1	67.8	68.5	69.2	69.9	70.6	71.3	72.1	72.8	73.5	74.2	74.9	75.7	76.4	77.1	77.8	78.6	79.3	80.0	80.8	81.5
2.1	64.3	65.0	65.7	66.3	67.0	67.7	68.4	69.1	69.8	70.5	71.2	71.9	72.6	73.3	74.0	74.8	75.5	76.2	76.9	77.6	78.4
2.0	61.5	62.1	62.8	63.5	64.1	64.8	65.5	66.2	66.8	67.5	68.2	68.9	69.6	70.3	71.0	71.7	72.4	73.1	73.8	74.5	75.2
	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160

Internal Temperature °F

Figure 12. Test of can failure for a national light beer in 12-oz proprietary cans based on the combination of CO_2 volume and temperature.

The 16-oz standard can from a national light beer had a much narrower range that hugged the 90 psi line closely (Fig. 11). All failures were lid buckles.

Most surprising of all were the test results for 12-oz proprietary cans from a national light beer (Fig. 12). Not only did they all fail at the same temperature, but all of them were dome failures.

Typical lid and dome failures are shown in Fig. 6A and B, respectively.

Limitations of the Calculations

From my in-plant experience testing CO_2 in tanks and packages, I know there is a variability inherent to typical CO_2 results. I have seen test variability between instruments, between technologies, and especially between operators. With that in mind, I always ask how CO_2 was measured when I advise on how close to the line I am willing to go. I once asked a cellar operator what results they had determined from the manual CO_2 tester they were using. The response was, with a wink, "What do you want it to be?" All instruments, no matter the technology, need to be calibrated, well maintained, and operated by individuals who are well trained to understand the use and limitations of the instrument.

Tunnel pasteurizers also need to be understood. Their capabilities and operating SOPs vary by location. Not all beverage manufacturers treat tunnel pasteurization as delicately as brewers do. One key point to understand is the difference between the hot-zone spray temperatures and the target maximum can temperature. Oftentimes the hot-zone spray temperature needs to be a degree or two higher than the max package temperature specification in order to achieve the desired PUs within the run time of the pasteurizer. You need to weigh the risk of downtime on the backend of the line that would cause those cans stuck in the hot zone to potentially exceed the specified temperature and possibly then exceed the pressure limits of the can. Every line and set of operating circumstances needs to be evaluated as a unique set.

Finally, I want to go back to my earlier comment that there is one way to influence the potential ability to avoid can pressure failure while achieving higher CO_2 and pasteurization temperature targets. To this point, I have assumed that all cans were filled to the designed volume of either 12 or 16 fluid ounces, which eliminates the variability of volume in the gas law calculations. In theory, if you were to underfill the can (while adjusting the labeling to indicate the lower fill), you would increase the headspace volume, creating more room for the gas to expand into before deforming the can. I did not test for this directly; however, I did observe some correlation between fill weight and the temperature at which failure occurred. Very generally speaking, lighter weight cans (suggesting lower fill) failed at higher temperatures. This is certainly an opportunity for further testing.

Conclusions

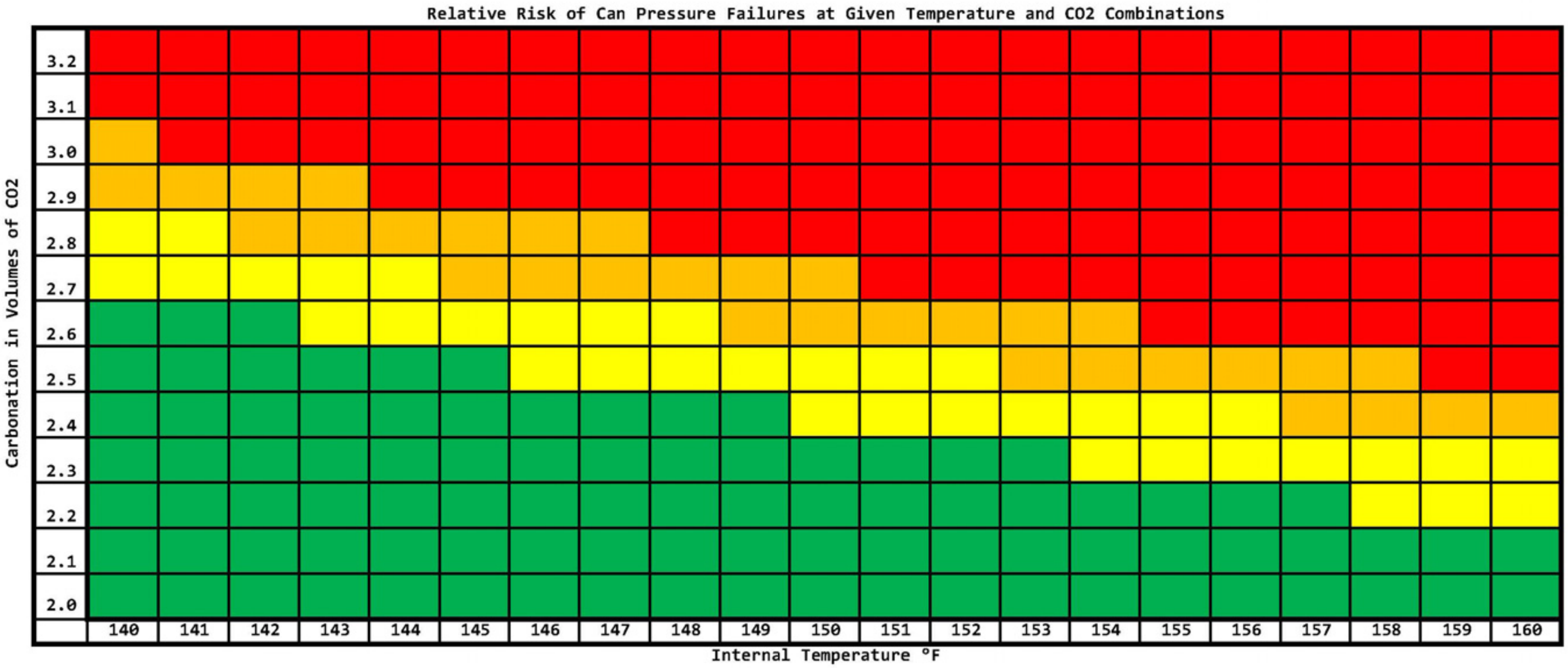
The charts and explanation of the test have been well-received by our clients and co-packers. In some cases, it has been used to educate brand owners about the limitations of cans and has allowed more realistic specifications to be set. In other circumstances, it has been used to influence co-packers who were understandably resistant to running higher carbonation products through their tunnel pasteurizers and had set exceedingly conservative limits. Like so many things in packaging, you have to look at the whole picture to able to make better decisions, and this is just one more tool to help with that.

I look forward to further refinement of the tool and for feedback on the science, math, and application of this in the field.

ACKNOWLEDGMENTS

I would like to thank my colleagues at BevSource for assistance with testing, vetting of the method, and application in the field. Although I have intentionally left out any reference to brands or can manufacturers, I would like to acknowledge the feedback that I did receive from several packaging and manufacturing professionals. Thank you all.

Appendix



Relative Risk of Can Pressure Failures at Given Temperature and CO2 Combinations

Carbonation in Volumes of CO2	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
3.2	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
3.1	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
3.0	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.9	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.8	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.7	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2.6	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥	🟥	🟥
2.5	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥
2.4	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧
2.3	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨
2.2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨
2.1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2.0	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Internal Temperature °F

Reference

https://www.hopsteiner.com/psi-calculator/

🟥 Above Design Spec of Package
🟧 On the high end of the range of possible failure
🟨 On the low end of the range of possible failure
🟩 Safe level of pressure

Fine Print

This chart is only an approximation of actual conditions. Results are affected by actual can and lid design and age, fill level, seam quality, and liquid characteristics, among others. Within the same lot of beverage (same can, lid and CO2 level), failures have been experienced across temperatures ranges as much as 8 degrees. Carbonation measurements are also affected by the method and instrument used, the calibration of the unit and, in the case of manual methods, the skill of the operator.