BREWERS ASSOCIATION

Preventing Package Over-pressurization

Controlling refermentation in packaging is an essential part of quality and food safety programs in breweries. Unintended refermentation can cause a package to rupture at the distributor, retailer or in a customer's possession, which is a potential consumer safety concern.

It is the brewer's responsibility to prevent package over-pressurization—not the customer's!

The purpose of this resource is to provide guidance to brewers on the following:

- The impact of carbonation on internal package pressure, especially when bottle or can conditioning is not intentional.
- Managing refermentation in packaged beer to prevent package over-pressurization.
- How CO_2 created in conditioning can increase and exceed the pressure rating of a bottle or can.

Knowing the pressure limitations of your package

The first step in preventing package over-pressurization is to know the specifications of the package itself, whether using cans, bottles, growlers, kegs or any other container. The pressure limitations vary by package, ranging from 0 to 100+ pounds per square inch (psi).

It is critical to obtain this information from the packaging supplier before using any packaging. It is also important to consider the temperature extremes packaged beer will encounter outside of the brewery, since headspace pressure will increase significantly under warm and hot conditions.

Ensuring fermentation is complete

To prevent package over-pressurization, it is critical to know when primary fermentation is complete and how much carbonation will be produced if priming for package conditioning. It is also critical to understand what factors can change a product's fermentability over time. This is particularly true of package-conditioned beers and beers that are not microbiologically stabilized by pasteurization or sterile filtration. Best practice is to perform lab-scale fermentations, or forced fermentation tests, on wort and in-process fermentations to establish a theoretical limit of fermentability. For more information on forced fermentations, see American Society of Brewing Chemists (ASBC) method Wort 5 - Yeast Fermentable Extract.

With dry-hopped beers, fermentability tests should be performed ***after*** dry-hopping, to account for potential "hop creep." Hops can contribute dextrin-degrading enzymes to beer, creating additional sugars that can be fermented by pitched yeast and beer-spoiling organisms.

Managing in-package conditioning

Once completion of fermentation has been confirmed, calculate the appropriate amount of sugar needed for package conditioning. Use a simple sugar that is easily quantified and 100% fermentable, such as granular or liquid dextrose. This allows correlation to degrees Plato (°P), where:

1 °P = 1 gram (g) of sucrose in 100 g water, or 10 g in 1 liter (L) water.

Other sources of fermentable sugar may need to be tested for fermentability, relative to their weight, to determine how much carbonation can be expected if used for package conditioning.

To simplify the following calculations, the following assumptions are made regarding the amount of extract required to achieve carbonation in volumes:

- 1 g of extract will yield 0.46 g of CO_2
- 1 g of CO_2 in 1 L of beer = 0.506 volumes of CO_2 per L of beer
- 1 °Plato of extract has the potential to create approximately 2.5 volumes of CO_2.

Sample calculation for adding granular dextrose to beer for in-package conditioning:

(Δ volumes CO_2) * (1 °Plato/2.5 volumes CO_2)	=	kg fermentable extract per hectoliter (hL) beer
(kg extract per hL) * (beer volume in hL)	=	kg total fermentable extract
(total fermentable extract kg) / (% solids in dextrose/100)	=	kg granular dextrose required

Example

- Beer is fully attenuated (according to forced fermentation test)
- Carbonation is currently 2.2 volumes of CO_2
- Target carbonation post-conditioning is 2.9 volumes of CO_2
- Granular dextrose is 91% solids
- Beer volume in brite tank (BBT) is 126 hL

How much granular dextrose should be added to achieve the target CO_2 volumes?

First, determine the desired change in CO_2 volumes, which is 0.7 volumes in this example (2.9 volumes – 2.2 volumes), using granular dextrose:

(0.7 volumes CO_2) * (1 °Plato / 2.5 volumes CO_2)	=	0.28 kg fermentable extract per hL beer
(0.28 kg extract/hL) * (126 hL)	=	35.28 kg total fermentable extract
(35.28 kg total fermentable extract) / (91/100)	=	**38.8 kg granular dextrose**

In this example, approximately 39 kg of granular dextrose would be added to 126 hL of beer in the BBT to achieve a package carbonation increase of 0.7 volumes through bottle refermentation.

Note: Forced fermentations frequently finish at a lower gravity than production fermentations. Brewers should quantify and standardize these trends for each beer.

If the terminal gravity of a forced fermentation test is lower than the batch terminal gravity, take this fermentable extract into account when calculating sugar additions.

Example

- Forced fermentation terminal gravity is 2.0 °Plato
- The production batch finishes at 2.2 °Plato
- Carbonation is currently 2.2 volumes of CO_2
- Target package carbonation post-conditioning is 2.9 volumes CO_2
- Granular dextrose used is 91% solids
- Beer volume in BBT is 126 hL

How much granular dextrose should be added to achieve the target CO_2 volumes?

First, identify the desired change in volumes CO_2, assuming the beer is fully attenuated. As above, this is 0.7 volumes (2.9 volumes – 2.2 volumes). Then, factor in the 0.2 °Plato difference between the production batch and the forced fermentation result.

Since 1 °Plato of fermentable sugar has the potential to create 2.5 volumes of CO_2, it follows that 0.2 °Plato has the potential to create 0.5 volumes of CO_2:

1 °Plato fermentable extract / 2.5 volumes CO_2 = 0.2 Plato fermentable extract / x volumes CO_2

Solving for ***x*** yields 0.5 volumes CO_2.

Since the residual extract will provide 0.5 volumes of the 0.7 volumes needed to bring the package to 2.9 total volumes of CO_2, calculate how much dextrose is needed to contribute the remaining CO_2:

(0.2 CO_2 volumes) * (1 °Plato / 2.5 volumes CO_2)	=	0.08 kg fermentable extract per hL beer
(0.08 kg extract per hL) * (126 hL)	=	10.1 kg total fermentable extract
(10.1 kg total fermentable extract) / (91/100)	=	**11.1 kg granular dextrose**

Yeast considerations

Typical ale and lager yeasts can ferment monosaccharides, disaccharides, and potentially trisaccharides. When yeast have completely utilized these simple sugars, the beer is said to be fully attenuated because only unfermentable dextrins remain in solution. As discussed in the previous section, the attenuation of the beer is taken into consideration when calculating sugar additions used for priming. The proper application of these calculations assures that there is not an excess of fermentable extract, which can lead to excess carbon dioxide production and package over-pressurization.

The above assumptions, however, do not protect against over-pressurization when the beer is contaminated with wild yeast or brewed with strains that can utilize dextrins left in the beer. Some cultured strains, such as

Brettanomyces and certain saison strains, can attenuate further than typical yeast strains. In addition, unwanted *Saccharomyces cerevisiae var*. *diastaticus* can be introduced into a brewery with contaminated yeast cultures and through poor brewery sanitation. Such strains can excrete glucoamylase enzymes which degrade dextrins, resulting in fermentable sugars that cultured and wild yeast can ferment. Check with your yeast supplier to determine if the strain you are planning to use is capable of degrading dextrins to fermentable sugars.

There are several steps that can be taken to reduce the risk of contamination with wild yeast strains:

- Buy yeast from a reputable vendor who can provide a certificate of purity.
- Put procedures in place to prevent mixing production strains.
- Clean and sanitize hoses, lines and equipment between transfers.
- Test for contamination! There are selective media available to screen for wild yeast contamination, such as Lin's Cupric Sulfate Medium (LCSM) and Farber Pham Diastaticus Medium (FPDM).
- Polymerase chain reaction (PCR) methods can be used to screen for and confirm the presence of diastatic strains.

Measuring in-process and in-package carbonation

Several different technologies are available for measuring CO_2 in beer and most rely on measuring and correlating temperature and pressure. Some examples include the Zahm & Nagel CO_2 Volume Meter, Anton-Paar CboxQC, and Haffmans c-DGM. Beer can be sampled from a BBT to get a pre-package carbonation reading and it can be measured directly from packaged beer. It is recommended to do both in order to ensure accurate results.

Package conditioning do's and don'ts

Please note that package refermentation can vary between batches since it is a biological process dependent on many factors such as yeast strain, yeast viability and vitality, mash saccharification, etc.

DO

- ✔ Err on the side of caution! It is better to have a slightly under-carbonated beer than an over-carbonated beer, particularly when the target carbonation is relatively high.
- ✔ Know where every fermentation will finish (using forced fermentation tests) and allow batches time to fully attenuate. This is especially true if cold-side enzymes are used and if hop creep is a possibility. If the beer is not fully attenuated, additional fermentation must be accounted for when calculating package refermentation.
- ✔ Keep a record of calculations used to determine sugar additions for every batch.
- ✔ Keep a library of packaged beers and measure carbonation levels over time. Best practice is to measure carbonation every month until the date of expiration, at least.
- ✔ Consider pasteurization, which can provide two benefits: 1) denaturation of any active enzymes and 2) killing active microbes.
- ✔ Consider sterile filtration, which can remove yeast and bacteria from the product prior to packaging.

DON'T

- ✘ Don't add a fermentable sugar to beer prior to packaging without quantifying the potential carbonation (pressure) it could create. Fruit and purees will add fermentable sugars to beer.
- ✘ Don't release a batch of package conditioned beer until the carbonation level has stabilized.
- ✘ Don't put the onus of consumer safety on the consumer. **Under the Food Safety Modernization Act (FSMA), the United States Food and Drug Administration (FDA) dictates that it is the responsibility of the brewer to protect consumers by proactively managing food safety hazards associated with the manufacture and transport of beer.**
- ✘ Don't expect consumers to follow instructions on packages in order to ensure their own safety! Including copy on a package instructing consumers to keep the package cold because it contains fermentable sugar does not constitute food safety assurance! Preventing package over-pressurization is your responsibility, not the customer's.

Failure to follow the guidelines above could result in:

- Package failure. Excessive carbonation and pressure within the package could cause a can seam to fail or a bottle to explode, possibly resulting in serious personal injury.
- Significantly over-carbonated beer that could gush when the package is opened.
- Microbiologically unstable beer. Fermentable sugar in the package can promote the growth of undesirable organisms such as bacteria and beer-spoiling yeast.
- Unwanted flavor development.
- The necessity to issue a recall for affected batches.
- Legal exposure for the producer due to damages resulting from package failure.

Guidance on internal package pressure

Ethanol Fermentation: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

On a per mass basis, yeast will ferment glucose into roughly equal parts ethanol and CO_2. It is the CO_2 gas formed that we are concerned about in terms of package over-pressurization. At a given temperature, as fermentation proceeds and CO_2 is produced, the internal pressure of a package will increase. If the package is warmed, pressure will further increase because the solubility of a gas decreases as temperature increases. In some cases, internal pressures can exceed the limitations of the package, potentially causing dangerous package failure.

The chart on the following page demonstrates the increase in package pressure as temperatures increase.

Internal Package Pressure

CO_2 Volumes

Temperaure	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1
40	12.2	13.3	14.4	15.4	16.5	17.6	18.7	19.7	20.8	21.9	23.0	24.0	25.1	26.2	27.3	28.4	29.4
45	15.1	16.2	17.4	18.6	19.8	21.0	22.2	23.4	24.6	25.8	27.0	28.1	29.3	30.5	31.7	32.9	34.1
50	18.1	19.4	20.7	22.0	23.3	24.6	25.9	27.2	28.5	29.8	31.2	32.5	33.8	35.1	36.4	37.7	39.0
55	21.2	22.6	24.1	25.5	27.0	28.4	29.8	31.3	32.7	34.1	35.6	37.0	38.4	39.9	40.0	40.0	44.2
60	24.5	26.1	27.7	29.2	30.8	32.4	33.9	35.5	37.1	38.6	40.2	41.8	43.3	44.9	46.5	48.0	49.6
65	28.0	29.7	31.4	33.1	34.8	36.5	38.2	39.9	41.6	43.3	45.0	46.7	48.4	50.2	51.9	53.6	55.3
70	31.6	33.4	35.3	37.1	39.0	40.8	42.7	44.5	46.4	48.2	50.1	51.9	53.8	55.6	57.5	59.3	61.2
75	35.3	37.3	39.3	41.3	43.3	45.3	47.3	49.3	51.3	53.3	55.3	57.3	59.3	61.3	63.3	65.3	67.3
80	39.1	41.3	43.4	45.6	47.7	49.9	52.0	54.2	56.3	58.5	60.6	62.8	64.9	67.1	69.3	71.4	73.6
85	43.1	45.4	47.7	50.0	52.3	54.6	56.9	59.2	61.6	63.9	66.2	68.5	70.8	73.1	75.4	77.7	80.0
90	47.1	49.6	52.1	54.5	57.0	59.5	62.0	64.4	66.9	69.4	71.9	74.3	76.8	79.3	81.8	84.2	86.7
95	51.3	53.9	56.6	59.2	61.8	64.5	67.1	69.8	72.4	75.0	77.7	80.3	83.0	85.6	88.2	90.9	93.5
100	55.5	58.3	61.1	63.9	66.8	69.6	72.4	75.2	78.0	80.8	83.6	86.4	89.2	92.0	94.8	97.7	100.5
105	59.8	62.8	65.8	68.8	71.8	74.7	77.7	80.7	83.7	86.7	89.7	92.6	95.6	98.6	101.6	104.6	107.5
110	64.2	67.4	70.5	73.7	76.8	80.0	83.2	86.3	89.5	92.6	95.8	98.9	102.1	105.3	108.4	111.6	114.7
115	68.6	72.0	75.3	78.7	82.0	85.3	88.7	92.0	95.3	98.7	102.0	105.3	108.7	112.0	115.3	118.7	122.0
120	73.1	76.6	80.2	83.7	87.2	90.7	94.2	97.7	101.2	104.7	108.3	111.8	115.3	118.8	122.3	125.8	129.3
125	77.6	81.3	85.0	88.7	92.4	96.1	99.8	103.5	107.2	110.9	114.6	118.3	122.0	125.7	129.3	133.0	136.7
130	82.2	86.0	89.9	93.8	97.7	101.5	105.4	109.3	113.2	117.0	120.9	124.8	128.7	132.5	136.4	140.3	144.2

< 60 psi | **60-90 psi - Warning** | **> 90 psi - Danger**

**Data derived with the assistance from McDantim, Inc. using formulas from Crovetto, R.,* Evaluation of Solubility Data of the System CO_2-H_2O from 273K to the Critical Point of Water

When considering target CO_2 volumes and calculating priming sugar additions, it is critical to consider the temperature that the package may be stored at in the supply chain or by the consumer. It is not safe to assume your beer will always be kept cold. High temperatures caused by beer being left in a hot garage or car, for example, should be taken into consideration. High temperatures can take a safe internal package pressure up to unsafe levels very quickly. Always consider the highest reasonable temperature the beer could be exposed to when considering target CO_2 levels from a package integrity perspective.

What is a safe package pressure?

The internal pressure specifications of a particular can or bottle can vary significantly by manufacturer. Factors can include glass or aluminum thickness, fill volume, CO_2 volumes and temperature. Smaller headspace volumes will make the package more sensitive to temperature increases. Please consult the can or bottle manufacturer when determining target CO_2 content. Suppliers should be able to provide their own package pressure ratings and limitations.