WHAT I KNOW ABOUT CIDER HEAT PASTEURISING AND CARBONATION

Heat pasteurisation is commonly practiced in the commercial beverage environment, such as fruit juice processing, beer bottling and canning, etc. The aim of pasteurising is to apply a lethal level of heat to yeast, pathogens, etc in the beverage in order to prevent spoilage of the product and to stop fermentation which could cause undesirable CO2 pressure to build up in the packaging containers.

Commercially, flash or tunnel pasteurising is often used, which as part of the production process exposes the packaged product to a high temperature for a short period of time.

This process isn't readily available to craft cidermakers, nor are other methods requiring special equipment such as small micron filtering. However, pasteurisation by exposing cider to enough heat to kill the yeast and stop fermentation is readily available and effective.

For craft cidermakers looking to produce sweet, carbonated cider without resorting to complex processes such as keeving, multiple rackings, or chemical means and artificial sweeteners, heat pasteurising is an attractive option.

Fermentation can be stopped by pasteurising at a point where sugar remains in the cider, and because pathogens are destroyed, the product can be stored at room temperature. Bottling before pasteurisation allows CO2 to be generated and remain in the cider. Once fermentation is stopped by pasteurisation, no more sugar is converted to CO2 so the resulting cider is left with unfermented sugar sweetness as well as carbonation from the residual CO2.

Generally, the differential between bottling and pasteurising point is in the order of five or so specific gravity points which results in 2 to 3 volumes of carbonation (as a "rule of thumb", one gravity point change results in the generation of 0.5 volumes of CO2). Medium Sweet ciders typically have a SG of 1.015 because of the residual sugar whereas Medium Dry is around 1.010. So, bottling at 0.005 above the desired sweetness level should result in a "Goldilocks" (just right) carbonated cider. An alternative approach is to fully ferment down to 1.000 then backsweetened to the appropriate level using sugar, apple juice or apple juice concentrate, bottle then pasteurise once the desired carbonation has taken place.

Carbonation progress can be estimated from the rate of fermentation, the firmness of a plastic "test bottle" or a bottle filled with the cider and fitted with a pressure gauge. When the carbonation level reaches the desired pressure (say, 2.5 Bar or 45 psi) then the cider is ready to be pasteurised.

One of the concerns with producing naturally carbonated cider is the potential for the CO2 pressure generated inside the sealed bottle to create a bottle bomb. This pressure can result from ineffective pasteurisation or excessive pasteurising temperature. Ineffective pasteurisation allows fermentation to continue, so cider bottled at 1.015 and allowed to ferment down to 1.000 can produce seven or eight volumes of CO2 and a bottle pressure at room temperature of over 100 psi. Similarly, a bottle carbonated to 3 volumes at room temperature could develop almost 200psi while being pasteurised if the temperature is too high.

Therefore, producing sweet, carbonated cider using heat pasteurisation is a tradeoff between carbonation level and pasteurising temperature. But, it can be done effectively and safely.

WHAT IS NEEDED FOR EFFECTIVE PASTEURISING

Most of the available information on pasteurising is in metric units. However where it helps with, imperial units such as temperature, mass, volume, etc, are in brackets.

According to work done in breweries by H.W. del Veccio and others in the 1950's, reliable pasteurisation takes place at temperatures above 60C (140F).

Pasteurisation is measured in Pasteurisation Units (PUs) where one PU is the level of yeast, pathogens, etc, destroyed when the product is exposed to 60C for one minute. The amount of pasteurisation required differs according to the potential pathogen, and yeast load, so the target PUs for effective pasteurisation can differ from beverage to beverage.

While brewery processes for beer typically require 5 to 40 PUs, because of cider's relatively high yeast load etc, the conventionally accepted target level for cider is 50 PUs (according to Lea and Jolicoeur). There are some views that 30 PUs is adequate for cider and some research has shown this to be the case, so anything approaching 50 PUs should work and have a reasonable margin of safety.

Recent work out of Washington State University indicates that anything over 60C (140F) for a short time will kill certain yeasts, but the study didn't address the effect on pathogens so aiming for a target of 30-50 PUs seems prudent.

The level of PUs generated per minute is calculated from del Veccio's formula of PU = t x 1.393 raised to the power of (T-60), where t = time in minutes and T = temperature C.

As the following chart (Fig 1) based on this formula shows, PUs per minute increase exponentially with temperature and quickly reach into the hundreds above 75C (167F) or so, hence the effectiveness of flash pasteurisation in commercial applications.

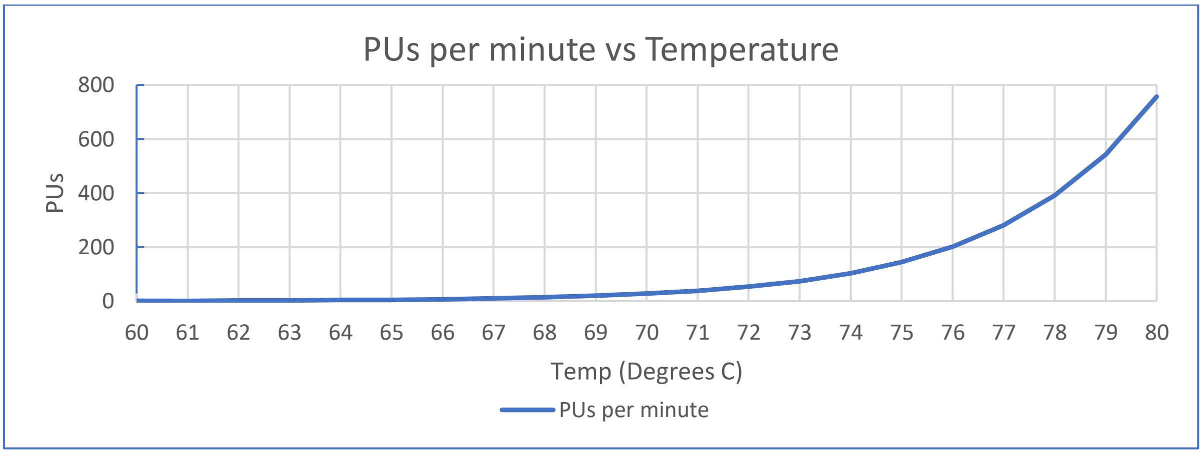

Fig 1

For the temperature range that craft cidermakers might typically deal with for cider pasteurising, there is a marked difference between 60C, 65C, 70C etc. Anything much above a bottle temperature of 65C doesn't need many minutes to produce more than enough PUs for effective pasteurisation in cider.

Temp C	60	61	62	63	64	65	66	67	68	69	70
Temp F	140	142	144	145	147	149	151	153	154	156	158
PUs per minute	**1.0**	**1.4**	**1.9**	**2.7**	**3.8**	**5.2**	**7.3**	**10.2**	**14.2**	**19.7**	**27.5**

Fig 2

BOTTLE BOMB CONCERNS

Unfortunately, as PUs per minute increase with temperature, so does the amount of CO_2 driven out of solution in the bottles, and hence the internal bottle pressure generated. Andrew Lea (author of Craft Cider Making) has an excellent spreadsheet, based on Henry's Law, which calculates bottle pressure for a range of temperatures at different volumes of CO_2 (http://www.**cider.org.uk/carbonation_table.xls**).

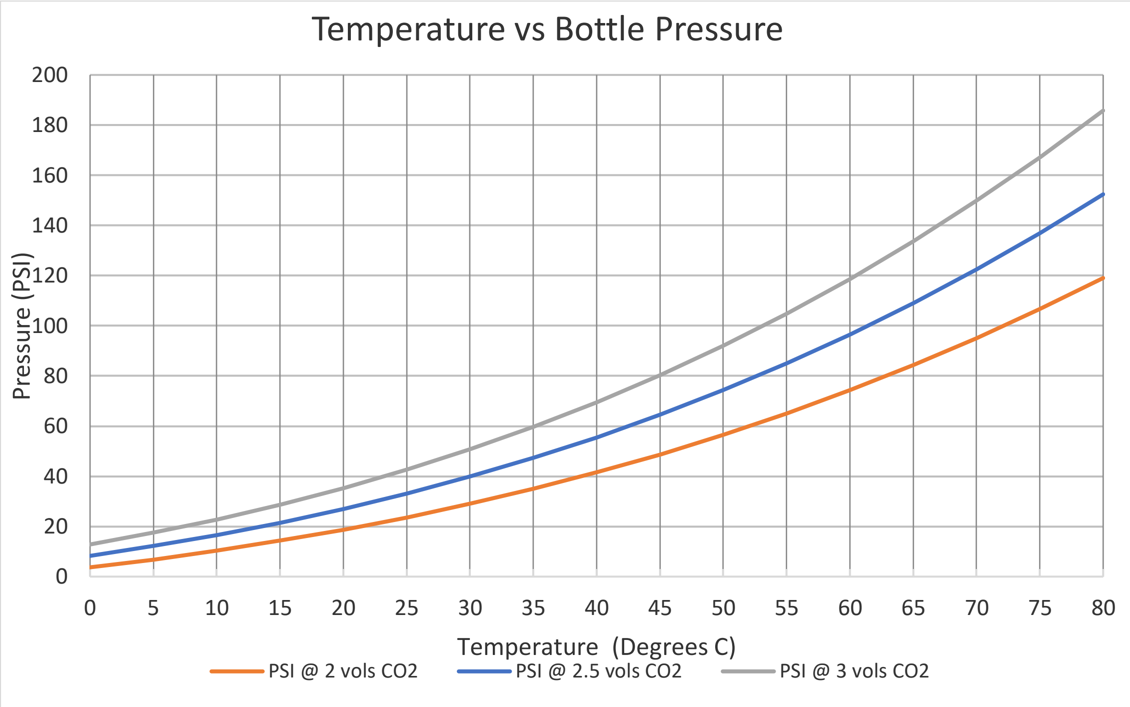

Fig 3

Figure 3 data is taken from Andrew Lea's spreadsheet and shows that for pasteurising temperatures below 70C (158F), pressure over the normal range of cider carbonation (2 vols - 3 vols of CO2) is unlikely to exceed 150psi.

Although the spreadsheet calculates the pressure in Bars, since pounds per square inch (psi) is generally more commonly used for pressure, the results here are shown in psi (A Bar is approximately 14.5 psi).

The main issue of concern with heat pasteurising is how much pressure bottles of cider can withstand before becoming "bottle bombs". There are lots of opinions and folklore out there, which tend to be quite conservative. Bottle manufacturers seem reluctant to publish information for their product, however there are some "pressure standards" that bottles are expected to meet. For example, China Misa Glass Co. (a supplier to Heinekin) quote GB4544 (a China standard) as requiring bottles to withstand 1.2MPa to 1.8MPa (174psi to 261psi) depending on the market the bottles are intended for. The US Department of Commerce quotes 225psi for refillable bottles and 200psi for non-refillable bottles.

While these limits seem to be quite high, they are based on batch testing. (i.e. samples from a batch are tested and if they pass, the batch is passed). Unfortunately, the range of failures in a batch can be quite wide (in the order of 30%-50% if all bottles rather than random samples are tested), so it is possible for some "worst case" bottles to be in the marketplace. This is a reason why bottle failures sometimes occur.

One of the characteristics of glass is that it can withstand stress for some time before failing. Stress slowly builds up to failure levels around "weak points" such as corners, sharp edges, flaws, etc, but the stresses reverse somewhat if the cause is removed. Because of this, different bottle shapes, etc, it is difficult to predict when a "bottle bomb" might happen, so conservative carbonation pressure and pasteurising temperatures help avoid the problem.

"In the interest of science" I tried to destruction test some commonly available bottles by carbonating to 2.5 volumes then subjecting them to temperatures in excess of normal pasteurising temperatures, in fact getting as close as possible to the boiling point of water.

With heat pasteurising, heat stress and internal pressure is only applied to bottles for a short time. This pressure might cause an issue if it remains in the long term. Fortunately, the stress doesn't necessarily reach a critical short term level during pasteurisation since heating time isn't long and when the bottles cool down, the stress is relieved quite quickly and bottle pressure returns to normal.

The bottles in the "destruction test" surprisingly reached over 90C (195F) without failure. In fact, the bath water was boiling at my altitude of 1000 metres so it couldn't get any hotter, and the bottles didn't reach their pressure limit at that temperature. It might be a different story with 100C (212F) at sea level. Perhaps some brave cidermaker might like to try it!

A further attempt involved commonly available salvaged bottles which were carbonated to 3.0 volumes of CO_2 at 25C (77F), then heated to above 90C (195F) in the water bath and held there for ten minutes. (The bottles were Heineken, Peroni, and James Squire which are probably similar to Coors, Bud, MGD, etc.). They all were 333ml (12 fl oz) bottles and weighed in the range 186 to 207 grams (6.5oz - 7.3 oz).

Similar capacity Grolsch bottles weigh 235 grams (8.3 oz), which suggests that they are up to 20% stronger than the others. Having said that, while the bottles were heating up the pressure was monitored using a Grolsch bottle fitted with a pressure gauge. The Grolsch seal started leaking at around 70C (160F) which generated an estimated pressure of 150psi, so they might have an unintentional "built in safety valve". In fact, Grolsch have acknowledged that their seals may leak near this pressure (see a post in HBT by Beaudoin dated 9 April 2013)

It is interesting to note that Claude Jolicoeur (The New Cidermaker's Handbook) refers to Grolsch bottle seals in his section on Ice Cider as *"these will let excess pressure exit and avoid bursting".*

There were no failures with the salvaged bottles up to 90C (195F), however the crown seal popped off the Peroni bottle at about 92C (198F). So, this seems to suggest that ordinary beer bottles are quite a bit stronger than we sometimes think, and could possibly be pressurised to 160 psi (or even beyond) for a short time with some confidence. Typically, pressure returns to normal (20 psi to 45 psi depending on carbonation level) as the CO_2 is taken back into solution at room temperature.

PASTEURISING METHODS

A number of different approaches to heat pasteurisation have been posted on the HBT forum.

The "Grandfather" of them all seems to be Pappers post "Easy Stove-Top Pasteurising" (sticky at the top of the forum). There is also JimRausch's "Cooler Pasteurisation" (see one of his posts 16 April 2018), and Bembel's "Pasteurisation Time and Temperature for Cider" (see a post 11 May 2016). There have also been others along similar lines.

The approaches fall into two broad categories, which for the sake of differentiation are described here as **"HIGH HEAT" and "LOW HEAT"**.

With "HIGH HEAT", bottles are put into a hot waterbath and left there until the temperature stabilises (i.e. the bottles heat up and the waterbath cools down until equilibrium is reached) or until a desired bottle temperature is reached. This is the approach described by Pappers and JimRausch and uses an initial waterbath temperature in the order of 80C(176F).

Equilibrium ideally occurs around 65C-70C(149F-158F), which ensured that more than enough PUs are produced in a short period of time to result in effective pasteurisation.

With "LOW HEAT", the bottles are put into a lower temperature waterbath which has its temperature maintained by external heating (such as a stovetop or sous vide heater) until the bottles reach close to the waterbath temperature. This is the approach described by Bembel and uses a waterbath of around 65C-70C (149F - 158F). The bottles heat up close to the waterbath temperature and are kept there for long enough to ensure pasteurisation.

Due to their residual heat, pasteurisation continues after the bottles are removed from the waterbath and they cool down towards 60C. This can account for more than half of the total PUs produced. When cooling down from temperatures between 65C and 70C, around 30-40 PUs are produced.

For both HIGH HEAT and LOW HEAT, the bottles are either left in the waterbath for long enough for the required temperature to be reached, or more precisely the bottle temperature is monitored using a cooking thermometer inside a test bottle.

Monitoring involves recording the time the bottles are at a particular temperature. (i.e. record the time that the bottles are at say, 60C, 61C, 62C etc, or record the temperature after 1 minute, two minutes etc.) The PUs are calculated for each set of readings and summed to get the cumulative PUs produced.

PASTEURISATION RESULTS

"HIGH HEAT" and "LOW HEAT" methods were trialled using bottles of water and also with "live" bottles of cider. The times, temperatures and PUs resulting from each trial are shown in Figure 4 to Figure 11.

Although the data might appear to be very precise, a word of caution is that the idea was to review commonly used approaches to heat pasteurising in order to understand what happens in practice, rather than carry out some sort of scientific study. So, the results may not be replicated exactly with every pasteurisation since there were some slight temperature and time differences between trials.

Also, there are some studies that suggest that it can take somewhere between 10 and 20 minutes for the temperature gradient in a bottle to stabilise, and that the temperature in the middle of the bottle might only be around 75% of the temperature at the edges after 10 minutes. So, it is likely that the pasteurisation levels achieved in the trials may be higher than those calculated, since the temperatures taken from the middle of the bottles may be lower than the temperature at the edges.

Other Computational Fluid Dynamics studies have shown that a uniform temperature gradient throughout the bottles can be reached in approximately five minutes (i.e. there is no "cold spot") so the temperature measured in the middle of a bottle should be representative of the temperature throughout in some cases.

In any case, any errors in temperature will be on the conservative side so the PUs achieved will be under, rather than over calculated.

Any minor inaccuracies don't seem to make a lot of difference in the calculations. After all, the aim was to achieve a broad target of PUs for effective pasteurising, rather than zero in on an absolute number.

The trials do reveal what happens during different heat pasteurisation approaches and indicates what level of pasteurisation each will produce. The bottle temperatures reached are such that under "normal" circumstances, bottle pressure shouldn't reach dangerous levels. But as always, safety precautions such as gloves and face protection is advisable.

Each trial involved an 8 litre (2 U.S. gallon) waterbath with five 333ml (12 fl oz) capacity bottles (each bottle and contents occupying a bit above 420 ml or 14 fl oz in the waterbath) and with room and bottle ambients between 18C and 20C (64F – 68F).

There isn't anything special about this setup. It is simply based the waterbath being a convenient size 10 litre container (a bottling bucket) and getting 15 bottles of cider from a 5 litre carboy which means three "pasteurisations" of five bottles each, per carboy.

The ratio of heated water volume (8 litres) to cold bottles volume (2.1 litres) was about 4:1 which seems to work well. Other configurations with different size waterbaths or number of bottles might produce slightly different results (especially equilibrium temperature). Nevertheless, the principles of each approach hold within reasonable limits.

METHOD 1 – **"HIGH HEAT" PASTEURISING** (High temperature waterbath without continuous heating)

82C (180F) WATERBATH - BOTTLES IN THE WATERBATH FOR 10 MINUTES

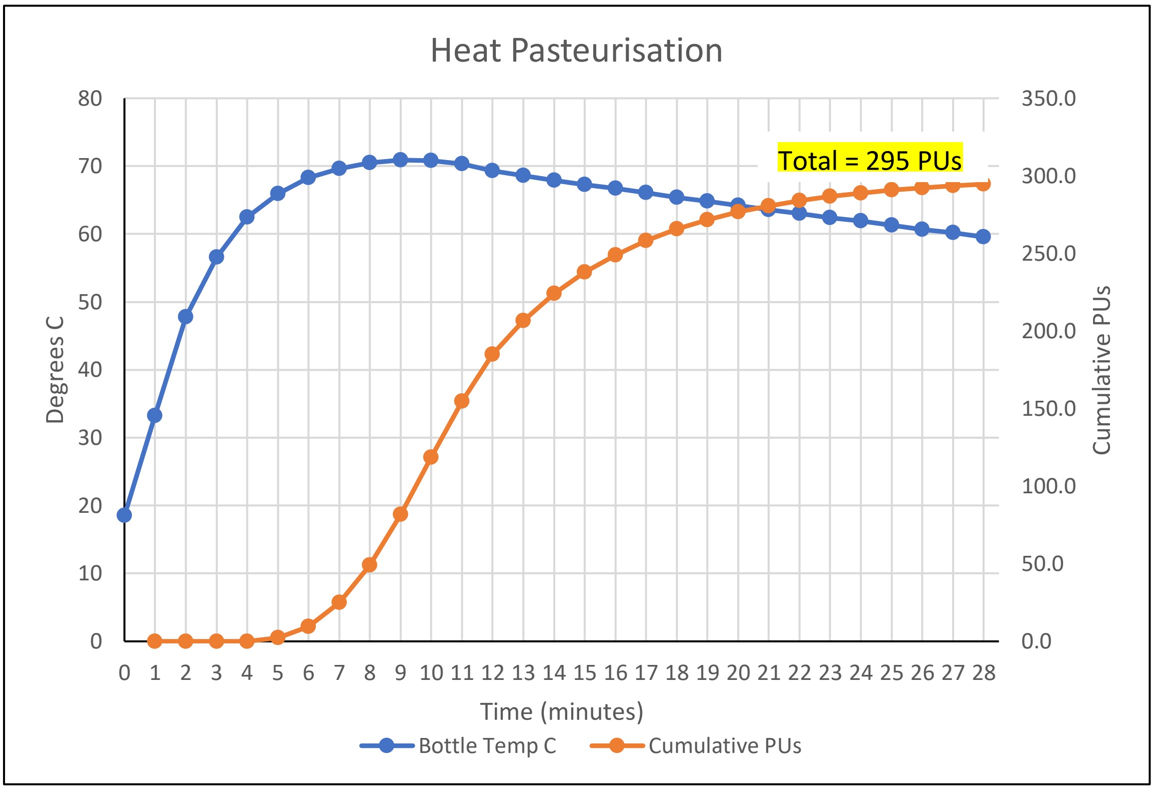

Fig 4

Figure 4 shows the effect of a high waterbath temperature. As the bottle temperature quickly reaches 70C, the number of PUs produced per minute (27.5 PUs) is more than half the total level required for cider. From 70C the long cooldown also results in a high level of PUs. So as shown in Figure 5, shorter heating time is appropriate. Maximum bottle pressure with 3 vols of CO_2 is around 160 psi.

82C (180F) WATERBATH - BOTTLES IN THE WATERBATH FOR 6 MINUTES

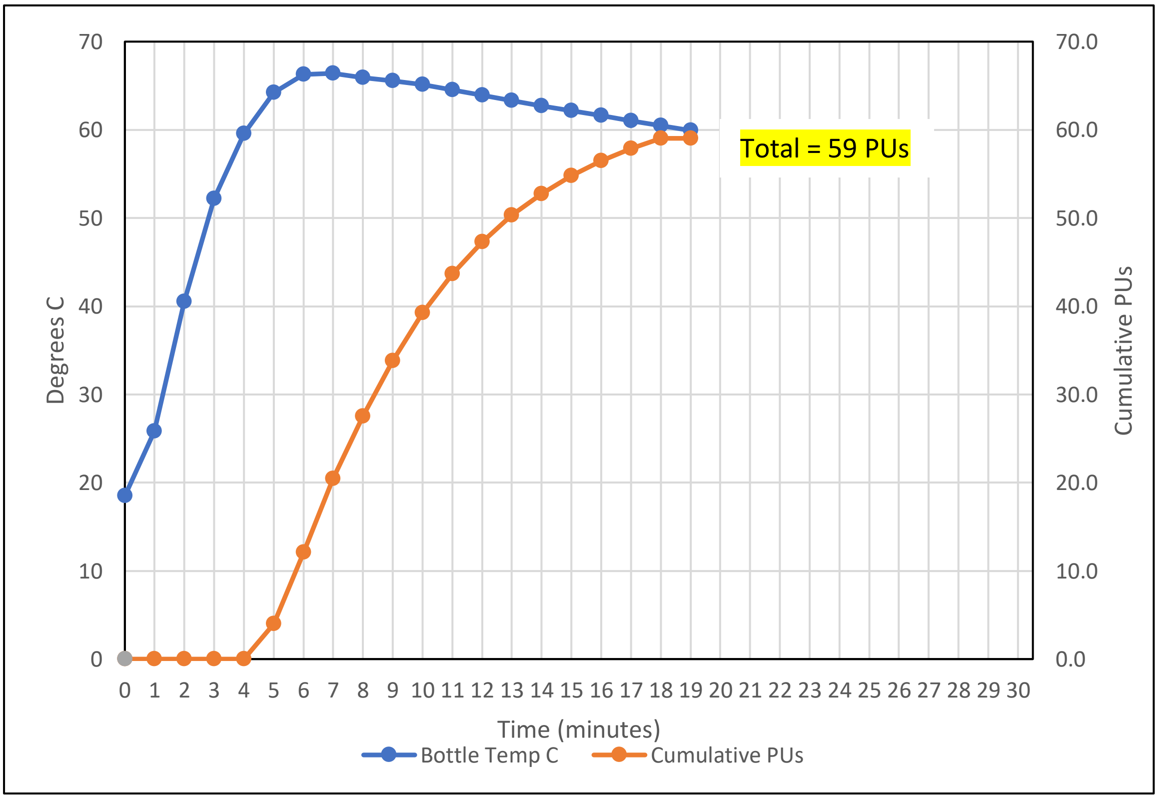

Fig 5

Figure 5 shows the significant reduction in total PUs with a shorter (6 minutes) heating phase since early removal of the bottles before equilibrium is reached limits the time spent producing high PUs per minute. Maximum bottle pressure with 3 vols of CO_2 is 140 psi.

80C(176F) WATERBATH - BOTTLES PRE-HEATED TO 50C(122F) THEN IN THE WATERBATH FOR 10 MINUTES

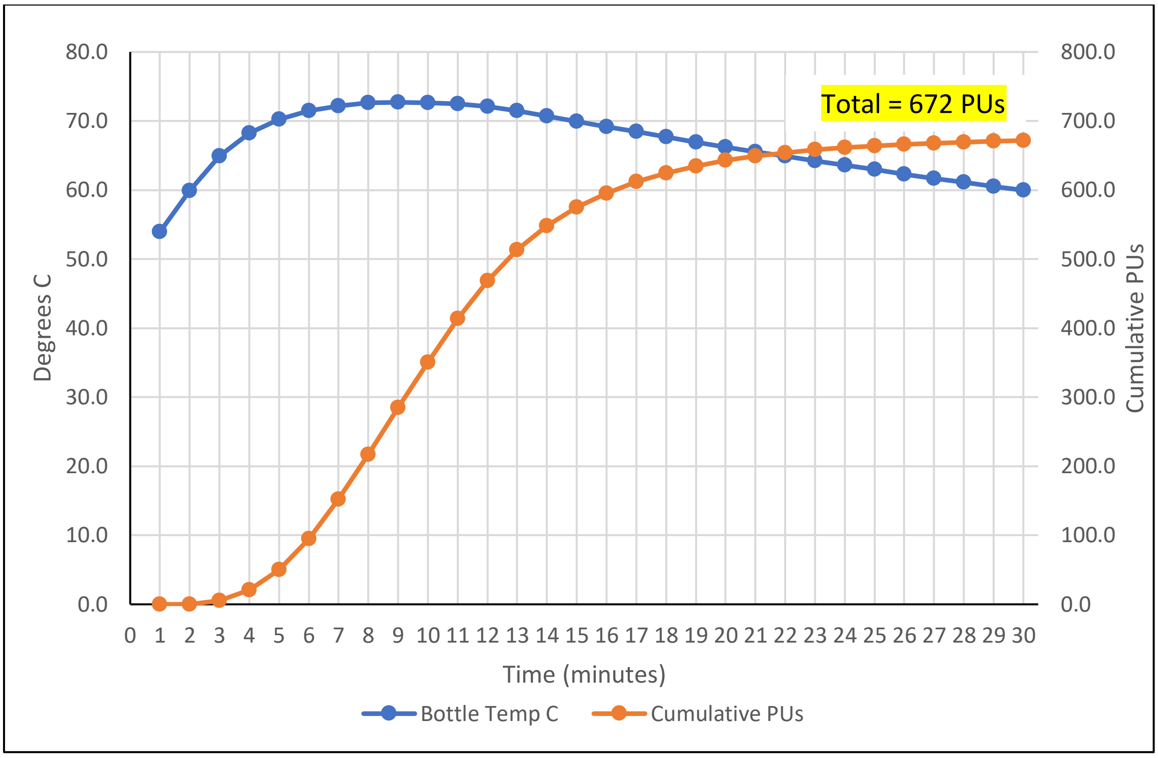

Fig 6

As with figure 4, the bottle temperature approached equilibrium above 70C. Preheating the bottles causes their temperature to reach above the target temperature very quickly and the consequent time at this temperature and long cooldown results in the high level of PUs.

80C(176F) WATERBATH - BOTTLES PRE-HEATED TO 50C(122F) THEN IN THE WATERBATH FOR 5 MINUTES

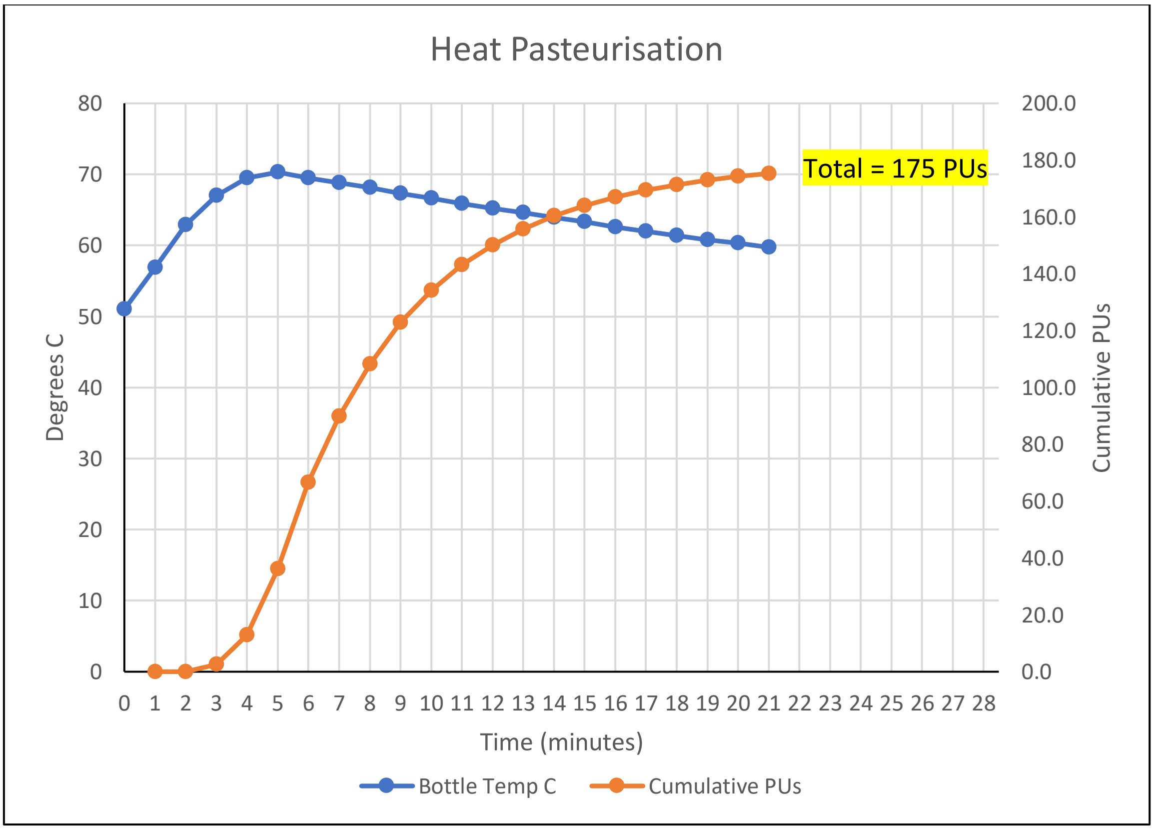

Fig 7

As with figure 5, figure 7 shows the effect on total PUs with a shorter (5 minute) heating phase where bottles are removed before equilibrium is reached. As with figs 5 & 6 maximum bottle pressure with 3 vols of CO_2 is 160 psi.

75C(157F) WATERBATH - BOTTLES IN THE WATERBATH FOR 10 MINUTES

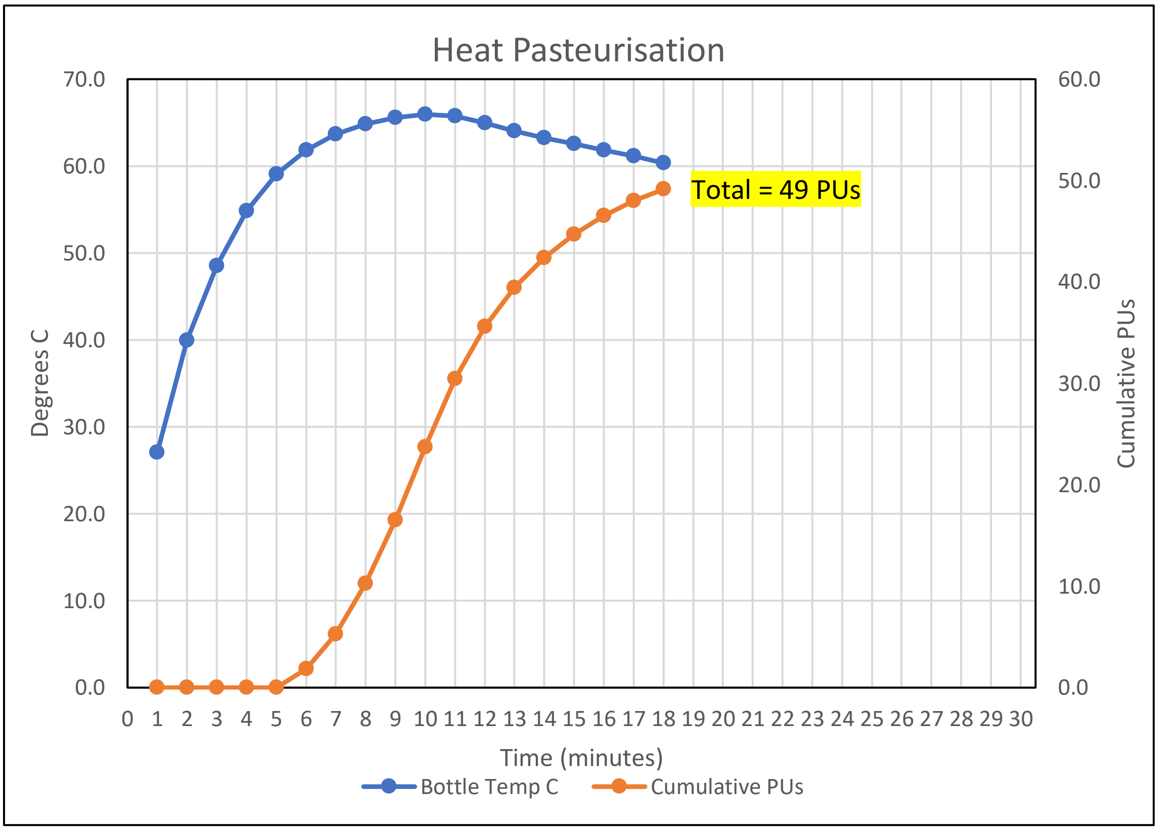

Fig 8

Figure 8 shows the effect of a lower waterbath temperature (75C). Although the heating phase takes 10 minutes, the bottle temperature (equilibrium) is just 66C. At this temperature, PUs per minute remain at modest levels and maximum bottle pressure with 3 vols of CO_2 is 137 psi.

METHOD 2 – "LOW HEAT" PASTEURISATION (Low temperature waterbath with continuous heating)

The waterbath temperature is maintained during pasteurisation using Stovetop or Sous Vide heat. When the cold bottles are put into the waterbath, the temperature drops by 2 or 3 degrees but recovers after a few minutes. This doesn't seem to affect the results.

HEATED 70C(158F) WATERBATH - BOTTLES IN UNTIL THEIR TEMPERATURE REACHES ABOVE 65C(149F)

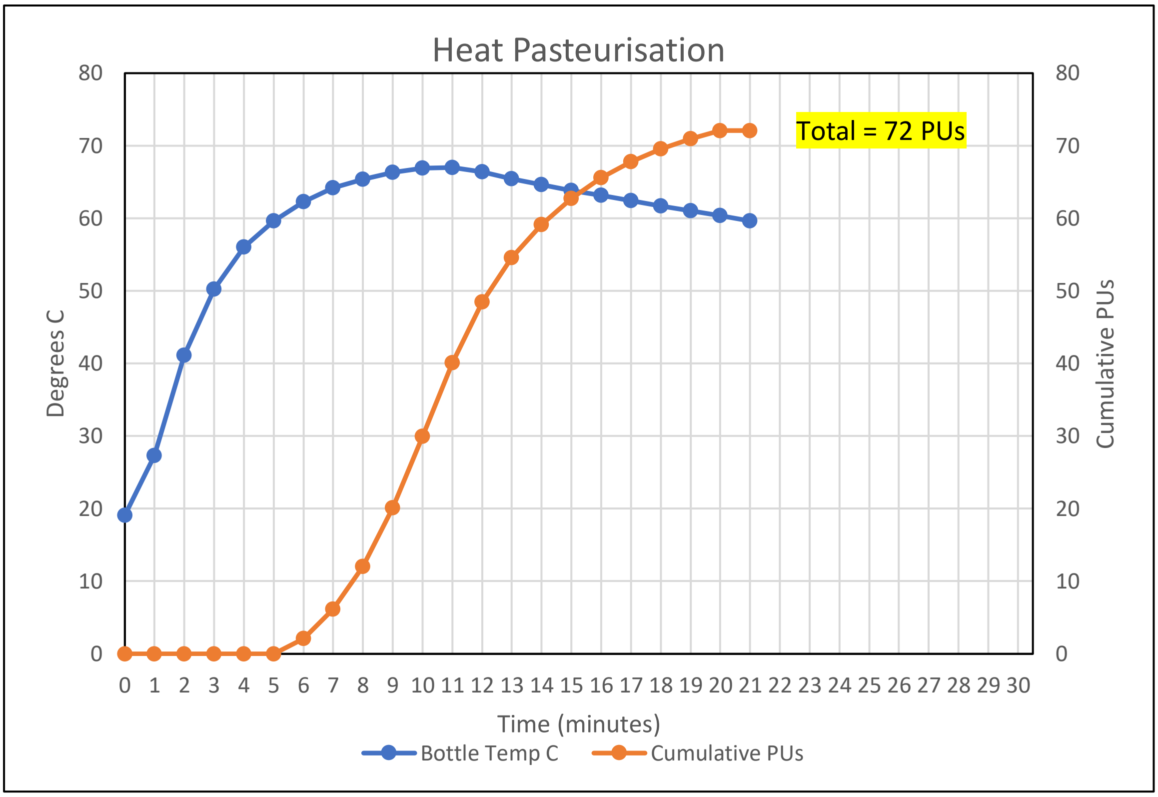

Fig 9

Figure 9 shows the effect of a constant low waterbath temperature. Bottle temperature (and hence PUs produced) is limited to equal or below the waterbath temperature. Maximum pasteurisation bottle pressure with 3.0 vols of CO_2 is 152 psi.

HEATED 67C(153F) WATERBATH - BOTTLES IN UNTIL THEIR TEMPERATURE REACHES ABOVE 65C(149F)

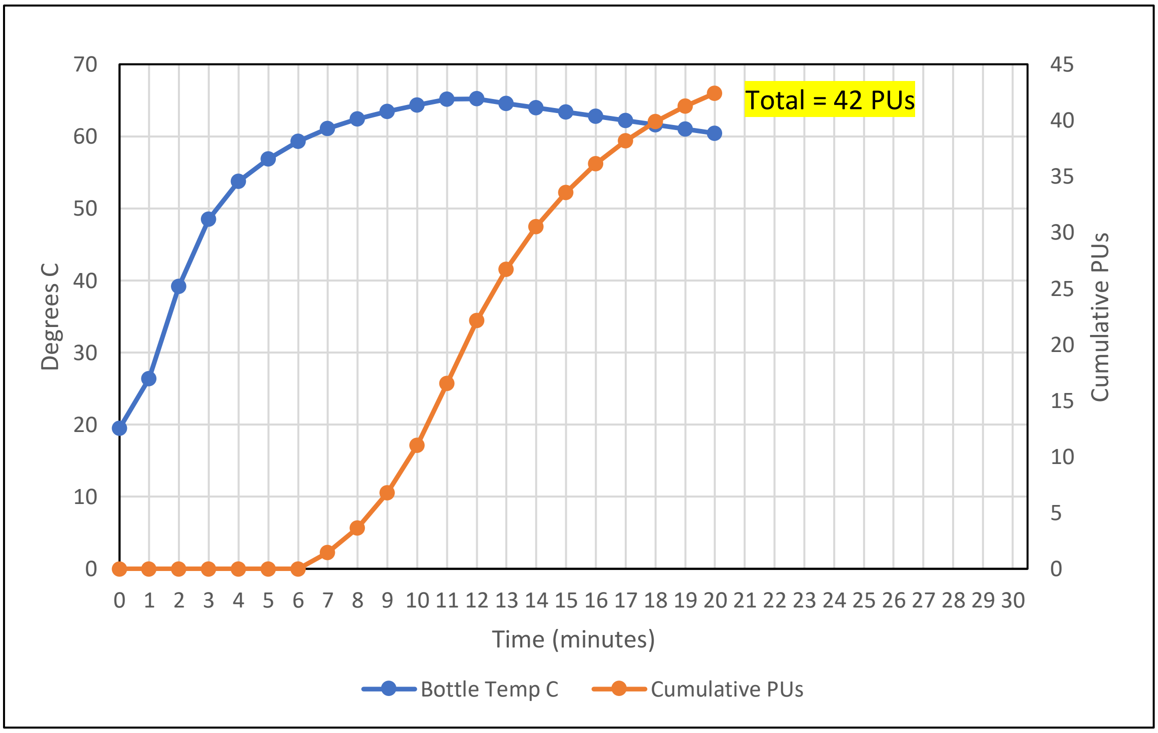

Fig 10

Figure 10 is a conservative, low waterbath temperature which limits pasteurisation to a maximum of about 6 PUs per minute. Maximum pasteurisation bottle pressure with 3.0 vols of CO_2 is 142 psi. The level of pasteurisation is controlled by the duration of the heating phase.

HEATED 65C(149F) WATERBATH - BOTTLES IN UNTIL THEIR TEMPERATURE REACHES CLOSE TO 65C(149F)

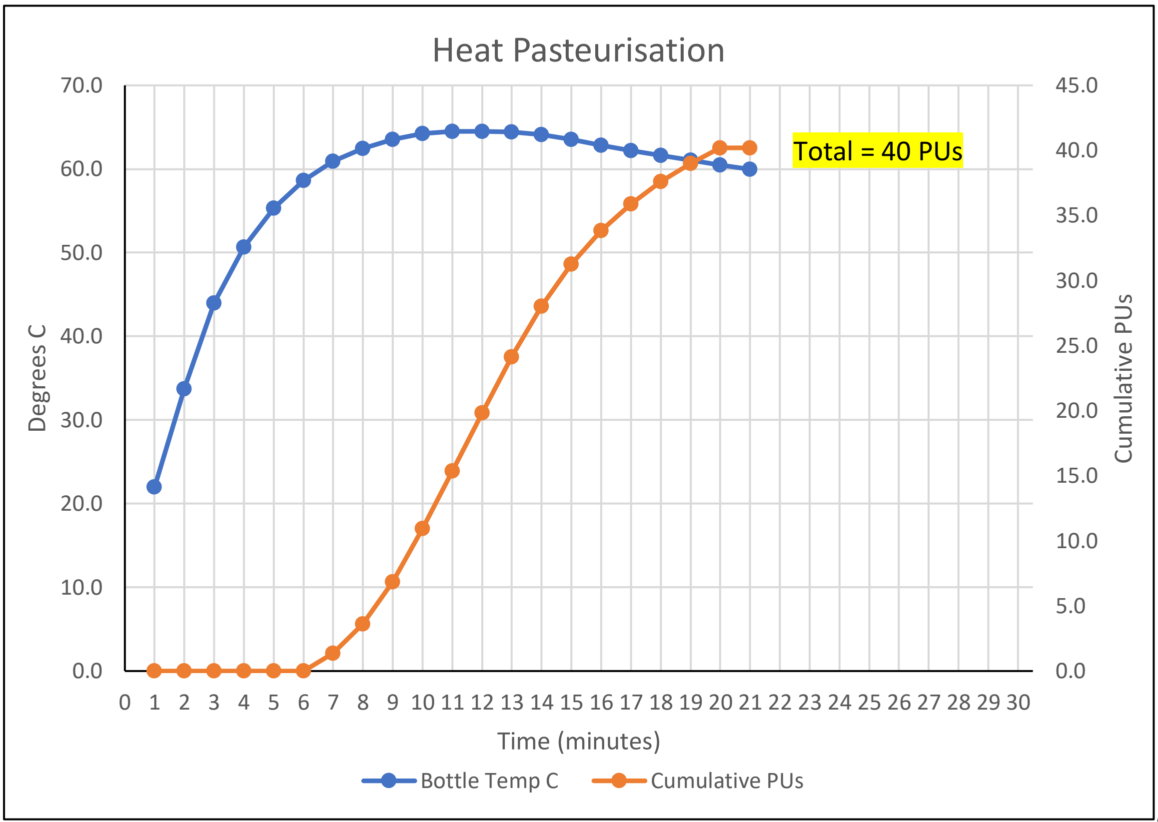

Fig 11

Figure 11 is a conservative, low waterbath temperature which limits pasteurisation to around 5 PUs per minute. The level of pasteurisation is controlled by the duration of the heating phase (e.g. leaving the bottles in for two more minutes of heating would add another 10 PUs to the total). Maximum pasteurisation bottle pressure with 3.0 vols of CO2 is 131 psi.

SUMMARY OBSERVATIONS AND COMMENTS

With the above approaches, less than half of the PUs are produced during the bottle heating time, and the rest result from the temperature retained in the bottles as they cool down to 60C. Shorter or longer times in the waterbath are an effective way to control the level of total PUs produced, especially in the case of pre heated bottles.

Putting room temperature (18C - 20C) bottles into a hot waterbath (70C – 80C) didn't result in any bottle failures from thermal shock.

Although it varies from case to case, the cooldown rate is in the range 3 to4 PUs per minute. This naturaly results in longer cooldown times from higher pasteurising temperatures and consequently higher PUs during cooldown. This can range from around 30 PUs at 65C (149F) pasteurisation to 150 PUs at over 70C (176F) pasteurisation.

Generally, as a rule of thumb for bottle temperatures which reach up to 70C (176F), a "formula" of ten minutes heat up and ten minutes cool down seems to produce effective pasteurisation around the conventional target 50 PUs without creating excessive bottle pressure. Recent research at Washington State University has indicated that 30PUs from 62C-65C is adequate for cider.

Pasteurising practices using high temperatures (above 80C) or long heating times tend to generate higher levels of pasteurisation than are needed for cider. However, these higher levels of pasteurisation don't appear to have any effect on the quality or taste of the cider unless the bottles reach much higher temperatures which cause the beverage to "cook".

Tailoring pasteurising time and temperature and calculating the resulting PUs per minute enables more precise pasteurisation targets to be achieved.

So, use all of this information as you wish to develop your own 'favourite" approach to heat pasteurising… good luck!

TJC February 2021

SOME REFERENCES

cider.org.uk/carbonation_table.xls

Andrew Lea's spreadsheet which calculates bottle pressure at different temperature for different volumes of CO2

Vinolab.hr

An excellent calculator which will calculate values of SG, ABV%, Sugar g/L

www.misaglass.com

Shanghai Misa Glass Co Ltd web site. Search GB4544 (Chinese Standard) to see bottle pressure limits for China, Japan and other developed countries

Search Google for "calconic pasteurisation"

Calculates PUs for beverages, temperature and time

Archive.org

Search "Glass bottles for carbonated soft drinks" to find the voluntary standard for bottle pressure issued by the US Department of Commerce/National Institute of Standards and Technology

Search Google for "Jo Morgan Teague"

Via Ohiolink, this will retrieve his 1950's PhD dissertation at Ohio State University that among other things contains the spread of pressure test data for batches of bottles.

Search Google for "Turnell Corp CFD study"

See the Youtube video of the temperature gradient in a bottle over time.

doi.org/10.3390/beverages6020024 (also www.mdpi.com, Journal: Beverages, Keyword: Cider)

A Preliminary Evaluation to Establish Bath Pasteurization Guidelines for Hard Cider (link posted by Jaypkk on HBT 4 Dec 2020)