

## THE FLAVOUR CONSEQUENCES OF GOOD INTENTIONS - COMMON BEER FLAVOUR PROBLEMS ARISING FROM SUSTAINABILITY INITIATIVES AND HOW TO AVOID THEM

**Dr W (Bill) J Simpson**

Cara Technology Limited, Leatherhead Enterprise Centre, Randalls Road, Leatherhead, Surrey, KT22 7RY, UK; email: [bill.simpson@cara-online.com](mailto:bill.simpson@cara-online.com)

### ABSTRACT

Making great beer is never easy. Aside from colour, haze, foam and gushing problems, issues related to product safety and microbiology can trip us up from time to time. On top of that, as many as 250 flavour faults can occur in beer. Most brewers can draw upon decades of experience to help them avoid such problems. However, policies and practices that have at their core the goal of sustainability, have the potential to open up a Pandora's Box of new flavour problems. Some of these can have powerful consequences for consumer confidence in the products. In this presentation these issues will be explored and talk about how the goal of top-class beer flavour can sit side-by-side with environmental and sustainability targets in modern brewery operations.

**Keywords:** *energy, extract loss, fermentation, flavour, flavour stability, off-flavour, packaging, sustainability, taint*

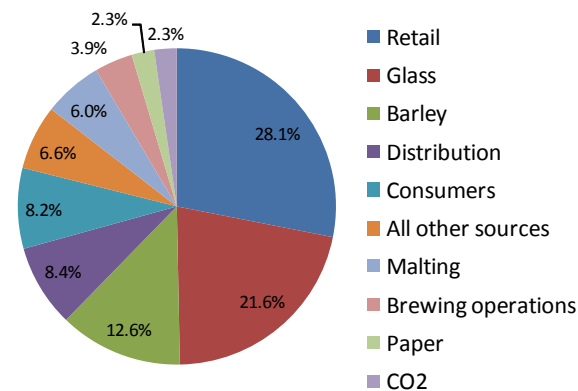
### INTRODUCTION

Sustainability initiatives no longer have to be justified in the way they were in the past. Today, most farmers, maltsters, brewers, packagers, distributors, retailers, consumers and recyclers make at least some effort to improve the sustainability of their activities and reduce their impact on the planet. Some organisations go further – placing sustainability and environmental stewardship at the heart of what they do.

In 2008, the New Belgium Brewing Company released a document entitled 'The Carbon Footprint of Fat Tire<sup>®</sup> Ale'<sup>1</sup>. This report represents a substantial step forward in relation to previous efforts<sup>5</sup> and gives us an insight into the impact on the environment of the commercial procurement, production, distribution and sales processes associated with the beer industry. The different contributions of these processes to the carbon emissions associated with beer are summarised in **Fig. 1**.

Some companies have placed an emphasis on carbon offsetting. For example, 'Cascade Green', a beer produced by Foster's Cascade Brewery in Tasmania has been certified Greenhouse Friendly<sup>TM</sup> by the Australian Government's Department of Climate Change. It is one of only a few products (of any sort) in Australia to be 100% carbon offset (see [www.cascadegreen.com.au](http://www.cascadegreen.com.au) for details).

Transparency and communication to the customer are also receiving increasing attention. During 2009 Japanese brewer Sapporo will become the first brewery to label beer cans with information on the total carbon emissions involved in its production: a figure of 161g CO<sub>2</sub> per 350ml can.



**Fig. 1 Contributions of different aspects of the beer supply chain to carbon emissions in the case of an American ale (based on data contained in New Belgium's 2008 report, *The Carbon Footprint of Fat Tire® Ale*). The total CO<sub>2</sub> emissions of a six pack of Fat Tire® Ale was estimated to be 3.189kg (173g from brewery operations, 1.53kg upstream of the brewery and 1.48kg downstream of the brewery).**

With the World's biggest brewer (Anheuser-Busch InBev) already recycling almost 98% of all materials used in production (see [www.inbev.com](http://www.inbev.com) for more details) and other major brewers aspiring to or achieving similar levels of environmental performance it could be argued that the industry is succeeding at many levels in its sustainability initiatives. This paper looks at the impact of some of the mechanisms by which such targets are achieved, with a particular emphasis of that most important of beer attributes – flavour.

### Beer flavour and its control

In any one beer more than 40 individual flavour notes can be discriminated by trained, expert tasters. Each and every flavour arises from something that is done or not done by someone or something in the malting, brewing, packaging, distribution and retail processes. Choices made in the design of products and processes impact directly on how the product is perceived by consumers<sup>4</sup>. Nowadays, brewery tasting activities are generally of a reasonable standard. This has come about as a result of a management focus on taster performance. Many brewers have made excellence in beer tasting a priority.

Tasting activities are directed toward management of product quality and improvement of core production processes. They have five main objectives:

- I. to screen incoming raw materials for off-flavours and taints;
- II. to act as a quality gate for different stages in the process, allowing remedial action to be taken as early as possible;
- III. to monitor the quality of final packaged beer;
- IV. to monitor beer shelf-life;
- V. to serve as a sensitive 'instrument' for brewery production trials.

As a result of these activities, waste is reduced by preventing beer from being brewed with poor raw materials and effort is not wasted in further processing beer already damaged beyond repair.

<b>TABLE I</b>	
<b>Positive beer flavours, off-flavours and taints impacted by sustainability initiatives</b>	
<b>Flavour Term</b>	<b>Chemicals</b>
Acetaldehyde	Acetaldehyde
Acetic	Acetic acid
Astringent	Various polyphenols
Bitter	Various hop-derived bitter acids, yeast-derived peptides
Bromophenol	Various bromophenols
Burnt rubber	Various sulphur compounds
Butyric	Butyric acid
Caprylic	Caprylic acid
Caramel	Various Maillard reaction products
Chlorophenol	Various chlorophenols
Citrus	Various hop-derived compounds
'Cooked'	Various Maillard reaction products and sulphur compounds
Diacetyl	Diacetyl
DMS	Dimethyl sulphide
Earthy	2-Ethyl fenchol
Ethyl acetate	Ethyl acetate
Ethyl butyrate	Ethyl butyrate
Ethyl hexanoate	Ethyl hexanoate
Floral	Geraniol, 2-Phenyl ethanol
Grainy	Various aldehydes, including isobutyraldehyde
Grapefruit	Various terpenes and terpenoids
H <sub>2</sub> S	Hydrogen sulphide
Honey	Phenylacetaldehyde, other unknown compounds
Indole	Indole
Inky	Various trihalomethanes
Isoamyl acetate	Isoamyl acetate
Isovaleric	Isovaleric acid
Lactic	Lactic acid
Leathery	Various compounds
Malty	Various compounds including heterocyclics such as 2-acetyl pyridine
Mercaptan	Methanethiol, Ethanethiol
Metallic	Various metal ions, including iron
Methional	Methional
Mouldy	Geosmin
Musty	Various haloanisoles
Papery	<i>trans</i> -2-Nonenal
Phenolic	4-Vinyl guaiacol, 4-Ethyl phenol
Rotten vegetable	Dimethyl disulphide
Smoky	Guaiacol
Solvent alcoholic	Isoamyl alcohol
Sweet	Various sugars (taste), various heterocyclic compounds (odour)
'Trubby'	Unknown
Woody	Unknown
Worty	Various aldehydes, heterocyclic compounds and sulphur compounds
'Yeast bite'	Yeast-derived peptides

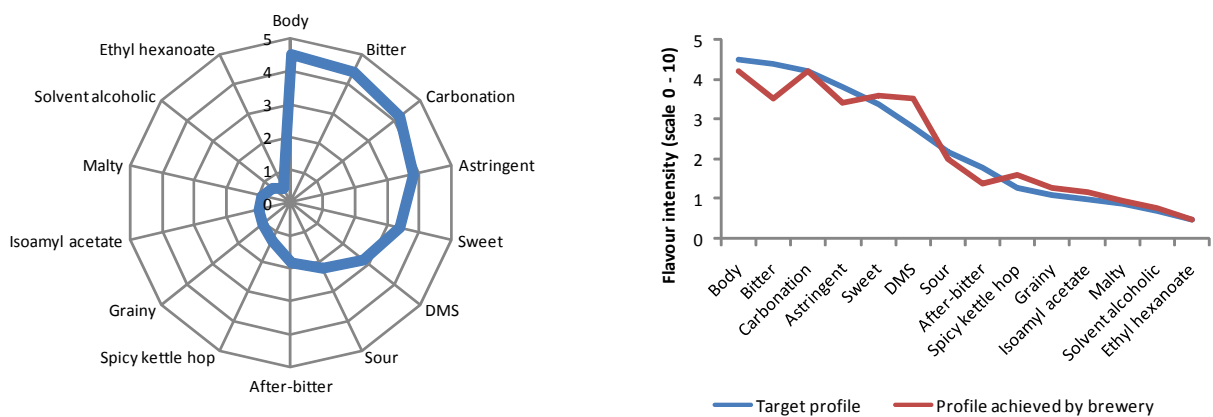
In addition, the corporate tasting function within a brewery Group may support product development (either through a technology-driven or a consumer-driven approach) and provide insight into issues such as desired product profiles, drinkability and product boredom. They can help protect against the risk of brand drift and assure compliance with desired profiles of brands brewed and packaged on different sites.

Knowledge of beer flavour and the origins of individual flavour components has never been better. The availability of well-trained taste panels, alongside sensitive analytical measurement technologies such as Gas Chromatography-Mass Spectrometry and High Performance Liquid Chromatography provides the possibility to look at beer flavour from the perspective of a cause and effect relationship.

How then can brewery practices carried out in the name of sustainability affect beer flavour and flavour stability? **Table I** lists the main flavours that are impacted by sustainability initiatives, together with the chemicals that give rise to them.

### Sustainability initiatives and their relationship to brand identity

Every brand needs a distinct flavour identity that can be recognised by its consumers (**Fig. 2**). Specific flavour attributes must be defined and present at consistent levels from one batch to the next. These flavour notes can range in number from seven to ten in the case of ‘clean’, modern pale lager beers, to more than 60 in the case of complex dark ales or stouts. How then can sustainability initiatives in the beer supply chain impact on brand identity?



**Fig. 2 Target brand profile for a pale lager beer: the chart on the left shows the most important flavour characters and their desired intensity (on a scale of 0–10) for one brand; the chart on the right compares the average production from one brewery site with the target profile**

**Local raw materials:** Ideally, sustainability encompasses production from local raw materials. But it remains a challenge to source the best raw materials, at the most competitive prices, as close as possible to the production site. Raw materials may be obtained from further afield for the very reason that they contribute distinctive flavour notes to the beer. This is perhaps most obvious in the case of hops; the flavours derived from them - including citrus, grapefruit, woody, and floral - are very important to the character of many beer brands (in addition, of course, to providing the bitter taste for which they are primarily employed).

To an extent this distinctiveness is related to hop variety. In practice, growth of certain hop varieties is restricted to specific parts of the world. This is partly due to climate and partly due to the risk of pests and diseases. In the last 18 months there has been a global shortage of hops. Distinctive hop varieties used to produce distinctive brands have sometimes not been available in the quantities needed. This has caused some to re-evaluate how they go about achieving their target brand profiles. There has been a shifting emphasis toward hop products that have a higher degree of security of supply and away from hops and hop products which carry with them an inherent seasonality in their availability.

To achieve greater security in production, a variety of processed hop products can be used, including hop oil extracts obtained from single hop varieties and/or separated by chromatography to accentuate certain flavour notes.

Alternatively, addition of traditional hop products (flowers and pellets) to the whirlpool, rather than to the wort kettle, can favour utilisation of volatile hop components. This has proven popular with some brewers.

**Natural raw materials:** The word 'natural' means different things to different people. Some use it to discriminate genetically-modified ingredients ('unnatural') from those which are not. The word is perhaps best used to describe raw materials which have been produced without 'excessive' intervention in the form of chemical fertilisers, waste streams, pesticides and downstream processing.

When raw materials are grown under close supervision without the use of chemical fertilisers, human or industrial waste or pesticides (often using traditional farming practices), they can be described as organic. Raw materials produced in this way can behave differently in the hands of the maltster and brewer compared to their more intensively-produced counterparts. For example, organic barley, aside from giving a reduced agronomic yield, may contain lower amounts of soluble protein (nitrogen) as a result of differences in the nutrient status of the soils in which they were grown. This can affect both the behaviour of the barley in the malting process and the way in which malt produced from it reacts in the brewhouse. Unless steps are taken to compensate for this different behaviour, lower concentrations of wort free amino nitrogen may result. This, in turn, may lead to reduced formation of volatile aromatic compounds by yeast (including higher alcohols and esters) and differences in fermentation rate and extent.

**Reduction in use of raw materials:** It could be argued that the global hop shortage has highlighted a need to economise in the use of precious raw materials. To make a smaller hop crop go further in relation to imparting bitterness to beer some brewers

have resorted to processing the hops available to them, rather than using dried hop leaves or minimally-processed hop pellets.

Isomerised hop pellets (type 60 and type 90) and isomerised hop extracts (produced using liquid CO<sub>2</sub>, super-critical CO<sub>2</sub>, and ethanol) have allowed brewers to achieve higher utilisation figures for the alpha-acids they have purchased. In this way, the bitterness of the beers made with such products has been conserved without putting other aspects of the brand profile at risk.

Of course, economy in use of hops has not been without impact on the other flavours which the hops impart to beer. Unless compensatory measures have been taken in the brewery, beers produced in this way have a different hop aroma and flavour profile as a result of the different concentrations of hop oil components delivered to the beer.

**Reduction in energy use in the brewhouse:** The wort boiling process is the most energy-intensive of all brewhouse processes and one of the most energy-consuming in the brewery. In the last 10–15 years improved wort boiling technologies and equipment have allowed energy use to be substantially reduced. This has been achieved through a combination of separating the different functional steps in the wort boiling process, improved ways of transferring heat into the wort and reclaiming energy that might otherwise have been lost. Whereas evaporation rates of 7–10% used to be the norm, 4%-5% has become the new benchmark. It is this reduction in evaporation rate that carries some risk in relation to retention of off-flavours in the wort.

Sulphury flavours from DMS and grainy flavours from wort aldehydes such as isobutyraldehyde are two cases in point. At the right level, both flavours can form an integral part of the brand profile, particularly in the case of pale lager beers. But if stripping of volatiles from the kettle is inadequate higher concentrations of both of these compounds will be left behind, leading to higher concentrations in packaged beer.

A focus on other parts of the process design can help reduce the risks. For example, if attention is paid to the content of S-methyl methionine in the malt the potential for DMS formation in the brewing process can be minimised and if whirlpool temperatures and stand times are also kept to a minimum (92°-95°C rather than close to 100°C) and 35–40 minutes, rather than 90–120 minutes, the concentration of DMS in the wort can be kept sufficiently low. The use of a healthy, active, pure yeast culture can eliminate wort aldehydes carried over from the brewhouse, reducing them to less flavour-active alcohols. This is not completely effective however. This is because a proportion of the aldehydes in the wort become bound to protein and are released later in the process (and often in packaged beer) by non-oxidative hydrolysis reactions.

The flavour and appearance of traditional Pilsner beers owes much to how worts are produced in the brewhouse. Decoction mashing is generally used, rather than infusion mashing. This gives rise to a number of flavours associated with this style of beer, including sweet, caramelised notes and distinctive malty flavours. Recently, concerns have been raised by European Union officials concerning the energy consumption associated with decoction brewing, in comparison with infusion mashing. At one point it was even suggested that a ban on the commercial use of the technique might ensue. So far the Czech industry and other brewers in Europe who use the technique, have resisted this movement. In fact in 2008, Czech beer was awarded regional status within

Europe, allowing its distinctive properties and production process to be protected to a degree.

### **Sustainability initiatives and their relationship to off-flavours and taints**

Flavours which are not designed into the brand profile and which are therefore foreign to the product, are known as off-flavours and taints. Off-flavours are generated by reactions (either chemical or biological) which take place within the product or process stream. Taints enter the product or process in a ready-made form, transferred intact from one environment to another with the aid of a 'vector' (e.g. water or air).

Some off-flavours and taints are more problematic than others. While consumers may tolerate a slight odour of boiled eggs (caused by low concentrations of H<sub>2</sub>S), the same will not be true of their reaction to the pungent musty flavour caused by even lower concentrations of tribromoanisole or trichloroanisole.

**Local raw materials:** Raw materials – regardless of where they come from – must be safe for human consumption and free from taints. In the case of water (which has historically always been sourced locally by breweries) this is not always the case. Treatments may be needed to render it suitable for use in beer production. Maintenance practices which are necessary for the success of such treatments may not always be carried out exactly as intended, not least because they are time-consuming, energy-intensive and expensive to perform.

For example, carbon filters used to filter incoming water have to be regularly regenerated, for example by steaming for 12–18 hours. If this is not done the filters will start to give up the off-flavours and taints they have adsorbed from the water over the previous weeks and months.

A failure of the brewery maintenance programme can lead to antiseptic flavours from various chlorophenols. Occasionally, inky flavours from trihalomethanes are also formed. A build-up of micro-organisms in the carbon filter can lead to formation of mouldy and earthy flavours (from geosmin and 2-ethyl fenchol), musty flavours (from chloroanisoles and bromoanisoles) and faecal characters (from indole and related compounds). Use of the wrong type of carbon also carries with it a risk of metal ion pick-up, which can generate metallic flavours in the water and ultimately, in the beer produced from it (the metal ions are also detrimental to beer flavour stability).

Malts and adjuncts also carry a risk of imparting off-flavours and taints to the beer produced from them. Musty flavours (from haloanisoles), mouldy and earthy flavours (from geosmin and 2-ethyl fenchol) and rancidity (from butyric acid) can all arise from time to time.

In some parts of Latin America rice used as an adjunct in lager beer production has historically been sourced from local farmers' co-operatives. Lacking the capital investment and associated infrastructure associated with larger concerns, the farmers have traditionally dried their rice close to where it is harvested, usually over open wood fires. Dried in this way the rice can pick up a distinctive smoky taint due to phenolic compounds such as guaiacol. Unless stringent precautions are taken in downstream

processing of such tainted rice (including extensive washing and boiling of the starch slurry produced from it), the flavour will inevitably find its way into the beer.

**Minimisation of water use:** Reduction in water use has been one of the success stories of sustainability initiatives over the last decade. Not so long ago, breweries would use in excess of 15hl of water to make one hl of beer, with some going as high as 30hl per hl. Today, according to the United Nations Environmental Programme (UNEP) a typical figure for an efficient brewery is 5hl per hl. At Foster's Yatala brewery in Australia water consumption has been reduced to an astonishing 2.3hl per hl.

So what risks to beer flavour are associated with more efficient use of water in the brewery? The main ones relate to poor hygiene. If water use minimisation (including re-use and re-cycling) is pushed beyond operational limits, inefficient cleaning, sanitisation and rinsing of brewery equipment will ensue. Consequently, micro-organisms will survive, grow and ultimately establish biofilms. These will be more difficult to remove from brewery equipment during future cleaning cycles. Having established themselves, the micro-organisms can go on to produce off-flavours such as diacetyl, 4-vinyl guaiacol, indole, DMS and lactic acid in beer, even before packaging and pasteurisation.

There is also a risk of carry-over of flavour from one type of product to another when water use is minimised. Perhaps most at risk are breweries that produce flavoured drinks (such as Flavoured Alcoholic Beverages and Soft Drinks) in addition to their portfolio of beer products. Trace residues of the flavours used to formulate such products can easily taint a batch of beer if cleaning and rinsing of brewery tanks and lines is inadequate.

The impact of water use reduction programmes on potential flavour carry-over and loss of microbiological control can depend on the details of the CIP system. For example, in the case of tanks fitted with high-efficiency rotary jet sprayballs, a reduction in water pressure and flow-rate might impact more negatively than would be the case for a conventional sprayball system, since the rotary movement of the spray head might be disproportionately affected by the drop in water pressure. This is despite that fact that under optimum operating conditions the rotary jet spray ball will be clearly superior in its performance.

Tunnel pasteurisers are significant consumers of water in a brewery and steps are being taken in many breweries to conserve the amount of water used in this area. The impact of these measures on beer flavour is discussed below.

**Minimisation of extract loss in the brewery:** An important step in any sustainability programme must surely be to make the best use of purchased resources and raw materials and ensure that waste is kept to a minimum. Extract loss is therefore an area of particular interest. Most brewers do not need the incentive of a sustainability programme to go looking for sources of extract loss and find ingenious ways of recovering as much extract as possible from their raw materials.

But a balance has to be struck between minimising extract loss and optimising beer flavour quality. Consider lautering: by employing extensive sparging to a last runnings gravity of as low as 0.3°P it is possible to recover a greater amount of soluble material

from the malt compared to that extracted when the last runnings gravity is in the range 4°-5°P. However, not all of this extract is of equally high quality. As the last runnings gravity is pushed lower and lower, the risk of extracting undesirable materials from the spent grains increases. This can lead to husky flavours being imparted to the beer, together with excessive astringency. An optimum has to be found between the quest for extract yield and flavour quality.

Inevitably, other considerations come into play, including brewhouse cycle times and the fact that energy has to be used to evaporate the excess water used in sparging once the brew goes into the kettle.

Recovery of extract from trub can also look appealing, but it also is not without risks for flavour. Addition of trub recovered from the whirlpool back into the lauter tun can lead to astringency, harsh bitterness and 'trubby' notes in the beer. Lipids contributed by trub can reduce the concentrations of esters produced by yeast during fermentation.

It is in the area of fermentation that a desire to minimise beer loss can have the greatest impact on off-flavour development. From a sustainability perspective – that of generating the largest possible volume of beer at the highest possible alcohol concentration - yeast should be left in contact with the beer for the longest possible time. This has two main effects. Firstly, the yeast which is removed from the fermenter will have the highest possible solids content (*i.e.* it will contain the least possible amount of beer). Secondly, during prolonged storage on beer the yeast will ferment its reserve carbohydrates (glycogen and trehalose) forming more ethanol than it would have had it been removed from the fermenter immediately on completion of primary fermentation. The impact of such practices on beer flavour is high. Waiting until the last possible moment to harvest yeast means that earlier crops, which include sedimented trub and cold break, are not removed earlier in the fermentation. Left in contact with fermenting beer, flavour-negative materials re-dissolve, imparting astringent, metallic and 'trubby' notes to the product.

Yeast left in contact with beer after fermentation is essentially starving. To stay alive it has to make use of its own cell components. This initiates a cascade of metabolic reactions which eventually results in cell autolysis (literally 'self-digestion'). This process is associated with release of a variety of sulphur compounds, including H<sub>2</sub>S (boiled eggs), methanethiol (mercaptan/drains) and methional (mashed potato). Further reactions between these compounds and other materials in the fermented beer can lead to formation of onion flavour (from dimethyl trisulphide) and burnt rubber character (from a variety of higher sulphides and disulphides). Fatty acids can also be released, giving rise to waxy/caprylic notes. Digestion of yeast proteins by intracellular proteases releases amino acids and peptides from the autolysing yeast. Some of these peptides impart a harsh bitterness (so-called 'yeast bite') to beer. This 'non-hop' bitterness can reduce drinkability and affect flavour quality.

The amino acids released into the beer can encourage growth of contaminant bacteria, particularly lactic acid bacteria such as *Lactobacillus* and *Pediococcus* spp. These micro-organisms may in turn produce diacetyl and its precursor which remain in the beer on account of the conditions in the fermenter not being conducive to its removal by yeast.

In practice, if this list of off-flavours is to be avoided, trub and cold break must be drained from the fermenter as early as possible and yeast must be harvested early and warm for re-pitching. Pre- and post-crops of yeast must be taken and discarded (or made into co-products or other value-adding materials). In this regard it becomes clear that beer loss is something to be optimised rather than minimised.

Recovery of beer from spent yeast and waste beer provides a means of maximising extract utilisation. This can be done in several ways, including the use of plate and frame filters, rotary vacuum filters and crossflow membrane filter systems. Regardless of how the beer is separated from the yeast, a negative impact on beer flavour is inevitable. Flavours arising from yeast autolysis, including mercaptan, methional and yeast bite are always extracted, even when the yeast slurry has been looked after prior to recovery.

In many breweries which practice beer recovery, the operations are by no means perfect and microbiological contamination is commonplace. In such cases, diacetyl, lactic and acetic acids and phenolic compounds such as 4-vinyl guaiacol and styrene can be added to the list.

A better alternative, which has been taken up now by several breweries, is to focus on recovering the ethanol from spent yeast and waste beer and make use of it outside of the brewing process. For example, it can be sold to petrol (gasoline) companies to blend with their fuel prior to sale to car and truck drivers (for a video report on the technology see [http://www.youtube.com/watch?v=JfSmdM\\_1baQ](http://www.youtube.com/watch?v=JfSmdM_1baQ)).

**Reduction of energy use:** Chilling of beer at the end of primary fermentation is an energy-intensive process. The time at which chilling should optimally be applied is determined by several factors including:

- (i) when the wort was pitched with yeast;
- (ii) the fermentation profile of the vessel;
- (iii) the yeast pitching rate;
- (iv) the sugar composition and gravity of the wort; and
- (v) the level of yeast activity.

From a flavour quality perspective, vessels should be placed on 'chill-back' as soon as they have reached both their target attenuation and 'total' diacetyl concentration. However, this time may coincide with a peak in the cost of electricity used to drive the cooling process and the brewer may choose to wait until off-peak tariffs apply before initiating cooling. While this practice is to be applauded from an energy cost and environmental viewpoint, it contributes to a deterioration in beer flavour quality as a result of the development of autolysis-related flavour notes during the extra 8–10 hours the beer spends in the fermentation vessel.

A wider issue is that of cold-maturation of beer in general. Lager beers are inherently more energy-intensive to produce than ales. It could be argued that, from a sustainability perspective, unfiltered, unpasteurised, traditional ales – matured at ambient temperatures without need of refrigeration – represent a more eco-friendly product category than modern pale lager beers.

For decades the most common way of preserving beer has been to pasteurise it in a tunnel pasteuriser. This has been proven to be a very reliable way of killing contaminant micro-organisms present in both the beer and the package into which it is filled. It is increasingly recognised that tunnel pasteurisation is wasteful in terms of both energy and water use. Furthermore, it is not completely neutral with respect to its effect on beer flavour; ‘cooked’ and ‘worty’ notes, including methional and other sulphur compounds can be formed during the prolonged heating cycles associated with tunnel pasteurisation. This is especially true of pasteurisers that have been subjected to water-saving initiatives. When water is recycled and re-used within a tunnel pasteuriser it tends to accumulate dirt and debris. If biocides are not used, or are used at the wrong concentration, microbial growth can occur. The net result of this accumulation is that pasteuriser spray balls become blocked leading to local hot spots and cool spots in the pasteuriser. This further damages beer flavour and promotes pack-to-pack inconsistency.

There are two main alternatives to tunnel pasteurisation and both have enjoyed a degree of success:

- (i) sterile filtration followed by aseptic packaging;
- (ii) flash pasteurisation followed by aseptic packaging.

Sterile filtration is very gentle on beer flavour, as it does not involve heating of the product. However it can be demanding in terms of the technical expertise needed to operate and clean the installation and in its requirements for water and electricity.

Flash pasteurisation seems to be the most sustainable solution from an energy and water perspective. Like sterile filtration, it presents a challenge in that, once the micro-organisms in the beer have been killed, the pasteurised beer must be packaged into sterile bottles, cans or kegs without re-contamination. This is not an easy thing to do and a high level of vigilance is needed to successfully run an aseptic packaging operation. Failure of the system leads to microbiological spoilage.

Strictly anaerobic bacteria such as *Pectinatus* and *Megasphaera* spp. are particularly troublesome. In addition to producing copious amounts of sediment, they form obnoxious off-flavours in the beers in which they grow. These include sulphur compounds (H<sub>2</sub>S [boiled egg], various mercaptans [drains], dimethyl disulphide [rotten vegetable] and dimethyl trisulphide [onion]), together with a range of volatile acids such as butyric, isobutyric, isovaleric and propionic acids. Additional risks include lactic acid bacteria, such as *Lactobacillus* and *Pediococcus* spp. which produce diacetyl and lactic acid. Wild yeasts, such as *Saccharomyces* and *Brettanomyces* spp., can produce phenolic off-flavours (such as 4-vinyl guaiacol and 4-ethyl phenol), esters (such as ethyl acetate) and acids (such as acetic, isovaleric and lactic acids).

Prevention of such problems requires investment in high quality packaging equipment, well-designed and effective operator training, stringent maintenance practices and attention to hygiene (in both cleaning and operational activities).

**Recycling of packaging materials:** The use of recyclable beer packaging (primarily bottles and kegs) and recycled materials in the packaging supply chain is often one of the highest profile activities in any sustainability initiative. What better bellwether for a reduction in environmental impact? While it is not without risk to beer flavour, the risks can be managed.

One area of risk is that of wood preservatives and fire retardants entering the packaging supply chain. Historically, phenolic preservatives have been applied to wood to protect it against attack by weather and microbes. Over time the concentration of such preservatives declines. If wood which has been preserved in this way is recycled, for example being used to make paper or cardboard packaging materials and in the process, is bleached with hypochlorite, small amounts of chlorophenols can be formed which will survive the pulping process.

About 20 years ago, in response to a realisation that the use of phenolic preservatives were the cause of some taint problems, a shift in the type of materials used took place. In retrospect, this shift turned out to be ill-advised. Rather than eliminating the problem it created a new and altogether more damaging problem – the risk of bromoanisole formation. These are among the most odour-active contaminant taints known. Some have odour thresholds of less than a femtogram per litre<sup>3</sup>.

Bromoanisoles are an emerging and increasing threat to product flavour, especially in relation to the use of recycled wood and cardboard. The threat is magnified by the practice of using 2,4,6-tribromophenol is used as a flame retardant in epoxy resins, polyurethanes, plastics, paper, textiles and as a wood preservative. The distinctive smell of tribromophenol can be detected in the vicinity of transformers and other areas of heightened fire risk in the brewery.

Halophenols (such as bromophenol) are easily converted to haloanisoles (such as bromoanisoles) through growth of moulds, often at surprisingly low moisture contents (12%–16% relative humidity) and temperatures (25°–35°C). Haloanisoles are incredibly flavour-active and can taint a product with a musty character at concentrations as low as a few picograms per litre.

The risk of contamination of beer and ingredients with halophenols and haloanisoles from wooden pallets can be circumvented by replacement with plastic or by covering them with foil liners. However, the risk remains, especially with respect to contamination from recycled packaging materials. For example, brewers are aware of several incidents of can body contamination arising from contact with recycled fibreboard dividers during shipping and storage of can bodies.

## **Sustainability initiatives and their relationship to beer flavour stability**

**Local raw materials:** When it comes to making flavour-stable beer not all malt is created equal. Some barley varieties are associated with food beer flavour stability. To an extent this is due to their content of lipids and lipid-oxidising enzymes, but the content of other constituents, such as pro- and anti-oxidant polyphenols, is probably also important. Today it is possible to obtain specially-bred varieties which do not contain the lipid-oxidising enzyme lipoxygenase (Hirota, 2005). Beers made from this malt have a higher degree of flavour stability than that produced from conventional malt.

In some markets, efforts to use locally-grown raw materials rather than imported malt has led to significant challenges for control of beer flavour stability. For example, substitution of malted barley with local grains such as sorghum can reduce the flavour life of the beer and change the profile of flavours formed during beer storage. While the

reasons for this are by no means certain, different polyphenol profiles and the lipid content of sorghum compared with that of malted barley are thought to play a role.

**Minimisation of energy input in the malting process:** Malt kilning makes an important contribution to the total energy required to make beer. New Belgium's study has shown that the energy consumed in kilning (expressed in terms of CO<sub>2</sub> emissions) equates to 182g/six pack of beer. This compares with just over 120g/six pack for the entire brewing operation! Since New Belgium's brewing operations are among the least carbon-emitting in the industry it would be safe to say that the CO<sub>2</sub> emissions resulting from malt kilning are roughly equivalent to those generated by the entire brewing process.

So what impact might a reduction in kilning energy (through reductions in time and/or temperature) have on the flavour stability of the beer produced? Residual lipoxygenase levels in malt will increase, giving rise to the potential for faster lipid oxidation in the brewhouse. To a degree this can be compensated for in the brewery by lowering the pH value of the mash, mashing in at higher temperatures and avoiding excessive oxygen pick-up during the early stages of mashing. But other precautions are also needed to assure good beer flavour stability (see *below*).

**Minimisation of refrigeration at the point of sale:** In well-developed first-world markets such as the USA and Japan, beer is kept cold from the time it leaves the brewery until the time it reaches the consumer. This is a remarkably effective way of preserving its flavour since the chemical reactions, which lead to premature aging, are temperature-dependent. The use of refrigeration in this way represents a considerable expenditure of energy and makes a major contribution to carbon emissions. New Belgium have shown that the CO<sub>2</sub> emissions associated with in-store refrigeration represents 26% of the entire emissions associated with the whole beer supply chain (from agriculture through consumption to post-consumption recycling).

What might be the consequences if steps were taken to reduce this consumption of energy and its associated carbon emissions? The main effect would be a shortening of beer flavour life, with the premature development of stale flavours such as papery, leathery, acetaldehyde, sweet, honey and metallic, together with a loss of bitterness and ester character. Taken together, these flavour changes would have the effect of reducing beer drinkability.

To an extent, some of this potential for staling can be compensated for by a focus on brewing practices. These include:

- (i) good control of dissolved oxygen concentrations in the beer at all stages following removal of yeast;
- (ii) management of yeast quality;
- (iii) avoidance of excessive heat load during wort production;
- (iv) adjustment of sparge liquor pH values to avoid extraction of undesirable materials;
- (v) minimisation of lipid oxidation during mashing in the ways referred to above; and
- (vi) avoidance of enzyme-catalysed lipid oxidation altogether by using malt produced from lipoxygenase-free barley varieties.

## CONCLUSIONS

Sound environmental stewardship and sustainability practices are becoming increasingly important in brewing and related operations all over the world. Tougher targets imposed both internally and externally will stretch what malting, brewing, distribution and retailing operations are capable of. While the benefits of such initiatives are undeniable, they carry with them a risk of changing the flavour of beer at the point of consumption.

There is a chance that such changes could result in beer in the market being less acceptable to the consumer than before. If this happens, there is the risk of biting the hand that feeds and the prospect of declining beer sales.

## ACKNOWLEDGEMENTS

I thank my various industry colleagues in the continents of Africa, the Americas, Asia, Australasia and Europe who contributed their experience, wisdom and insight in helping me put this paper together.

## REFERENCES

1. Anon (2008). The Carbon Footprint of Fat Tire<sup>®</sup> Ale. The Climate Conservancy. Accessed on-line on 5 February 2009 at [www.newbelgium.com/sustainability](http://www.newbelgium.com/sustainability).
2. Hirota, N. *et al* (2005). Development of novel barley with improved beer foam and flavour stability – the impact of lipoxygenase-1-less barley in brewing industry. European Brewery Convention, Proceedings of the 30th Congress, pp 46-52.
3. Lambert, D.E., Shaw, K.J., Whitfield, F.B. (1993). Lacquered aluminium cans as an indirect source of 2,4,6-trichloroanisole. *Chemistry & Industry*, 461-462.
4. Simpson, W.J. (2006). Brewing Control Systems: Sensory Evaluation. In: *Brewing: New Technologies*, Edited by C.W. Bamforth, Woodhead Publishing, Oxford, UK, pp. 427-460.
5. Talve, S. (2001). Life cycle assessment of a basic lager beer. *International Journal of Life Cycle Assessment*, **6**, 293-298.