Food Packaging and Shelf Life 11 (2017) 91–97

Contents lists available at ScienceDirect

Food Packaging and Shelf Life

journal homepage: http://www.elsevier.com/locate/fpsl

The performance of beer packaging: Vibration damping and thermal insulation

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ARTICLE INFO

Article history:
Received 20 July 2016
Received in revised form 28 November 2016
Accepted 16 January 2017
Available online xxx

Keywords:
Beer packaging
Vibrations
Temperature
Packaging strategy

ABSTRACT

Poor transport conditions can result in an accelerated decay in beer quality. Optimal beer packaging should minimize the impact of temperature changes and vibrations, which occur during (long-haul) transport. In this research, the performance of different beer packagings (BP) regarding vibration damping and thermal insulation was investigated. Three BP's were tested (A: 24 × 33cl cardboard crate/B: 6 × 25cl cardboard crate + plastic foil/C: 24 × 25cl plastic crate).

Cardboard in combination with plastic foil (BP- B) appears to be the best packaging strategy due to the positive thermal insulation properties of cardboard. The plastic foil ties the beer bottles together leaving little space for the bottles to move and therefor reduces the air transfer contributing to better thermal insulation properties. Finally, cardboard in combination with plastic foil exhibits damping characteristics. With a holistic BP strategy, one can control vibrations and temperature biases, which is beneficial for the quality of beer.

1. Introduction

In recent years European beer exports have significantly increased, growing to 78 million hL in 2012 (Brewers of Europe, 2015). Market globalization has induced higher beer production and export volumes. As a result, beer is increasingly more exposed to longer transportation times and variable storage conditions. These transport and storage conditions lead to chemical reactions that cause changes in the chemical composition of beer (Vanderhaegen, Neven, Verachtert, & Derdelinckx, 2006). Chemical reactions, mostly initiated by oxidative reactions, generate chemical compounds that alter the sensorial properties of beer (Jaskula-Goiris, De Causmaecker, De Rouck, De Cooman, & Aerts, 2011; Malfliet et al., 2008). While aging with respect to wines is sometimes perceived as desirable since it enhances certain flavours and aromas, beer ageing results in undesirable flavour changes. As a consequence, the flavour quality and stability of beer change over time. An increase of aldehydes, a decrease in bitterness compounds (iso-α-acids), permanent haze and change of colour are some of the effects related to beer ageing. Ageing characteristics differ between beer types, however, in general, an increase in sweet aromas and a decrease of bitter tastes are mostly observed (Baert, De Clippeleer, Hughes, De Cooman, & Aerts, 2012; Malfliet et al., 2008; Vanderhaegen et al., 2006). Shelf-life problems due to flavour instability have become an important issue to breweries. In order to meet the expectations of the consumer beer should have a constant uniform flavour. When beer has aged and the flavour and aroma diverges from fresh beer, the latter may result in a rejection of the beer brand by the consumer and decreasing sales (Vanderhaegen et al., 2006).

1.1. Beer packaging

A dedicated packaging strategy is essential to maintain a high quality and stable beer flavour. Beer is predominantly stored in kegs, glass bottles, aluminum cans, and PET-bottles (Donoghue, Jackson, Koop, & Heuven, 2012). Since consumer expectations and preferences differ, the type of packaging varies significantly between countries. European countries, for example, use primarily glass bottles, while the consumers in the USA prefer the use of aluminum cans. Marketability and product appeal are important factors when determining the packaging strategy. In recent years, efforts of countries were intensified to reduce the environmental

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http://dx.doi.org/10.1016/j.fpsl.2017.01.004
2214-2894/

impact of the packaging. As a consequence, also the regional legislation regarding packaging taxes and deposit systems influences the packaging decision. The packaging materials used by the European breweries (in 2010) are:

1) Glass bottles (44.2%), of which returnable (24.5%) and non-returnable (19.7%)
2) Metal cans (24.7%)
3) Kegs (20.7%)
4) PET bottles (6.8%), of which returnable (0.7%) and non-returnable (6.1%)
5) Bulk beer tanks (2.8%)
6) Others (0.8%)

Source: (Donoghue, Jackson, Koop, & Heuven, 2012)

The use of the different beer containers can also be segmented by transportation distance. Due to its recycling logistics, kegs are mostly not transported to foreign countries with long transportation distances. Therefore, beer in kegs is predominantly used for domestic consumption. Bottles and metal cans, on the other hand, are used domestically and also exported to foreign countries. Non-returnable glass bottles or 'single-use' bottles are mainly used for export. Returnable or reusable glass bottles are heavier to make them more durable as each bottle can be used multiple times in a recycling process. A secondary packaging is used to transport bottles and metal cans. Glass bottles used for domestic consumption are mostly transported in hard plastic crates to accommodate the recycling logistics. When exporting to other countries, bottles and cans are packaged using cardboard (cardboard crate or holder) and plastic foil (not required when using a cardboard crate) (Donoghue et al., 2012; Euromonitor International, 2014).

1.2. Parameters influencing beer quality

Research of Burns, Heyerick, De Keukeleire, and Forbes (2001) and Jaskula-Goiris et al. (2011) indicated that exposure to light and temperature influence the amount of chemical ageing reactions occurring in beer. Until recently, breweries focused on minimizing the exposure to light and temperature changes in order to maintain the quality of beer when choosing their packaging strategy. However, by limiting the mass and the materials used in the packaging also economic and ecological considerations are incorporated in the packaging decision process. The optimal temperature of beer storage suggested in literature is fixed between 0 and 5 °C. The freshness of beer decreases with higher temperatures, lowering the reaction activation energy and thereby increasing the amount of chemical reactions that take place. Furthermore, every reaction type has a different level of activation energy, which implies that reaction rates are different with increasing temperature. As a result, with increasing temperature different chemical compounds of different reactions are formed in an unequal volume (Jaskula-Goiris et al., 2011). Quality deterioration of beer can also be caused by an exposure to light, a phenomenon referred to as 'lightstruck flavor'. This can be attributed to the absorption of energy, generating an intramolecular energy transfer which causes several chemical reactions (Burns et al., 2001). The vulnerability of iso-α-acids to light can be indicated as the main contributor to photodegradation of beer or its 'lightstruck flavor'. In order to prevent light-induced deterioration, breweries store their beers in light-proof containers (e.g. colored bottles or cans) (Caballero, Blanco, & Porras, 2012).

During transport, beer is also exposed to vibrations and shocks. In rare experiments (Janssen et al., 2014) it was found that vibrations could have an influence on the quality of a food product. Moreover, the authors signaled the emergence of turbidity in beer caused by vibrations. However, limited research has been done on the impact of vibrations on the chemical and sensorial quality of beer. Oxidative reactions initiate a range of different chemical reactions that result in beer ageing. As a consequence, breweries tend to avoid a high level of oxygen when producing and bottling beer. In recent years, the oxygen in beer can be reduced to 0,1 mg/l with modern filling techniques (Caballero et al., 2012). When beer is exposed to vibrations, the oxygen in the upper part of the bottle under the crown will be mixed with the beer. This will enable the beer to have more oxidative reactions and thereby accelerate the beer ageing process. Furthermore, vibrations could increase the collision of molecules, which will lower the reaction activation energy. As a consequence, the generation of ageing compounds will be facilitated. Hence, one can conclude that vibrations can be harmful to the beer quality, and should therefore be avoided.

Beer is commonly transported using trucks, trains, and ships. Depending on the transport carrier, beer is exposed to different vibrations and shocks. Vibrations are periodic in nature while a shock is a single-event or transient phenomenon (Harris & Piersol, 2002). Vibrations generated by a truck, for example, are influenced by the road conditions (roughness), the driving performance (traveling speed) and the specifications of the truck (load, suspension, the number of axles, etc.) (Garcia-Romeu-Martinez, Singh, & Cloquell-Ballester, 2008; Jarimopas, Singh, & Saengnil, 2005; Lu, Ishikawa, Kitazawa, & Satake, 2010). Furthermore, the position inside a container has an influence on the amplitude of the vibrations (Berardinelli, Donati, Giunchi, Guarnieri, & Ragni, 2003; Zhou, Su, Yan, & Li, 2007). The vibration spectrum of trucks, trains and ships are characterized in the academic literature (mostly an averaged spectrum to characterize multiple transport vehicles) (Maheras, Lahti, & Ross, 2013). Most of the vibrations of these transport vehicles occur in the frequency range below 100 Hz with accelerations smaller than 10 m/s^2. Based on these findings, boundaries in frequency and acceleration were defined in the experimental design presented in Section 2.1.

1.3. Paper structure and flow

The aim of the current work is twofold: (1) to identify the vibration damping performance of three beer packaging strategies that are commonly used in industry, and (2) to look into the thermal conductivity of the beer packaging. During transport, beer is exposed to vibrations with amplified or attenuated magnitude due the vibration transmissibility performance of the beer packaging. Different packaging strategies have different transmissibility curves and vibration damping performance, making it able to compare and benchmark them. The second objective was to look into the thermal conductivity or thermal insulation of the beer packaging. Increasingly breweries export beer in cooled containers to counteract the influence of temperature on the beer flavor. However, thereafter in next steps in the supply chain, the temperature may rise and can be as high as 50 °C (Weiskircher, 2008). With an experimental set-up, the insulating performance of the beer packaging was tested. To summarize, the objective is to identify the performance of three commonly used beer packaging strategies regarding thermal insulation and vibration damping.

The research performed in current paper can be generalized for other food and beverage products. Diverse academic papers focus on the impact of shocks on the mechanical damage of fresh products (apples, kiwis, tangerines, etc.) (Jarimopas et al., 2005; Tabatabaekoloor, Hashemi, & Taghizade, 2013; Van Zeebroeck et al., 2008). Other research papers (Berardinelli et al., 2003; La Scalia et al., 2015) investigate the influence of vibrations on the microbial growth and change of chemical components of highly perishable products (strawberries, eggs etc.). Besides, the effects of temperature during transport and storage on food and beverage quality (wine, tomatoes, etc.) has been extensively investigated