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Heat transfer analysis of pasteurization of bottled beer in a tunnel pasteurizer using computational fluid dynamics

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ABSTRACT

Beer is one of the most widely consumed alcoholic beverages in the world. Pasteurization is an important unit operation in beer processing that inactivates the spoilage microorganisms present in beer thereby extending its shelf life. It is difficult to determine the temperature profile and slowest heating zone (i.e. minimum heating region) inside the bottle during industrial scale tunnel pasteurization. Computational fluid dynamics (CFD) modeling can be used as a tool to determine the temperature distribution pattern inside the bottled beer. This study is unique in terms of using the actual thermophysical properties of beer unlike in earlier published works. Further, CFD simulation prediction of the temperature profile in the bottled beer was validated with experimental measurements. The study was extended to investigate the effects of different zones' temperatures on inactivation of *Saccharomyces cerevisiae*, the most common beer spoilage organism. A tunnel pasteurizer with seven zones was selected to study the temperature profile inside the bottled beer and found to be in good agreement with the published temperature profiles in different zones. In addition, the effectiveness of pasteurization was investigated in terms of pasteurization unit (PU) and the resultant PU value (15 to 30 PU) was adequate for achieving the maximum sterility of beer.

Industrial relevance: In recent years, a rapid development in the application of CFD in food processing operations has been witnessed. The main need for CFD analysis of pasteurization is to determine the uniform and effective heat distribution inside the bottled beer and to examine the position of slowest heating zone (SHZ). Relatively few works have been published related to applications of CFD during beer pasteurization. However, all the studies were performed with water as a model fluid. So far no work has been published on the CFD simulation during the pasteurization process in bottled beer by using the thermophysical properties of beer. Hence, the present study was aimed at investigating the temperature distribution inside the beer bottle during the pasteurization process and in each zone of the industrial tunnel pasteurizer. This model can be used for the brewery industry to ensure that the required pasteurization temperature has been reached inside the beer bottle when conveyed through a tunnel pasteurizer. This is very essential to render a safe product with extended shelf life to the consumers.

1. Introduction

Fermented beverages and foods have a unique place in most societies because of their economical and cultural importance (Legras, Merdinoglu, Cornuet, & Karst, 2007). Beer is one such most consumed fermented beverage in the world and it continues to be a popular drink. The shelf-life of beer has become one of the most critical issues as it is produced and marketed both nationally and internationally (Takashio & Shinots, 1998). The shelf-life of beer is mostly determined by its microbiological, colloidal, foam, colour and flavour stabilities (Vanderhaegen, Neven, Verachtert, & Derdelinck, 2006). Heat treatment is the widely applied and effective method for extending shelf-life of beverages packed in containers such as glass bottles (Horn, Franke, Blakemore, & Stannek, 1997). The stability of the final product through several months can be achieved if common contaminants of beer such as *Pediococcus spp*., *Lactobacillus spp*., and wild yeasts like *Saccharomyces spp*., *Hansenula*, *Dekkera*, *Brettanomyces*, *Candida* and *Pichia* are inactivated (Priest & Stewart, 2006). These organisms can be inactivated at a time–temperature combination of around 60 °C for 20 min (Briggs, Boulton, Brookes, & Stevens, 2004). Currently, the heat treatment of beer is either performed by flash pasteurization (first pasteurized and then packaged aseptically) or by tunnel pasteurization (first filled into container (bottles or cans) and then pasteurized through tunnel pasteurizers) or batch pasteurization (Buzrul, 2007). Tunnel pasteurization is an important unit operation in the brewery packaging line. It deserves most attention in terms of energy cost due to high steam consumption. A tunnel pasteurizer comprises a large metal-cased enclosure, divided into a series of zones through which the bottles are passed by a conveying system. The continuous pasteurization of the product is achieved during the bottles' transit

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through the tunnel, which consists of progressive hotter zones, holding zone and progressively cooler zones (Briggs et al., 2004).

Most beers are pasteurized after filling to achieve microbiological stability and to inactivate molds and yeasts that might otherwise alter and deteriorate the product after processing (Reveron, Barreiro, & Sandoval, 2003). Beer spoilage organisms include wild yeasts, the predominant of which belongs to the Saccharomyces species (Jespersen & Jakobsen, 1996). The inactivation of *Saccharomyces cerevisiae* in beer, based on PU values was studied by Zufall and Wackerbauer (2000) and Reveron et al. (2003). Reveron et al. (2003) studied the thermal resistance of *S. cerevisiae* and reported the decimal reduction times ($D_{T\,°C}$) at various temperatures from 47 °C to 60 °C as follows: $D_{47\,°C} = 3.16$ min, $D_{48\,°C} = 2.65$ min, $D_{49\,°C} = 1.74$ min, $D_{50\,°C} = 0.68$ min and $D_{60\,°C} = 0.01$ min.

The time–temperature combination for pasteurization of beer has a major impact on product quality. Heat treatment affects the original characteristics of beer in terms of flavour, colour, bitterness, chill haze and protein sensitivity (Buzrul, Alpas, & Bozoglu, 2005). The inactivation kinetics of beer spoilage micro-organisms forms the basis for PU calculation (Zufall & Wackerbauer, 2000). Higher pasteurization temperature with shorter holding time favours the beer quality. Hence, the process temperature needs to be controlled by the water spray on the beer bottles, during their residence inside the tunnel pasteurizer (Briggs et al., 2004).

In recent years, a rapid development in the application of CFD in food processing operations such as drying, sterilization, mixing, refrigeration and storage has been witnessed (Anandharamakrishnan, 2003; Norton & Sun, 2006; Scott & Richardson, 1997). CFD is a simulation tool, which uses powerful computers in combination with applied mathematics to model fluid flow situations and aid in the optimal design of equipments and industrial processes (Chhanwal, Anishaparvin, Indrani, Raghavarao, & Anandharamakrishnan, 2010; Kuriakose & Anandharamakrishnan, 2010). The CFD simulations have been widely used to determine the distribution of temperature and velocity profiles in the thermal pasteurization and sterilization of canned food products (Anandpaul, Anishaparvin, & Anandharamakrishnan, 2011). It can be used to determine the slowest heating zone (SHZ), which is defined as the location that receives the minimum heat (i.e. cold spot) during thermal processing and it can be tracked from temperature distribution predictions.

Relatively few works have been published on applications of CFD in the pasteurization of beer. Augusto, Pinheiro, and Cristianini (2010) studied the effect of can orientation on beer pasteurization using CFD. They reported that, the orientation of beer cans did not result in any improvement during beer pasteurization process. A major limitation of their study was that instead of using beer thermophysical properties, they used thermophysical properties of water in their simulation. Dilay, Vargas, Amico, and Ordonez (2006) optimized the pasteurization tunnel configuration using CFD, with respect to minimum energy consumption. But, this model dealt only with the internal environment of the tunnel pasteurizer rather than the heat transfer inside the bottle. Hence, the present study was aimed at developing a CFD model for pasteurization of bottled beer, using thermophysical properties of beer to investigate the effect of thermal processing time on beer temperature and location of SHZ. Further, the study was extended to investigate the degree of inactivation of yeasts in the bottled beer during the tunnel pasteurization process. In this study, *S. cerevisiae* was selected as the target organism and PU value was used as the deciding parameter to ascertain the influence of different tunnel pasteurization zone temperatures on the inactivation of the aforementioned target organism.

2. Materials and methods

2.1. Experimental methodology

Beer bottles of different shapes and sizes are available in the market. Due to its extensive usage, a standard size long neck bottle (28.3 cm height and 7.3 cm width), containing beer (650 ml) with 7% alcohol content was selected (strong premium beer, United Brewery Pvt. Ltd.) for the experiment and CFD simulation studies. During experimentation, a small hole was made at the centre of bottle's metal cap for insertion of the calibrated thermocouple. The hole was sealed to ensure that air does not escape and the T-type thermocouple (sensitivity ± 0.5 °C) was held at the centre of the bottled beer (9.6 cm from the bottom of the bottle). The thermocouple was connected to data acquisition system (VR-18, Brainchild Electronics Co., Ltd.) for temperature and time acquisition. The water bath (pasteurizer) was allowed to reach a set point temperature of 60 ± 0.5 °C. As soon as the water bath attained the desired temperature, the whole setup of the beer bottle (in a vertical position) along with the probe was immersed into the water bath. The time–temperature reading was recorded every 30 s till the beer reached a stable temperature.

In this experimental setup, heat transfer occurred by natural convection through water bath followed by conduction from glass bottle to beer and inside the bottle, beer was heated by natural convection. Similar conditions were used in this present study (boundary conditions described below) for experimental validation. While the beer bottles were moved through different heating zones in a real case, different heating zones were moved around the stationary beer bottle under the simulated conditions. Hence, conditions used in this simulation study are expected to be similar to that prevalent in industrial scale tunnel pasteurization.

2.2. CFD simulation

Bottle geometry in three dimensions was created using GAMBIT. The geometrical structure of beer bottle is depicted in Fig. 1. The geometry consisted of three volumes, with the first volume representing the

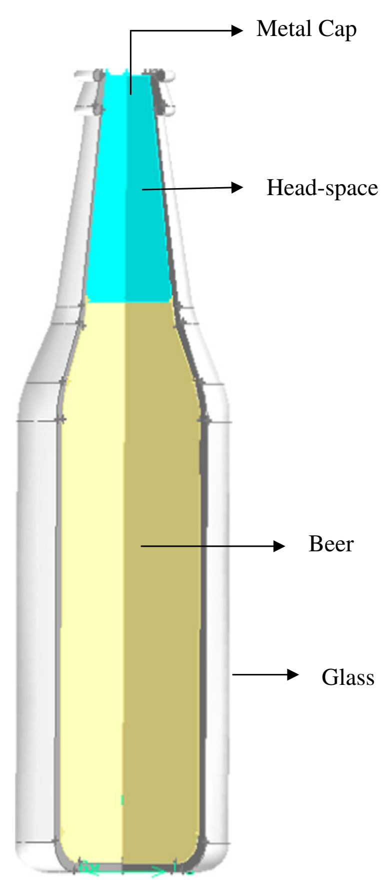

Fig. 1. Three-dimensional geometry of standard long neck beer bottle.