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Investigation of parameters causing can bulging during pasteurization process of carbonated beverage

[1,4]Thongon, R., [2,*]Netramai, S., [2]Kijchavengkul, T., [3]Yaijam, G. and [4]Debhakam, R.

[1]*School of Bioinnovation and Bio-based Product Intelligence, Faculty of Science, Mahidol university, Bangkok 10400, Thailand*
[2]*School of Bioinnovation and Bio-based Product Intelligence, Faculty of Science, Mahidol university, Nakhon Pathom 73170, Thailand*
[3]*Boonrawd Brewery Co., Ltd, Bangkok 10300, Thailand*
[4]*Singha Beverage Co., Ltd (Branch No.00001), Nakhon Pathom 73130, Thailand*

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Abstract

In-package pasteurization was typically used to achieve microbial and quality stabilization in the beer industry. However, the process can cause can bulging, resulting in product loss. This work aimed to construct a mathematical model describing correlations between can thickness, fill volume, and pasteurization temperature and their effects on internal pressure of canned beer. Selected ranges of these parameters for the study were 0.245-0.270 mm, 320-338 mL and 59-66°C, respectively. Canned beer samples were pasteurized using laboratory-scale pasteurization set up for two hrs before being measured for their internal pressures. A mathematical model (R^2 = 0.90) was obtained and validated. It showed that all independent parameters significantly affected internal pressure ($p<0.05$). This model can serve as a guideline for packaging and heating process optimization to reduce the possibility of can bulging from buildup of internal pressure.

1. Introduction

Beer has the highest market share of alcoholic beverages in all regions (Gómez-Corona *et al*., 2016; Prasannan, 2018; Statista Research Department, 2021). In Thailand, its market share in 2017 was 72.2% of alcoholic beverages (Yongpisanphob, 2019). Commercial beer is pasteurized to remove unwanted pathogenic- and spoilage microorganisms. Beer is often pasteurized at 60°C for 15-30 mins (~15-30 pasteurization unit; PU) (Dilay *et al*., 2006; Buzrul, 2007; Bhuvaneswari and Anandharamakrishnan, 2014; Harrison and Albanese, 2019; Yalçınçıray *et al*., 2021). For pasteurization of canned beer, the temperature should not be higher than 62°C (Kunze, 2004), and the preferred technique is in-package pasteurization which requires that beer and package being heated at the same time. This process prevents post-filling contamination in beer. Tunnel pasteurizer is typically used for in-package pasteurization of beverages (Kunze, 2004; Dilay *et al*., 2006; Priest and Stewart, 2006; Augusto *et al*., 2010; Bhuvaneswari and Anandharamakrishnan, 2014).

During in-package pasteurization of canned beer, gas expansion increases internal pressure inside the package. Other factors reported to affect internal pressure of canned beer included can thickness, carbon dioxide (CO_2) content, and fill volume of the product. Additionally, during commercial pasteurization, canned beer might be subjected to abnormal process conditions causing can be held in pasteurizer for longer than usual, increasing its internal pressure even further. If the can's internal pressure is higher than its value of pressure resistance, the can will bulge, resulting in product loss (American Society of Brewing Chemists, 1949; Felmingham, 1960; Hackworth and Henshaw, 2000; Kunze, 2004; Erdogdu and Tutar, 2011; Speers and MacIntosh, 2013; Kuntzleman and Sturgis, 2020).

Several studies have constructed and applied mathematical models to depict the effects of parameters related to pasteurization on microbial inactivation or quality of beverages, as well as to optimize the heating process (Lamo *et al*., 2019; Bertolini *et al*., 2020; Bayati *et al*., 2021). For example, Lamo *et al*. (2019) created mathematical model to optimize concentration of sodium benzoate, pasteurization temperature, and pasteurization time for shelf life extension of guava juice. And Bayati *et al*. (2021) used a mathematical model to study the effects of process parameters on cold pasteurization and optimize them for microbial reduction with the lowest

*Corresponding author.
Email: *siriyupa.net@mahidol.ac.th*

effect on the physicochemical characteristics of the beverage. However, none has utilized response surface methodology (RSM) to study effects of production parameters on can bulging incident.

Therefore, this work aimed to construct mathematical model describing effects of can thickness, fill volume, and pasteurization temperature on can bulging during beer pasteurization scenario that included process breakdown which is a common process error often occurred during commercial beer production. The findings in this study could be used in optimization of packaging and process parameters related to the pasteurization of canned beers to minimize production loss.

2. Materials and methods

To study the effects and correlations of process and packaging parameters on can bulging incident, selected parameters and their ranges listed in Table 1 were used to design treatments using RSM with Box-Behnken design in this study (Table 2).

2.1 Sample preparation

Brewed lager beer was supplied by Boonrawd brewery Co., Ltd (Nakhon Pathom, Thailand). It was stored in the temperature-controlled storage tank at 3±1°C until use. To prepare canned beer, beer was filled in 330 mL aluminum cans (Bangkok can manufacturing Co., Ltd; BCM, Pathum Thani, Thailand) and sealed with an easy open-end lid (BCM). For each treatment (Table 2), 15 cans were selected for laboratory-scale pasteurization experimental setup. The samples were also subjected to CO_2 content measurement (The Haffmans Inpack CO_2 Calculator, Netherlands). CO_2 content was controlled at 5.90±0.05 g/L based on the average value of CO_2 content in commercial beers (Singha Beverage Co., 2020).

2.2 Pasteurization of canned beer

Canned beer samples were pasteurized in a laboratory-scale pasteurization experimental setup, consisting of temperature-controlled water bath (Waterbath WTB24, Germany) and dataloggers (Haffmans Redpost PU-Monitor RPU-351, Netherlands) to monitor treatment temperature. Samples were pasteurized for two hrs (Table 2). The selected treatment time simulated the worst condition for can bulging incident based on total time commercial canned beers spent in tunnel pasteurizer, including breakdown time due to process errors (Beer filling department, 2021). All treatments were conducted in triplicate.

2.3 Measurement of internal pressure after pasteurization

Immediately after pasteurization, three canned beer samples were measured for their internal pressure using analog pressure gauge meter (CQTE-06BTC Vacuum/ Pressure Gauge, Thailand).

2.4 Characterization of beer quality after pasteurization

To assess pasteurization efficiency, microbial enumerations of beer samples were performed using membrane filtration method (Kunze, 2004). Wort agar (Millipore, Germany) was used for brewer's yeast and wild yeast (incubation at 28°C for 5 days) according to method in Merck KGaA (2018). White-cream colonies were identified as brewer's yeast (Kubizniakova *et al.*, 2014). For *Escherichia coli* and coliforms, chromogenic agar (ChromID™ Coli agar, France) was used (incubation at 37°C for 18-24 hrs) as described in BioMérieux SA (2016). Observed pink to red colonies and dark blue/violet colonies were enumerated as *E. coli* and coliforms, respectively (BioMérieux SA, 2016). All tests were conducted in three replicates. Lactic acid bacteria and genus *Bacillus* were tested by a certified microbiology laboratory (Microbiology analysis quality control department, Singha beverage Co., Ltd., Thailand).

2.5 Data analysis

A mathematical model depicting the influences of process and packaging parameters on the internal pressure of canned beer during pasteurization was constructed using Minitab software (Version 21.2, Minitab, LLC., Pennsylvania, USA). The 2nd-order polynomial equation was used to develop a predictive model for canned beer pasteurization:

$$[Y] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \varepsilon \quad (1)$$

Where [Y] is estimated internal pressure of canned beer after pasteurization (bar); X_1, X_2, and X_3 are

Table 1. Parameters for pasteurization of canned beer.

Parameter	Range	Low level (-1)	Middle level (0)	High level (+1)
Can thickness (mm)	0.245–0.270*	0.245	0.255	0.270
Fill volume (mL)	320–338	320	329	338
Pasteurization temperature (°C)	59–66	59.0	62.5	66.0

*The current wall thickness of commercial cans for beers is 0.270 mm (Boon Rawd Brewery Co., 2018).

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Table 2. Pasteurization conditions assigned from RSM with Box-Behnken design and corresponding internal pressures (mean±SD) and qualities of pasteurized canned beer. Each value was derived from triplicates.

Condition	Can thickness (mm)	Fill volume (mL)	Pasteurization temperature (°C)	Internal pressure (bar[†])	Brewer's yeast (CFU/mL)	Wild yeast (CFU/mL)	*Escherichia coli* (CFU/mL)	Coliforms (CFU/mL)	Lactic acid bacteria (CFU/mL)	Genus Bacillus (CFU/mL)
1	0.245	329	59.0	5.79±0.26	ND	ND	ND	ND	ND	ND
2*	0.245	338	62.5	6.08±0.23	ND	ND	ND	ND	ND	ND
3	0.245	320	62.5	5.74±0.24	ND	ND	ND	ND	ND	ND
4	0.245	329	66.0	6.36±0.04	ND	ND	ND	ND	ND	ND
5	0.255	320	59.0	5.39±0.01	ND	ND	ND	ND	ND	ND
6*	0.255	338	59.0	6.22±0.12	ND	ND	ND	ND	ND	ND
7	0.255	329	62.5	6.16±0.08	ND	ND	ND	ND	ND	ND
8	0.255	329	62.5	6.11±0.04	ND	ND	ND	ND	ND	ND
9	0.255	329	62.5	6.15±0.06	ND	ND	ND	ND	ND	ND
10*	0.255	338	66.0	6.53±0.05	ND	ND	ND	ND	ND	ND
11	0.255	320	66.0	6.05±0.07	ND	ND	ND	ND	ND	ND
12	0.270	329	59.0	5.75±0.12	ND	ND	ND	ND	ND	ND
13	0.270	338	62.5	6.26±0.06	ND	ND	ND	ND	ND	ND
14	0.270	320	62.5	5.31±0.13	ND	ND	ND	ND	ND	ND
15	0.270	329	66.0	6.18±0.08	ND	ND	ND	ND	ND	ND

* Condition with ≥3 bulged cans out of 15 samples during pasteurization before pasteurization was completed.
[†] 1 bar = 100,000 Pa
D: detected, ND: not detected

uncoded values of can thickness (mm), fill volume (mL), and pasteurization temperature (°C), respectively; β_0 is intercept; β_1, β_2, and β_3 are linear effects of can thickness, fill volume, and pasteurization temperature, respectively; β_{11}, β_{22}, and β_{33} are quadratic effects of can thickness, fill volume, and pasteurization temperature, respectively; β_{12} is an interaction effect of can thickness and fill volume; β_{13} is an interaction effect of can thickness and pasteurization temperature; and β_{23} is an interaction effect of fill volume and pasteurization temperature.

Data of biological property of beer obtained from study were statistically analyzed by two-way analysis of variance using SPSS software (version 18; International Business Machines Corp, New York, USA) at the p-value < 0.05 with Tukey's Group Range Test for comparison of the means.

3. Results and discussion

Gas expansion in package headspace changes the internal pressure of product and cause can bulging in carbonated beverage (American Society of Brewing Chemists, 1949; Kunze, 2004; Erdogdu and Tutar, 2011; Speers and MacIntosh, 2013; Kuntzleman and Sturgis, 2020). Therefore, the internal pressure was used as a response for modeling in this work. The data obtained were used to construct a mathematical model depicting the effects of process and package parameters on internal pressure inside the can after pasteurization. Table 3 and Equation 2 show parameter estimates of the model (R^2 = 0.8969). To validate the predictive model, two additional random combinations of canned beer pasteurization (Table 4) were selected. The actual pressures obtained, which were 6.25±0.03 and 5.79±0.05 bars, respectively, fell within the range of predicted internal pressure for both conditions. This indicated that the model was valid and could be applied to predict the internal pressure of canned beer pasteurization within these independent parameter ranges listed in Table 1.

$$[Y] = -200.02872841 + 174.37280423X_1 + 0.94353767X_2 + 0.68160015X_3 - 940.44444445X_1^2 - 0.00150549X_2^2 + 0.00344671X_3^2 + 1.00740741X_1X_2 - 0.43809524X_1X_3 - 0.00283069X_2X_3 \quad (2)$$

Where [Y] is estimated internal pressure of canned beer after pasteurization (bar); X_1, X_2, and X_3 are uncoded values of can thickness (mm), fill volume (mL), and pasteurization temperature (°C), respectively; X_1^2, X_2^2, and X_3^2 are uncoded values of quadratic effects of can thickness, fill volume, and pasteurization temperature, respectively; X_1X_2 is uncoded values of an interaction effect of can thickness and fill volume; X_1X_3 is uncoded values of an interaction effect of can thickness and pasteurization temperature; X_2X_3 is uncoded values of an interaction effect of fill volume and pasteurization temperature.

According to Equation 2, internal pressure inside pasteurized canned beer was significantly influenced by can thickness, fill volume, and pasteurization temperature ($p<0.05$) (Table 3). Internal pressure increased as fill volume or pasteurization temperature increased while it decreased as can thickness increased.

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Table 3. Parameter estimates of RSM equation for canned beer pasteurization.

Parameter	Estimate	Standard error	Prob > | t |
Intercept	6.1356	0.0410	<0.0001*
Can thickness	-0.0737	0.0251	0.006*
Fill volume	0.3188	0.0251	<0.0001*
Pasteurization temperature	0.2392	0.0251	<0.0001*
Can thickness*Can thickness	-0.1469	0.0370	<0.0001*
Fill volume*Fill volume	-0.1219	0.0370	0.002*
Pasteurization temperature*Pasteurization temperature	0.0422	0.0370	0.261
Can thickness*Fill volume	0.1133	0.0355	0.003*
Can thickness* Pasteurization temperature	-0.0192	0.0355	0.593
Fill volume* Pasteurization temperature	-0.0892	0.0355	0.017*

*Significant at p<0.05.

Table 4. Validation conditions of RSM model for canned beer pasteurization (mean±SD) from three replicates.

Condition	Can thickness (mm)	Fill volume (mL)	Pasteurization temperature (°C)	Internal pressure (bar*) 95% confident interval range	Internal pressure (bar*) Results
1	0.255	330	62	6.24-6.41	6.25±0.03
2	0.270	327	60	5.74-5.95	5.79±0.05

* 1 bar = 100,000 Pa

At increasing temperature, CO_2 was released into the headspace of a can, resulting in higher internal pressure (Speers and MacIntosh, 2013; Kuntzleman and Sturgis, 2020). At the same pasteurization temperature, cans with higher fill volume had higher internal pressure (Table 2) due to a reduction of headspace (Kunze, 2004). At a given temperature, the headspace volume of aluminum can with a thicker wall increases more as compared to a can with a thinner wall due to the thermal expansion characteristic of aluminum (Carvill, 1993).

From Table 2, *E. coli*, coliforms, lactic acid bacteria, *Bacillus cereus*, brewer's yeast, and wild yeast were not detected in any of treated beer samples, indicating that the efficiency of all experimental pasteurization conditions fell within the acceptable range (>30 PU). The maximum internal pressure observed was 6.53±0.05 bars which was detected in cans with 0.255 mm can thickness and 338 mL fill volume treated at 66°C. The value was well above the maximum pressure resistance of the can (6.20 bars) specified by the supplier (Boon Rawd Brewery Co., 2018). In some severe testing conditions, especially at high pasteurization temperature and/or fill volume, some cans bulged during pasteurization (Table 2). On the other hand, can with a smaller thickness (0.245 and 0.255 mm) than that of current commercial use under certain conditions, for instance, fill volume of 320 mL and 329 mL or pasteurization temperature of 59°C and 62.5°C, could be used in beer production to reduce packaging cost without significant risk of can bulging.

Aluminum cans for carbonated beverages, especially beer, must withstand high pressure due to the nature of the product and additional pressure from gas expansion during heat treatment process (Felmingham, 1960; Hackworth and Henshaw, 2000). Currently, aluminum cans for pasteurized beer often has a wall thickness of 0.270 mm. The process temperature can be elevated to up to 65°C (Dilay *et al.*, 2006; Yalçınçıray *et al.*, 2021). This could lead to a higher frequency of can bulging. Based on the model (Figure 1), assuming pasteurization

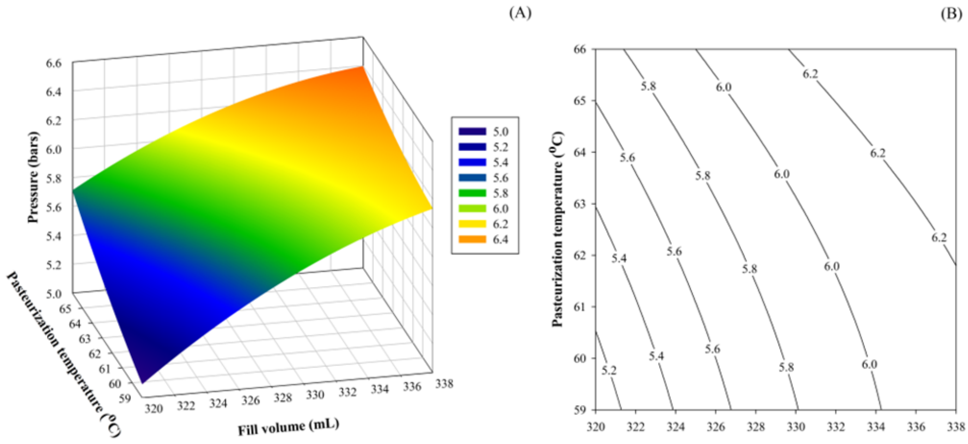

Figure 1. Effects of fill volume and pasteurization temperature on internal pressure of canned beer after pasteurization at can thickness of 0.270 mm, based on model (Equation 2): response surface plot (A) and contour plot (B).

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temperature of ≤65°C, canned beers in a can with the thickness of 0.270 mm should have a fill volume of ≤332 mL in order for internal pressure to be ≤6.20 bars to minimize the possibility of bulged can incident.

4. Conclusion

A mathematical model was constructed to explain the effects of the process and packaging parameters on the internal pressure of pasteurized cans which was used as an indication of potential can bulging incidents in tunnel pasteurizer. Internal pressure inside canned beer was significantly affected by can thickness (0.245-0.270 mm), fill volume (320-338 mL), and pasteurization temperature (59-66°C). The model can be used as a guideline for commercial canned beer manufactures to optimize pasteurization conditions and reduce can loss due to can bulging incident.

Conflict of interest

The authors declare no conflicts of interest.

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