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Air Quality in a Brewery Bottling Plant

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1. Introduction

A brewery is one example of a traditional workplace where, despite a significant automation of the production processes, the employees continue to be exposed to the emitted pollutants (Spitaels et al. 2014). Physical, chemical or biological air pollutants are emitted at each individual stage of the beer production process such as boiling, fermenting and beer bottling. The type of such pollutants depends mainly on the specific technological processes applied at the given beer brewing stage (Bokulich & Bamforth 2013). The preparation of intermediate products yields mainly volatile beer wort and hops components. Hops contains approximately 250 ethers which give beer its unique aroma. The most important ones include: myrcene, β-caryophyllene, and β-farnesene. Glucose, maltose and maltotriose, as well as proteins and lipids are metabolized during fermentation (Wunderlich & Back 2009). The fermentation by-products comprise, among other things, diacetyl, higher alcohols, esters and aldehydes. Significant concentrations of air pollutants and related intensive odors may be found in the brewhouse in which beer wort is boiled. Unpleasant olfactory sensations may be perceived during the acidification of grain stillage which occurs when the temperature is too high or the storing period is excessively long. Foul odors may also arise due to the purification of diatomaceous earth employed in beer filtration processes (Poreda et al. 2015). Beer bottling is the most extended process and includes various different procedures from bottle washing and disinfection through removing old and placing new labels to filling the bottles with beer. All such procedures may be a source of hazardous air pollutants.

This paper presents the results of air quality measurements in the beer bottling plant during the final stage of the beer production process. Particular attention was placed on the emitted aerosol and bioaerosol pollutants and the concentrations of carbonyl compounds.

2. Methods

Air quality measurements were conducted at Perła-Browary Lubelskie S.A. in Lublin, a brewery that was established in 1846. The brewery underwent modernization in the late 90s. It is located in the southern part of Lublin, close to urban developments, near two busy streets, in the vicinity of a small river and the train station. The measurements were performed in the bottling plant operated in 3 shifts and which was equipped with typical devices such as a bottle washer, beer dispenser, labeling and packing machine. The air quality measurement instruments in the bottling plant were placed at the height of 1.3 m in two locations – near the bottle washer and near the beer dispenser. Aerosol concentrations were determined during 24 hours continuous measurements. Particle mass concentrations were measured with the use of aerosol monitor DustTrak DRX model 8533 (TSI Inc., USA). This instrument was applied to record approximations of mass concentrations of PM1, PM2.5, PM4, PM10, RESP and TSP (particles with an aerodynamic diameter equal or less than 1, 2.5, 4, 10 µm, respirable and total suspended particles, respectively). These fractions of particles are referred to as "uncut" in this paper. The DustTrak monitor was subject to standard real-time size correction factor calibration (Polednik 2013a). The optical spectrometer OPS 3330 (TSI Inc., USA) was applied to determine the mass and number concentration and size distribution of particles greater than 0.3 µm ($PN_{0.3\text{-}0.5}$, $PN_{0.5\text{-}1}$, $PN_{1\text{-}2}$, $PN_{2\text{-}5}$ and $PN_{5\text{-}10}$). In this paper, such particle fractions are referred to as "cut". The sampling time for the instruments was 1 minute and the logging interval was 5 minutes. Concentrations of bioaerosol particles were determined by means of the sedimentation method with the use of Petri plates with relevant nutrients. Bacteria concentrations were determined using *Tryptone Soya Agar* nutrient and fungi concentrations were determined using *Agar Sabouraud* nutrient (Rożej et al. 2008). Two measurement series were carried out at each of the measurement points. After the set exposition time amounting to 15 minutes the Petrie plates were incubated. The incubation conditions were as follow: for bacteria the incubation time was 48h and the temperature was 37°C, for fungi the incubation time was 72h and the temperature was 27°C. After the incubation period, grown colonies of microorganisms were counted and bacteria and fungi concentrations were determined in the bottling plant air. The results were presented as colony forming units per cubic meter of air (CFU/m^3). Carbonyl compound concentrations in the bottling plant air were determined by means of the passive method with the use of Radiello dosimeters. Carbonyl compounds were sorbed on the dosimeters, extracted with acetonitrile (HPLC grade) and analyzed using RP HPLC (Waters) with a Restek Allure AK column; acetonitrile/water elution and UV detection set at 365 nm. Average concentrations during long-term exposure as well as peak concentrations (15-minute exposure) were determined. All air quality measurements in the bottling plant were carried out in June 2015.

The Statistica 12 software package was used for data analyses. Descriptive statistics were used to characterize the indoor carbonyl compound, aerosol and bioaerosol concentrations. A value of $p < 0.05$ was considered statistically significant. The observed distributions of aerosol particle concentrations fit to lognormal distributions were compared using the nonparametric Kolmogorov-Smirnov two-sample test.

3. Results and discussion

3.1. Aerosol particles

Internal factors related to the production process as well as external factors have an impact on the air quality in the bottling plant. The same obviously applies to aerosol concentration levels. Figure 1 presents the time series of particle mass concentrations in the bottling plant which were obtained during continuous measurements that lasted for 24 hours – changes of mass particle concentrations during a typical one day of the bottling plant's operation.

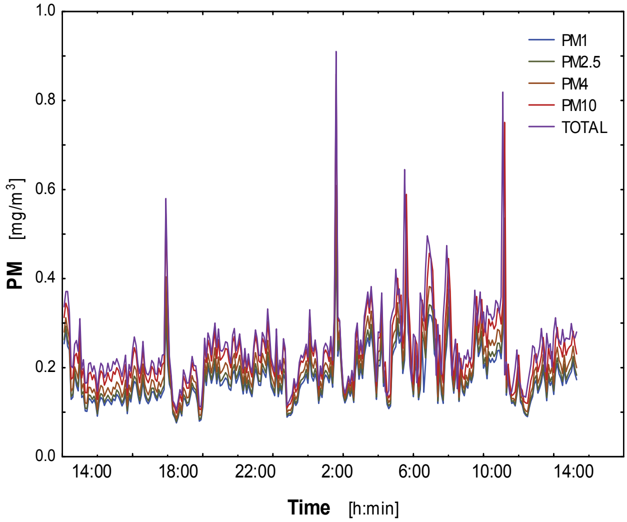

Fig. 1. Time series of particle mass concentrations in the bottling plant
Rys. 1. Zmiany stężeń masowych cząstek w rozlewni piwa

Four distinctive increases (up to about 5 times) in the mass particle concentrations can be observed which took place at about 6 p.m., 2 a.m. and 6 a.m. and 11 a.m. The exact reason of such increases has not been established. Most probably they were caused by the changes in the technological process or were connected with routine activities of the bottling plant employees. The lowest aerosol particle concentrations were observed in the evening and at night i.e. during both planned and unplanned downtimes. The distributions and cumulative distributions of particle mass concentrations of the measured fractions PM1, PM2,5, PM4 and PM10 obtained using DustTrak monitor which were fit by lognormal functions are shown in Figure 2. It can be seen that the distributions of mass concentrations of all the measured particle fractions are very similar. Both the average values and the medians of the mass particle concentrations are within a relatively narrow range from 0.16 to 0.23 mg/m^3. Steep cumulative distribution functions indicate that for all the considered particle fractions their predominant scope of mass concentrations (80%) was in the range from 0.12 to 0.31 mg/m^3. Figure 3 presents the particle mass concentration distributions obtained using the OPS spectrometer. In turn, Figure 4 presents the particle number concentration distributions obtained with the use of the OPS sizer.

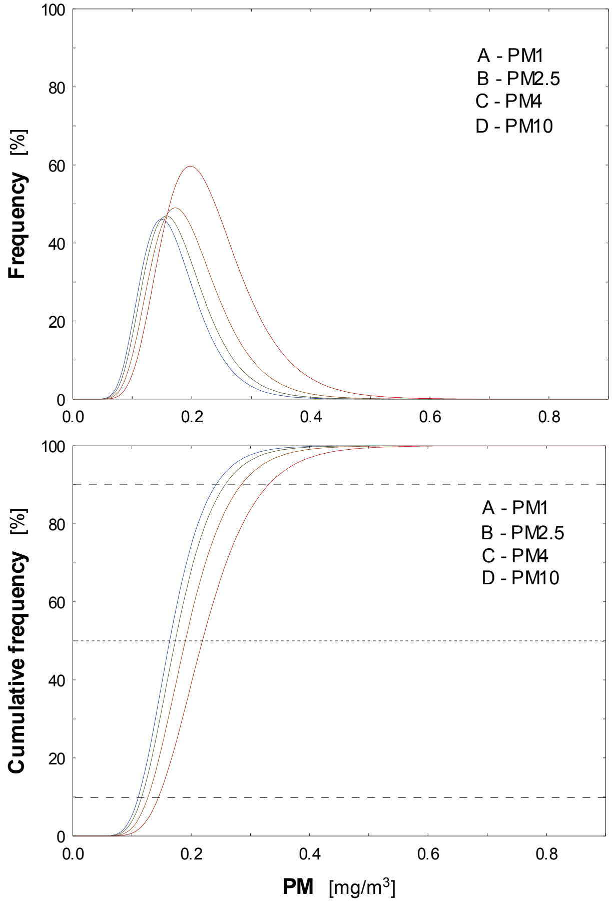

Fig. 2. Distribution and cumulative distribution functions of mass concentrations of PM1, PM2,5, PM4 and PM10
Rys. 2. Rozkłady i dystrybuanty masowych stężeń PM1, PM2,5, PM4 i PM10

Distribution functions of particle mass concentrations for the "cut" fractions that were obtained by the OPS spectrometer ($PM_{0,3\text{-}05}$, $PM_{0,5\text{-}1}$, $PM_{1\text{-}2}$, $PM_{2\text{-}5}$ and $PM_{5\text{-}10}$) are similar to those obtained by the DustTrak monitor for the "uncut" fractions (PM1, PM2.5, PM4 and PM10). The average values and medians of the particle mass concentrations $PN_{0,3\text{-}05}$, $PN_{0,5\text{-}1}$, $PN_{1\text{-}2}$, and $PN_{5\text{-}10}$ were within the range from approximately 44 to 63 μg/m^3. Slightly different values of these parameters were obtained for the $PM_{2\text{-}5}$ particles. The lognormal distribution of such particle mass concentrations is shifted towards higher particle concentrations.

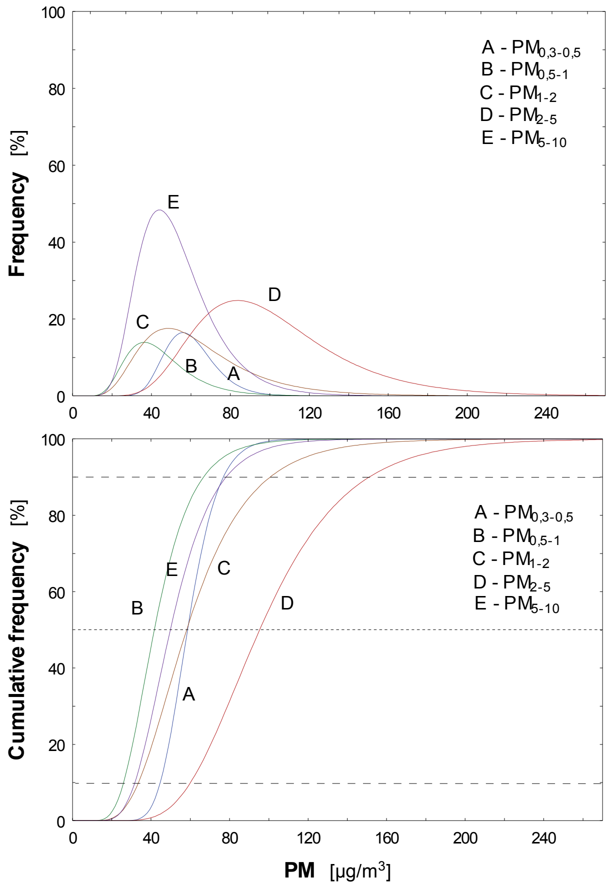

Fig. 3. Distribution and cumulative distribution functions of mass concentrations of the particle fractions $PM_{0,3\text{-}05}$, $PM_{0,5\text{-}1}$, $PM_{1\text{-}2}$, $PM_{2\text{-}5}$ and $PM_{5\text{-}10}$
Rys. 3. Rozkłady i dystrybuanty masowych stężeń cząstek $PM_{0,3\text{-}05}$, $PM_{0,5\text{-}1}$, $PM_{1\text{-}2}$, $PM_{2\text{-}5}$ oraz $PM_{5\text{-}10}$

Their average value and median amount to approximately 101.4 and 99.6 μg/m^3. The cumulative distribution function for the concentrations of such particles is not as steep. The predominant range of their mass concentrations (80%) amounts to from approximately 60 to 150 μg/m^3. The two-sample Kolmogorov-Smirnov test proved that the data sets for mass concentrations of $PM_{2\text{-}5}$ and other considered particle fractions were being drawn from different distributions. Such results confirm that in terms of the mass, medium-sized particles (of a few micrometers) prevail in the indoor air and their mass has a significant impact on the overall mass concentration of aerosol particles (Polednik 2013b).

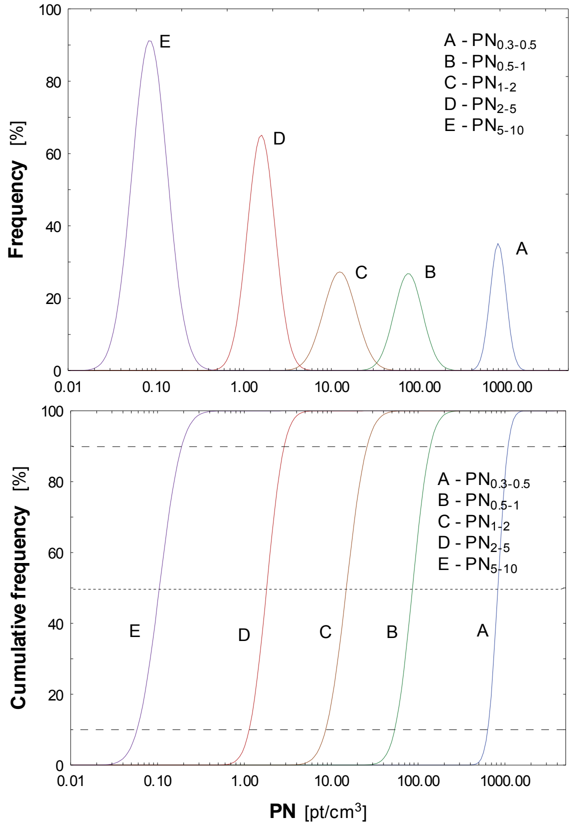

Fig. 4. Distribution and cumulative distribution functions of number concentrations of the particle fractions $PN_{0,3\text{-}05}$, $PN_{0,5\text{-}1}$, $PN_{1\text{-}2}$, $PN_{2\text{-}5}$ and $PN_{5\text{-}10}$
Rys. 4. Rozkłady i dystrybuanty koncentracji ilościowych cząstek $PN_{0,3\text{-}05}$, $PN_{0,5\text{-}1}$, $PN_{1\text{-}2}$, $PN_{2\text{-}5}$ oraz $PN_{5\text{-}10}$

In turn, the distributions of number concentrations of the measured particles are considerably different. Their concentrations depend on the size of the particles and may differ by several orders of magnitude. The average number concentrations of $PN_{0,3\text{-}05}$, $PN_{0,5\text{-}1}$, $PN_{1\text{-}2}$, $PN_{2\text{-}5}$ and $PN_{5\text{-}10}$ particles amount to about 847, 92, 16, 1.9 and 0.1 pt/cm^3 respectively. The predominant concentrations of such particles amount to respectively 689, 112, 12.6, 1.7 and 0.1 pt/cm^3. The above results confirm the obvious, namely that in terms of the number of particles, the air is mostly composed of the finest particles and contains small amounts of coarse particles. Similar observations have been reported in numerous publications (Morawska et al. 2013, Polednik 2014).

3.2. Microbiological contaminations

Table 1 presents the results of microbiological measurements i.e. the concentrations of bacteria and fungi in the bottling plant air which were carried out in two locations (measurement points A and B).

Table 1. Concentrations of bacteria and fungi in the bottling plant
Tabela 1. Stężenia bakterii i grzybów w rozlewni piwa

Sample	Colony No.	Concentration [CFU/m^3]	Average [CFU/m^3]
		Bacteria	
A1	46	1205	1415
A2	62	1624	
B1	65	1703	1467
B2	47	1231	
		Fungi	
A1	29	760	537
A2	12	314	
B1	23	603	577
B2	21	550	

Average concentrations of bacteria in the bottling plant were at the level of 1441 CFU/m^3, while average fungi concentrations amounted to 557 CFU/m^3. These contaminations did not exceed the values of the occupational exposure limit for industrial settings in Poland (Polish Gov. Reg. 2005). They were also below the permitted value i.e. 5000 CFU/m^3 proposed for indoor air in residential and public utility buildings.

3.3. Carbonyl compounds

Table 2 presents 24-hour average carbonyl compound concentrations obtained in 3 measurement series in two locations (measurement points A and B) in the bottling plant.

Table 2. Carbonyl compound concentrations in the bottling plant
Tabela 2. Stężenia związków karbonylowych w rozlewni piwa

Carbonyl compound	Concentration [μg/m^3]		
	A	B	LOD
Formaldehyde	139.8 (5.7)	127.0 (11.2)	0.5
Acetaldehyde	165.9 (9.1)	156.7 (10.2)	0.5
Acroleine	12.5 (1.6)	22.7 (1.8)	0.9
Acetone	29.2 (1.5)	30.1 (1.2)	0,5
Propanal	16.9 (0.9)	17.8 (1.1)	1.5
Butanal	62.7 (1.7)	47.0 (1.9)	2.0
Butanon	16.9 (1.4)	16.3 (1.3)	1.5
Pentanal	46.1 (2.5)	30.2 (2.1)	0.9
Hexanal	51.9 (3.1)	44.0 (2.0)	1.5

Mean (Standard deviation); LOD – limit of detection

The obtained results do not evidence considerable carbonyl compound concentrations in the bottling plant air. When comparing these compound concentrations measured in both locations, slightly higher concentrations of formaldehyde (metanal), butanal, pentanal and hexanal were obtained at the measurement point A. This may be related to the fact that this measurement point was located near the bottle washer. Washing agents could be responsible for the increased concentrations of butanal and hexanal commonly present in all dishwashers as well as formaldehyde present in industrial dishwashers due to its antibacterial properties (Niu & Burnett, 2001). Formaldehyde is commonly present in all indoor surface layers, including low-VOC wall paints and its emissions are elevated with the increase of temperature and humidity (Dudzińska et al. 2009). In turn, acroleine concentrations were considerably higher at the measurement point B which could be explained by the presence of tobacco smoke in the air (Dudzińska 2011). Formaldehyde concentrations measured in a weekly period did not exceed the permitted values for working conditions (Polish Gov. Reg. 2014). However, periodical (15 min) significant increases of up to 800 μg/m^3 were observed for this compound. Concentrations of other measured carbonyl compounds were within the acceptable range for indoor premises (Polish Gov. Reg. 1996).

The presented results indicate that the employees of the beer bottling plant are potentially exposed to health hazards related to the periodical concentration increases of the measured pollutants. Information on such concentration levels may be helpful in implementing measures protecting the employees against the harmful effects of such pollutants as well as measures aimed at limiting the exposure of the bottling plant employees. The limitation or elimination of pollutant emitting processes during beer production is also of high importance.

4. Conclusions

On the basis of the obtained measurement results it may be concluded that the air quality in the brewery bottling plant is affected by the production processes. Periodical increases of the measured pollutants were observed, however, in the long term the average levels of pollutants did not exceed the permitted levels for such type of facilities. Repetitive increases of aerosol and carbonyl concentrations may nevertheless have a potential adverse health effect on the brewery employees.

The knowledge about hazards present in the beer bottling plant may be helpful in preventive activities consisting in, among other things, the provision of better protection for the employees against the harmful effects of air pollutants as well as in a more effective limitation or elimination of pollutant generating processes and other air pollutant sources in the beer bottling plant.

Acknowledgement
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Jakość powietrza w rozlewni piwa w browarze

Streszczenie

Przedstawione wyniki badań dotyczą jakości powietrza w rozlewni piwa. W trakcie normalnej pracy rozlewni mierzone były stężenia masowe i koncentracje ilościowe cząstek aerozolowych, stężenia bakterii i grzybów oraz stężenia związków karbonylowych w powietrzu. Stężenia aerozoli określano w sposób ciągły metodami spektrometrii optycznej. Zanieczyszczenia biologiczne oznaczano metodą sedymentacyjną wykorzystując płytki Petriego z odpowiednimi pożywkami. Stężenia związków karbonylowych w powietrzu określano metodą pasywną używając dozymetrów Radiello. Przy oznaczaniu stężeń zanieczyszczeń biologicznych i związków karbonylowych wykonano odpowiednio dwie i trzy serie pomiarowe w dwóch miejscach rozlewni piwa.

Pomimo zautomatyzowania procesu rozlewania piwa do butelek zaobserwowano okresowe znaczące wzrosty stężeń mierzonych zanieczyszczeń. Średnie stężenia masowe wszystkich mierzonych frakcji cząstek aerozolowych miały podobne wartości i wynosiły ok. 0,2 mg/m^3. Maksymalnie ok. 5-cio krotne wzrosty koncentracji masowych cząstek obserwowano w nieregularnych odstępach czasu. Największe koncentracje ilościowe zmierzono dla cząstek drobnych. Średnie koncentracje cząstek o wielkościach 0,3-0,5 µm i 0,5-1 µm miały odpowiednio wartości 847 i 93 cząstki/cm^3. W przypadku zanieczyszczeń biologicznych średnie stężenie bakterii w powietrzu w rozlewni piwa wynosiło 1441 JTK/m^3, a średnie stężenie grzybów 557 JTK/m^3. Wartości te są niższe niż proponowane dopuszczalne poziomy stężeń bakterii i grzybów w budynkach użyteczności publicznej. Średnie stężenia mierzonych związków karbonylowych również nie przekraczały wartości, które są dopuszczalnych w środowisku pracy. Oprócz formaldehydu, którego okresowe stężenia wzrastały do prawie 800 µg/m^3 stężenia innych związków były w zakresie akceptowalnym dla pomieszczeń przeznaczonych na pobyt ludzi. Nieco wyższe stężenia niektórych związków karbonylowych odnotowano w punkcie pomiarowym w pobliży myjni butelek.

Przedstawione wyniki wskazują, że istnieje potencjalne zagrożenie dla zdrowia pracowników rozlewni piwa związane z okresowymi wzrostami stężeń mierzonych zanieczyszczeń.

Słowa kluczowe:
jakość powietrza, aerozole, bioaerozole, związki karbonylowe, rozlewnia piwa

Keywords:
air quality, aerosols, bioaerosols, carbonyl compounds, bottling plant