

## Closed-cycle brine graduation towers: History, operating principle, and microbiological safety of use

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### ABSTRACT

Brine graduation towers represent a significant component of health resort infrastructure, predominantly functioning as inhalers. The operation of these devices is predicated on the generation of a salt aerosol, which exhibits the properties analogous to those of a seaside microclimate. These properties are conducive to the prevention and treatment of respiratory diseases. In recent years, however, there has been an intensive development of municipal micro-graduation towers, which raises legitimate concerns about the sanitary safety of their use. Whilst the majority of publications concentrate on the design, principles of operation, and health benefits of brine graduation towers, relatively few studies point to the potential risks associated with their operation. The objective of this study was to draw attention to these risks. It presented the results of authors' own research, which involved the analysis of microbiological contamination of brine circulating in a closed-cycle municipal graduation tower and the mist inhaled by people. The innovative nature of this study renders it groundbreaking within the context of the discussion on the proper operation and legitimacy of the construction of municipal micro-graduation towers. This research related to the detection of pathogens in brine and mist used for inhalation, as well as the lack of legal regulations concerning the operation and sanitary supervision of this type of installation, has prompted the Chief Sanitary Inspectorate (Główny Inspektorat Sanitarny – GIS) to draw attention to this problem. At present, the GIS is planning to develop recommendations for the operation of micro-graduation towers for their owners and managers, rules for the safe use of these facilities by the public, and rules for their supervision.

**Keywords:** brine graduation tower, closed cycle, micro-graduation tower, microbiological contamination, brine, brine mist.

### INTRODUCTION

The name 'graduation tower' comes from the term 'grade', which refers to the process of increasing the salt concentration in brine. In the past, salinity levels were determined in 'grading' units, thus explaining the etymology of the term. This facility is also referred to as a 'thorn house'. Historically, graduation towers were predominantly used for production purposes, with a focus on salt production. In contrast, contemporary applications primarily encompass health and recreational activities (Chudzińska and Dybczyńska-Bułyżsko 2019; Rogula-Kozłowska et al., 2022).

The history of brine graduation towers is inextricably linked to the history of salt extraction

and use, a process that has played a pivotal role in human life for millennia. Evidence suggests that salt was obtained by evaporating seawater, salt lake water and brine from natural sources as early as the Neolithic period (4300–3500 BC). The oldest traces of salt production originate from this period. Archaeological research indicates that one of the oldest salt works in Europe, dating back to around 6000 years ago, operated in Wieliczka. In contrast, the tradition of salt mining in this region has only been developing since the 13th century (Gawel and Kuczaj, 2012; Langer, 2014). In Poland, the development of salt production technology was particularly intense during the Roman period. The first traces of the use of wooden structures for salt evaporation were recorded as

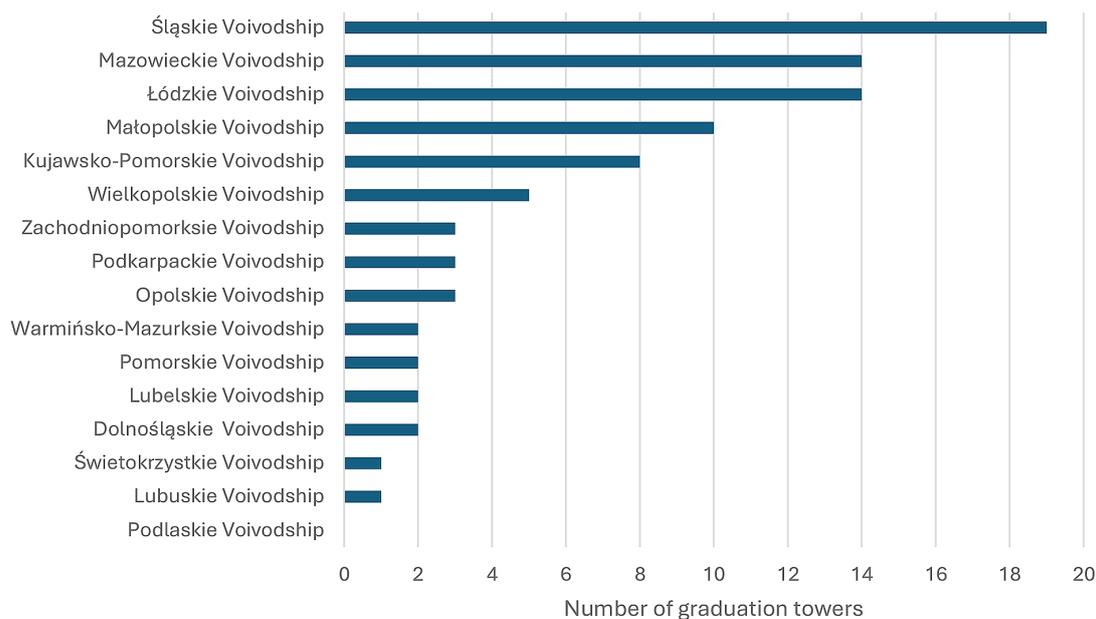
early as the 2nd–1st century BC, in the vicinity of Ciechocinek (Faracik, 2020; Kejna et al., 2022). In subsequent eras, including the Bronze Age (c. 800–650 BC) and the Iron Age (800–400 BC), the development of salt production technology was linked to an increase in the demand for salt. The first devices for concentrating brine, known as ‘briquette machines’, emerged, assuming a function analogous to that of contemporary graduation towers (Gaweł and Kuczaj, 2012). Subsequently, between the 2nd and 4th centuries CE, at least five wooden structures were present in Inowrocław, bearing no resemblance to their current appearance. These were primitive structures in which brine flowed by gravity through straw, which served the same function as the current blackthorn (Faracik, 2020; Kejna et al., 2022). Further traces of wooden structures resembling brine graduation towers have been found in Italy (Lombardy) and Germany, dating back to the turn of the 14th and 15th centuries. At that time, brine was distributed in large wooden boxes filled with straw (Engelhardt and Von Borstel, 2015). It was not until 1700 that blackthorn began to be used instead of straw, as it was more effective in the evaporation process (Faracik, 2020).

The dynamic development of brine graduation towers took place in the 19th century with the construction of impressive structures in Ciechocinek. Between 1824 and 1859, three monumental graduation towers with a total length of over 1,700 m were built according to a design by Professor Jakub Graff. To this day, they constitute the largest complex of this type in the world and are a characteristic element of Ciechocinek health resort infrastructure, distinguishing this town from other health resorts in Poland and Europe. These structures constituted an integral part of the salt processing plant designed by Graff (Tłoczek, 1958; Gaweł and Kuczaj, 2012).

Initially, the technology behind graduation towers was very primitive. The brine was extracted directly from the source and distributed manually at the top of the wooden structure. From this point, it flowed down a system of wooden troughs over blackthorn branches, breaking up into small drops, which promoted natural evaporation of the water. This process was repeated many times until the desired concentration was achieved. The brine was then transferred to the saltworks, where it was heated and concentrated to about 33%, thereby enabling the crystallization of salt. In addition to salt, sludge and lye were also obtained, which

were used for medicinal purposes (Chudzińska and Dybczyńska-Bułyszko, 2019). Subsequently, the advent of the pumping technology enabled the transportation of brine to elevated heights, thereby allowing the construction of more monumental structures. Pumps facilitated the operation of graduation towers, yet did not modify the principle of their operation; the brine still flowed down the buckthorn by gravity, creating a natural aerosol. In the 19th century, this aerosol was regarded as an undesirable byproduct due to the loss of raw material. However, today it is the composition of this aerosol that dictates its health benefits, as evidenced by recent research (Rogula-Kozłowska et al., 2022). In the mid-19th century, the industrial use of graduation towers gradually began to lose its importance due to the development of rock salt mining. However, their health benefits became increasingly evident. The phenomenon of brine aerosolization, formerly undesirable due to the loss of raw material, has emerged as a therapeutic modality (Rogula-Kozłowska et al., 2022). The next Polish graduation tower was not built until the second half of the 20th century. In 1978, the first graduation tower in Poland, constructed expressly for therapeutic purposes, was launched in Konstancin (today Konstancin-Jeziorna). This graduation tower is supplied with brine with a concentration of 7.5% and is characterized by a closed polygon shape with a circumference of 140 m and a height of 6 m (Faracik, 2020). Another well-known health resort that built a brine graduation tower was Inowrocław (1995). In the following years, similar facilities were constructed in Grudziądz (2006) and Rabka-Zdrój (2009). The location decisions were dictated both by the availability of nearby brine springs and the desire to create a health complex that would raise the town’s status as a health resort (Faracik, 2020).

Since 2015, there has been a dynamic development of municipal graduation towers (micro-graduation towers), especially in industrialized regions dominated by the metallurgical and mining industries (Figure 1). There are over 100 brine graduation towers throughout Poland, and their number is constantly growing. These facilities are constructed both in parks and near housing estates, schools, and shopping centers. Most often, they are small structures (height >3 m, length >2 m) filled with blackthorn or birch, with a closed circulation of brine stored in underground tanks. Municipal graduation towers are usually available to residents for a period of 6 months and



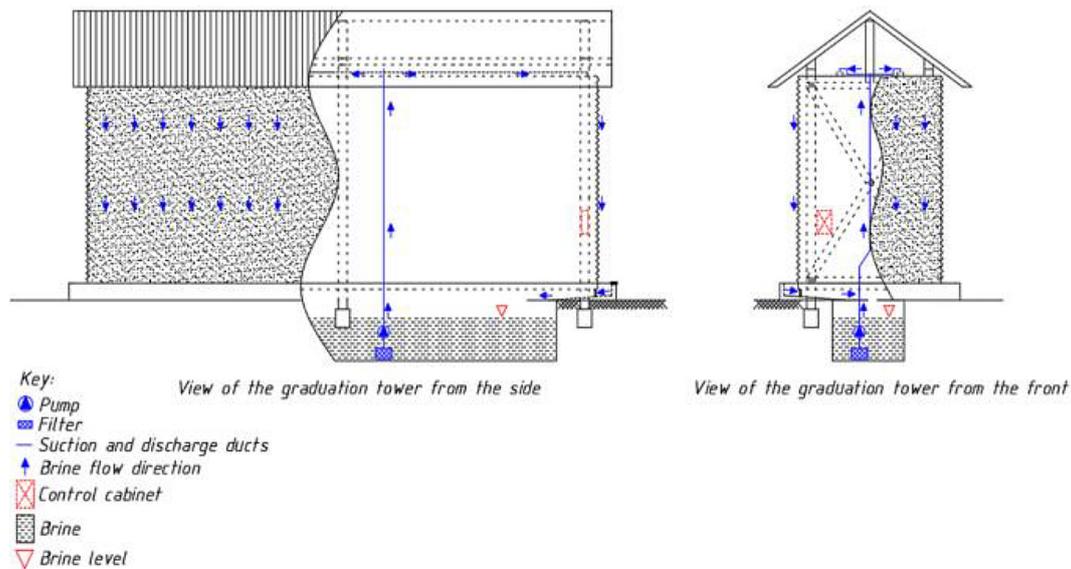
**Figure 1.** Number of graduation towers in voivodships (based on Faracik, 2020)

serve as natural inhalers (Faracik, 2020; Rataj and Holewa-Rataj, 2020; Wojtal, 2018; Bodziacki and Wolny-Koładka, 2023). The development of these facilities is related to the increase in health awareness among the population and the need to counteract the effects of air pollution, especially in large cities such as Krakow, where smog is a significant problem. The employment of closed brine circulation technology enables graduation towers to function in urban environments without reliance on natural sources and with reduced resource utilization (Bodziacki and Wolny-Koładka, 2023; Bodziacki et al., 2024). Brine graduation towers can be constructed in various ways. In many towns and municipalities, it is the residents who decide on such investments, for example by submitting projects to the participatory budget and then voting on them. Where the idea gains support, the local government finances the implementation from accumulated funds (taxes). Another method is investments planned directly by the municipality, as well as co-financing from the EU funds. Occasionally, private partners, such as developers, also engage in construction activities.

## STRUCTURE AND OPERATING PRINCIPLES OF BRINE GRADUATION TOWERS

Brine graduation towers, also referred to as thorn houses, represent a distinctive architectural category that fulfills dual roles in technological

and health-related contexts. Their origins are linked to the salt production process; however, in the contemporary era, they function as outdoor inhalers and constitute an integral component of balneological health resorts (d'Obyrn and Rajche, 2015; Lenger, 2014; Czubernat and Tomaszewska, 2021). A brine graduation tower is a structure composed of wooden logs, most often oak or spruce, which form a solid structural framework. The interior is filled with bundles of blackthorn branches, over which brine flows, breaking into tiny droplets and creating a healing bioaerosol (d'Obyrn and Rajche, 2015; Rogula-Kozłowska et al., 2022; Kostrzyń et al., 2018). The structure is equipped with valves, taps, pipelines, and pumps, among other components, and is set on a solid foundation, which ensures its stability (Figure 2). A critical aspect that must be taken into consideration for the optimal functionality of a graduation tower is its height, which is imperative for ensuring a sufficiently long trajectory for salt droplets to fall by gravity into the basin. The objective of the entire process is to obtain a minimum 16% sodium chloride solution in water (maximum approximate: 27%). The concentration process is contingent upon meteorological conditions. Sunny and windy days are conducive to the evaporation of brine and the formation of a therapeutic bioaerosol, while rainy and foggy days are disadvantageous to such a microclimate (Bodziacki and Wolny-Koładka, 2023; Bodziacki et



**Figure 2.** Schematic of a closed-cycle brine graduation tower structure (Bodziacki and Wolny-Kołodka., 2023)

al., 2024; Rogula-Kozłowska et al., 2022). The intensity of evaporation depends on atmospheric factors, chief among them relative humidity, temperature, and wind speed. The ideal conditions are sunny weather, temperatures above 20 °C, and a gentle breeze. Under these conditions, maximum concentration can be achieved in three days (Kalwasińska et al., 2018). Brines are classified as medicinal mineral waters characterized by high chemical and microbiological purity. They must have a total mineralization of at least 35 g·dm<sup>-3</sup>, whereas their main components are chloride and sodium ions. The water with a NaCl concentration above 1.5% is considered brine, while the solutions with concentrations below 1.5% are referred to as saltwater (Kamińska and Krusiec-Świdergoń, 2023). As brine flows down branches, it disperses into very fine droplets. This significantly increases the evaporation surface area. Additionally, the flow through the blackthorn stack purifies the brine, as unwanted mineral compounds, primarily clay, gypsum, and other salts, precipitate out of it (Lenger, 2014).

Depending on their function and location, graduation towers can vary in size. The largest structures are built in health resort towns, where there is a constant supply of fresh brine. One example is the famous graduation tower in Ciechocinek, which is one of the largest of its kind in Europe at 16 m high and 1,741 m long. Other large structures can be found in Inowrocław, Konstancin-Jeziorna, and Gołdap (Tłoczek,

1958; Bodziacki and Wolny-Kołodka, 2023). In addition to monumental structures, smaller municipal graduation towers over 3 m high and over 2 m long are being increasingly built. These structures can be found in town parks and housing estates, where they serve as recreational and health facilities. Some graduation towers have additional roofing to protect against birds nesting and adverse weather conditions. Benches for visitors are often installed near the structures, allowing them to enjoy the salt-rich microclimate for longer periods of time (Bodziacki and Wolny-Kołodka, 2023).

Graduation towers can be categorized by the type of brine circulation system they use, which can be either open or closed. Closed-cycle towers are used in the locations devoid of natural brine sources. The salt solution is taken from a tank situated at the base of the tower. The brine droplets then flow down and are collected in basins before being returned to the tank. From there, they are pumped back to the top of the structure. Deficits resulting from evaporation or droplet losses are replenished with tap water, and the NaCl concentration is regularly checked; if necessary, it is corrected by adding the initial solution (Faracik, 2020; Bodziacki and Wolny-Kołodka 2023; Kostrzyń et al., 2018). Closed-cycle graduation towers are usually small, with an initial height of 3 m and a length that exceeds 2 m. They are supplied with brine stored in specially designed tanks with capacities ranging from several to tens of thousands of liters.

This allows them to function in urban spaces, thereby providing residents with a microclimate similar to that found in traditional health resorts (as declared by manufacturers and proponents of this type of construction) (Bodziacki and Wolny-Koładka 2023; Kostrzyń et al., 2018). Conversely, open-cycle graduation towers are mainly used in health resorts with access to natural brine sources. The brine water is pumped to the top of the structure, where it enters special distribution channels. Subsequently, the flow descends along walls lined with blackthorn, breaking against the branches and creating a

bioaerosol. The flowing brine is collected in a system of basins and directed to pools or back to the top of the graduation tower (Bodziacki and Wolny-Koładka, 2023; Luścińska and Gadziemska, 2011; Tłoczek, 1958).

A comprehensive review of the construction and layout of graduation towers revealed the presence of six distinct architectural forms (Figure 3) (Chudzińska and Dybczyńska-Bułyszko, 2019): longitudinal (a), longitudinal with a roof for health resort visitors (b), central (c), central with a roof for health resort visitors (d), observation tower (e), and facade (f).



**Figure 3.** Architectural forms of brine graduation towers: A – longitudinal, B – longitudinal with a roof for visitors, C – central, D – central with a roof for visitors, E – observation tower, F – facade (<https://zsm.lodz.pl>; <https://aranzacjekopalniane.pl>; <https://www.twoja-praga.pl>; <https://sucha-beskidzka.pl>; <https://turystyka.glucholazy.pl>; <https://dorako.pl>)

## HEALTH BENEFITS OF BRINE GRADUATION TOWERS IN HEALTH RESORTS

The properties of salt were already well-understood in ancient times. The use of salt medicine in the treatment of various diseases was first recommended by Hippocrates and subsequently developed by Paracelsus in the 15th and 16th centuries. The true breakthrough in this field occurred in the 19th century with the advent of balneology in Europe, largely due to the efforts of prominent figures, such as Sebastian Kneipp and Vincent Priessnitz (Lenger, 2014). Currently, salt is mainly used in balneotherapy (brine baths) and halotherapy (salt microclimate therapy). The natural properties of salt have been demonstrated to inhibit the growth of bacteria, fungi, and mites, thus making it a useful agent in the prevention and treatment of respiratory, allergic, and dermatological diseases (Lenger, 2014).

Brine graduation towers and other forms of salt therapy, such as halotherapy and subterraneanotherapy, are an important element of modern climatotherapy. Their significance stems both from the properties of salt aerosol and from the specific microclimate created in the vicinity of therapeutic facilities. The effectiveness of brine inhalation depends largely on the size of the aerosol particles. The largest particles,  $>10\ \mu\text{m}$  in size, settle in the upper respiratory tract, while smaller ones ( $<10\ \mu\text{m}$ ) reach the trachea, bronchi, and bronchioles, including particles with a diameter of  $1\text{--}5\ \mu\text{m}$ , which reach the alveoli and constitute the respirable fraction. The most beneficial respirable fraction includes particles with a diameter of  $1\text{--}3\ \mu\text{m}$ , which penetrate as far as the alveoli and support the treatment of obstructive diseases. On the other hand, very fine particles ( $0.5\text{--}1\ \mu\text{m}$ ) that accumulate in the alveoli are the least desirable (Śliwiński et al., 2014).

The objective of the study by Rogula-Kozłowska et al. (2022) was to ascertain the impact of the brine graduation tower at the Wieliczka Salt Mine on the concentration and composition of aerosols. The study revealed a discernible discrepancy in the chemical composition of PM10 particulate matter samples collected from within and outside the graduation tower. The composition of the substance was found to contain chlorides, sodium, and sulfates, with sodium and chlorides accounting for a minimum of 20% of the total mass. Conversely, the

proportion of these ions was significantly lower outdoors, with carbon compounds predominating in the aerosol. The composition of PM10 at a site distant from the graduation tower exhibited discrepancies from conventional inland locations and demonstrated resemblances to the aerosol characteristics observed in coastal regions. This finding suggests that, despite the observed variations in the chemical composition of particulate matter at specific measuring points, the brine graduation tower had a discernible impact on the air quality within the health resort. The increased proportion of sodium chloride, a compound with strong adsorptive properties, likely contributes to the purification of the air from certain hazardous substances, particularly volatile organic compounds (Rogula-Kozłowska et al., 2022). In addition to the chemical aspect, the impact on the microbiological quality of the air is also significant. Research conducted at the Ciechocinek Health Resort has demonstrated that the bacterial load in the vicinity of the graduation towers is up to fourfold lower than in the town center, thereby validating the efficacy of graduation towers in reducing biological pollutants (Burkowska-But et al., 2014).

Brine graduation towers, similarly to chambers in salt mines, have a beneficial effect in the treatment of chronic respiratory diseases such as asthma, chronic bronchitis, pneumonia, and allergies. Breathing air saturated with salt aerosol helps cleanse and moisturize the respiratory tract as well as alleviates inflammatory processes. Studies have shown that the microclimate surrounding the graduation tower exhibits the characteristics reminiscent of the seaside climate, and its beneficial effects can be felt not only inside the facility, but also in its surroundings, even at a distance of several hundred meters. Inhalation of brine aerosol, which is rich in minerals such as sodium chloride, iodine, bromine, calcium, and iron compounds, can support treatment of respiratory diseases and have a beneficial effect on the cardiovascular system. This therapeutic modality is also efficacious in the cases of immune disorders, iodine deficiency, hypertension, and thyroid diseases (Affelt, 2003; Rogula-Kozłowska et al., 2022; Pawalczyk et al., 2012; Kuchcik et al., 2013).

Clean air, reduced temperature, and high humidity are conducive to respiratory rehabilitation. The most common therapeutic methods using brine include:

- Subterraneotherapy, which is a therapeutic modality conducted in specially prepared underground chambers. Its tradition dates back to the 19th century, and it is currently used, among others, in the Bochnia Salt Mine and the Wieliczka Salt Mine. The microclimate of these places is conducive to the treatment of respiratory diseases such as asthma, chronic bronchitis, bronchiectasis, chronic pharyngitis and laryngitis, as well as allergies (Frączek et al., 2013; Bralewska et al., 2022).
- Halotherapy, which uses rooms lined with salt blocks (halite) with a unique microclimate. The therapeutic factors include high-concentration dry salt mist, air free of allergens and microorganisms, as well as stable temperature and humidity conditions. The first person to draw attention to the health benefits of such an environment was Feliks Boczkowski, who studied miners from Wieliczka in the 19th century and noticed that their respiratory tracts were in better condition than those of other occupational groups (Lenger, 2014).

People of all ages and health conditions, including children and seniors, as well as residents of the areas with high levels of air pollution, can benefit from treatments in brine graduation towers and salt halls. Regular inhalations improve airway patency, moisturize the mucous membranes, strengthen immunity, and support overall regeneration of the body. The treatments also have a beneficial effect on the cardiovascular system, help in the prevention of allergic diseases, and support the treatment of osteoporosis, diabetes, and certain orthopedic conditions. The atmosphere surrounding graduation towers is characterized by high bacteriological quality and low particulate matter levels, which makes walking, sitting, or lying down in their vicinity therapeutic (Affelt, 2003; Kejna et al., 2022; Rogula-Kozłowska et al., 2022).

The advantages of brine graduation towers and related salt therapy methods are multidimensional. They include positive influence on the respiratory, cardiovascular, and immune systems, antimicrobial as well as anti-inflammatory effects, and overall regeneration of the body. Given these features, graduation towers and salt chambers function not solely as recreational facilities, but rather as integral components of contemporary preventive and spa therapy practices, continuing the traditions dating back to ancient times.

## RISKS ASSOCIATED WITH THE OPERATION OF BRINE GRADUATION TOWERS

Brine graduation towers have been valued for centuries due to their advantageous microclimate and health benefits. They create specific environments saturated with salt aerosols that support the treatment of respiratory diseases. However, it should be remembered that this environment, characterized by its high humidity, elevated salt content, and substantial human exploitation, can concurrently engender specific environmental and epidemiological hazards.

The long-term impact of salt water and the salt microclimate it engenders can contribute to soil degradation, cause metal corrosion, and reduce the quality of agricultural crops. A study conducted by Krzyżaniak-Sitarz (2011, 2012) in the Health Resort Park in Inowrocław demonstrated that the black soils exposed to the constant action of a graduation tower undergo changes into saline-sodium soils with a significantly altered sorption complex composition. Calcium became the predominant cation, with concentrations reaching levels up to two or three times higher than in control soils. The second most significant element was sodium, whose content exceeded the levels recorded in non-saline soils by severalfold. Despite the fact that substantial quantities of calcium can mitigate the negative effects of sodium, this process gives rise to substantial soil degradation and a concomitant loss of its original properties (Krzyżaniak-Sitarz, 2011; Krzyżaniak-Sitarz, 2012). Turhan et al. (2014) demonstrated that irrigating crops with seawater at concentrations up to 5% resulted in a slight decrease in yields. A yield decrease of approximately 20% was observed when irrigating with seawater at a concentration of 10%, approximately 25% at a concentration of 15%, and approximately 45% at a concentration of 20%. Birati et al. (2025) conducted soil tests in an area that had previously been irrigated with fresh water flowing from the mountains. In recent years, due to diminished river flow, seawater has begun to infiltrate the area. This phenomenon has resulted in substantial and irreversible losses in the agricultural sector, leading to the region being characterized as a “graveyard of date palms.” Analyses have shown that the intrusion of sodium-rich seawater has induced soil salinization and alkalization. Furthermore, it was determined that the salinity levels in the areas proximate to the river mouths exhibited a marked increase

in comparison to those observed in the upper reaches of the river. Hou et al. (2018) showed in their study that during the seawater desalination process, salt water causes metal corrosion. The authors emphasized that the most severe corrosion is typically caused by splash water (a large number of small droplets). Nomura et al. (2025) also noted in their study that salt water droplets cause metals to corrode faster than in an immersed solution. In addition, it was determined that an increase in salinity accompanied by a decrease in temperature results in accelerated metal corrosion. The dissemination of this information indicates that, despite the significant interest in inhalations in graduation towers, an increasing number of individuals, particularly those residing in proximity to these facilities, are expressing opposition to their operation. They are concerned about the condition of their car bodies and house facades. For many people, the environmental aspect related to soil salinity and the negative impact on plants (graduation towers are very often located in parks) is also important.

The structural characteristics of graduation towers and the microclimates they engender can promote the growth of microorganisms, as evidenced by Luścińska and Gadziemska (2011). The authors identified as many as 52 taxa of algae, including representatives of cyanobacteria, diatoms, and green algae, on wooden elements of the graduation tower in Ciechocinek and in brine tanks. The greatest species diversity was documented in environments with low salinity (approximately 4%), suggesting that not all organisms perish under the conditions of high mineralization. As it was discussed in authors' publications on the microbiological contamination of municipal brine graduation towers (Bodziacki and Wolny-Koładka, 2023), there are even more serious threats to be considered. To the best of authors' knowledge, these publications are first in Poland and worldwide to take an interest in the microbiological quality of brine circulating in municipal graduation towers (micro-graduation towers) and the mist produced by them for inhalation. The research conducted in Krakow has unequivocally demonstrated that during periods of intensive use of closed-cycle brine graduation towers, indicator bacteria such as *Escherichia coli*, *Enterococcus faecalis*, and *Clostridium perfringens* emerge in the brine. This phenomenon is ethically and morally problematic, because brine is the water used for inhalation. According

to the Regulation of the Minister of Health of 13<sup>th</sup> April 2006 on the scope of tests necessary to determine the medicinal properties of natural medicinal raw materials and the medicinal properties of the climate, the criteria for their assessment and the model certificate confirming these properties, the presence of the above-mentioned pathogens in brine is prohibited (Bodziacki and Wolny-Koładka, 2023; Journal of Laws of 2006, no. 80, item 565). Furthermore, Kalwasińska et al. (2018) have demonstrated that the brine environment within graduation towers fosters the proliferation of intricate microbial communities. The researchers indicated that an increase in salinity ranging from 4.5% to 27% results in the development of diverse bacterial and archaeal communities, among which potentially new, previously undescribed taxa appear. This suggests that the graduation tower environment may constitute a distinctive microbiological ecosystem the implications of which for human health remain to be fully elucidated. In addition, the unique characteristics of this environment facilitate the selection of salt-tolerant strains, which may be emitted by graduation towers into the environment over time (Kalwasińska et al., 2018). In the aftermath of the publication of authors' research outcomes (Bodziacki and Wolny-Koładka, 2023; Bodziacki et al., 2024; Bodziacki and Wolny-Koładka, 2025), Zarząd Zieleni Miejskiej in Krakow (ZZM, Krakow Municipal Greenspace Authority), the entity responsible for the oversight of the municipal graduation towers, undertook the initiative of installing UV lamps with the objective of disinfecting the brine that circulates in a closed system. The lamps are flow-through and operate on a continuous basis, 24 hours a day, 7 days a week. Following the installation of the UV lamps in July 2025, the microbiological purity tests of the brine were conducted once more, resulting in the detection of *E. coli* and *E. faecalis* at concentrations of 25 CFU·100 ml<sup>-1</sup> and 35 CFU·100 ml<sup>-1</sup> (unpublished data). This finding serves to refute the hypothesis that the proposed solution, which utilizes UV lamps, is effective. In August 2025, further tests were conducted to ascertain whether the complete replacement of brine and the disinfection of the installation by Zarząd Zieleni Miejskiej in Krakow contributed to the elimination of the pathogens detected. Four days after the complete replacement of the brine in the graduation tower, samples were collected and *E. coli* and *E. faecalis* were detected in quantities of 7

CFU·100 ml<sup>-1</sup> and 11 CFU·100 ml<sup>-1</sup>, respectively (unpublished data). The obtained results clearly show that the measures taken by the ZZM concerning the graduation tower are ineffective and necessitate a review as well as redefinition. This review should be conducted with the input of experts in the field of microbiology, who, leveraging their expertise, can propose an alternative, effective model of action.

In prior research (Bodziacki and Wolny-Koładka, 2025), the authors also analyzed the drug resistance of *E. coli* strains isolated from brine in Krakow's municipal graduation towers. The focus was on determining the drug resistance profile and the presence of genes causing the ESBL (extended-spectrum  $\beta$ -lactamase) mechanism in the *E. coli* isolated from the brine circulating in a closed-cycle brine graduation tower. Most strains were resistant to two antibiotics simultaneously, while one strain was found to be resistant to as many as eight antibiotics at the same time. The genes (at least one of the five tested) responsible for the ESBL mechanism were identified in 39 of the 40 isolates analyzed. The most common genes responsible for  $\beta$ -lactamase production were blaTEM (87.5%) and blaCTXM-9 (70%). The brine supplying the graduation tower was found to be a reservoir of drug-resistant *E. coli* strains, which pose a potential threat to public health. The presence of drug-resistant *E. coli* in brine water has the potential to affect the people inhaling water from graduation towers, which undermines the health-promoting properties of such treatment methods (Bodziacki and Wolny-Koładka, 2025).

Another aspect related to the proper functioning of municipal graduation towers is the microbiological quality of the mist used for inhalation, the topic the authors were also the first to address in their study (Bodziacki et al., 2024). Unfortunately, there are currently no legal standards in Poland regarding the microbiological quality of atmospheric air. Therefore, the results of the study were referred to the proposed limit values for microorganism concentrations recommended by scientists from Poland and abroad, as well as to scientific publications by the authors of this paper and other researchers: PN-EN 13098:2020-0, Wolny-Koładka et al. (2017) and Górny (2020). Over the course of several years, the authors conducted research on the microbiological quality of brine mist in closed-cycle graduation towers in Krakow. It was found that in 2021 and 2022, during the holiday season (when the most people

use inhalation in graduation towers), the concentrations of the analyzed microorganisms were the highest (Bodziacki et al., 2024). During the summer months, there was a marked increase in the number of actinomycetes and *Staphylococcus* spp., which was further exacerbated by elevated air temperatures. The total bacterial and fungal counts did not exceed the recommended limits. However, the presence of actinomycetes and mold fungi, which are allergenic, is a cause for concern. At that time, no pathogenic or potentially pathogenic microorganisms found in brine (*E. coli*, *E. faecalis*, *C. perfringens*) were detected in the mist. It was also observed that as the air temperature rose and the brine concentration decreased (due to heavy rainfall), the number of microorganisms analyzed (especially actinomycetes and *Staphylococcus* spp.) increased. When discussing air quality, it is imperative to also address particulate matter pollution, which is present in brine mist. A study by Rogula-Kozłowska et al. (2022) showed that the concentration of PM10 particulate matter within the graduation tower is significantly higher (averaging 38  $\mu\text{g}\cdot\text{m}^{-3}$ ) than at points distant from the structure (averaging 25  $\mu\text{g}\cdot\text{m}^{-3}$ ). Consequently, the inhaled brine aerosol contains not only beneficial ions but also solid particles that have an adverse effect on the respiratory system. Unfortunately, the conducted analyses repeated in August 2025 clearly showed that the mist contained *E. coli* bacteria at a concentration of 90 CFU·m<sup>-3</sup> (unpublished data). This phenomenon is particularly alarming, as it demonstrates the bacterium's capacity to withstand the saline environment and penetrate the respiratory system of humans.

## CLOSED-CYCLE BRINE GRADUATION TOWERS

The research that the authors have been conducting for 5 years in Krakow's graduation towers has yielded a substantial body of valuable data and observations. A portion of this research has been published, presented at conferences, and is currently under review for publication. It should be emphasized that the conducted research on the microbiological quality of municipal graduation towers is pioneering and unparalleled in the country, thereby contributing to science with entirely novel, previously unrecognized knowledge and unique content in the field of environmental microbiology. The initial focus of the Krakow media

on authors' publications (Bodziacki and Wolny-Koładka, 2023; Bodziacki et al., 2024; Bodziacki and Wolny-Koładka, 2025) was swiftly followed by the attention of the national media, which rapidly disseminated the information extensively. Given the considerable public interest in the matter of municipal graduation towers, a significant number of press articles, interviews, television reports, and podcasts have emerged, offering opportunities to discuss the research and disseminate the findings to officials, local government representatives, environmental and urban activists, and most notably, individuals who utilize inhalation therapy (<https://smoglab.pl/teznice>; <https://turystyka.wp.pl>; <https://www.rmf24.pl>; <https://smoglab.pl/miejskie>; <https://www.radiokrakow.pl/audycje/bakterie>; <https://podroze.onet.pl>; <https://www.radiokrakow.pl/audycje/gis>; <https://www.youtube.com>). It is noteworthy that since the initiation of the three graduation towers in Krakow, the authors have been continuously monitoring them microbiologically during each operational season.

In accordance with the Article 18 of the Regulation of the Minister of Health of 30<sup>th</sup> September 2024 on the requirements to be met by spa treatment facilities and devices (Journal of Laws of 2024, item 1476), micro-graduation towers, as an element of small pro-health architecture in public spaces, are not classified as therapeutic devices. “Relaxation, stress reduction, and a unique therapeutic microclimate”; “improved mental well-being from long walks surrounded by graduation towers”; “an hour at a graduation tower being akin to three days at the seaside”; “the construction of a micro-graduation tower being health-promoting” – these are just the first advantages that come to mind, pointed out by graduation tower manufacturers and officials who praise the benefits of these installations. The narrative surrounding the purported benefits of this solution has garnered significant credence among the authorities of Polish towns, contributing to the proliferation of graduation towers within the urban landscape. They are particularly popular with seniors and parents with children. The research conducted by the authors of this paper, which has been widely discussed in Poland, has raised public awareness of urban graduation towers. Despite initial resistance, officials also began to take a closer look at the problem we had defined. Unfortunately, as subsequent events showed, this was only a partial shift in the prevailing narrative. Indeed, in their official statements, the relevant authorities have asserted that

micro-graduation towers do not possess a therapeutic nature, but rather serve a recreational purpose, and this assertion aligned with the demands that have been previously outlined. However, the municipality persisted in its approval of projects for the construction of new municipal graduation towers, which are primarily financed from the so-called participatory budget of the city. This budget is allocated to the projects selected through a democratic process involving resident votes, and subsequently implemented in Krakow. It was within the framework of these competitions that the graduation towers were erected. Of particular concern is the persistent promotion of discredited slogans in the descriptions of such competitions, which explicitly reference the purported health-promoting effects of micro-graduation towers (<https://budzet.krakow.pl>).

Currently, there are no regulations in Poland mandating Państwowa Inspekcja Sanitarna (the State Sanitary Inspection) to oversee such facilities. Consequently, the authors are profoundly gratified that their research has prompted the Chief Sanitary Inspectorate in Warsaw to initiate a project aimed at establishing legal regulations and guidelines for manufacturers of graduation towers and facility managers. The regulations would encompass practical recommendations and guidelines for the operation of micro-graduation towers for their owners and managers, the safe use of these facilities by the public, and rules for the supervision of the installations.

When evaluating the merits of constructing municipal brine graduation towers, it is imperative to consider the economic viability of such a project. According to city activists, citing information from the Krakow City Council, the average cost of constructing one brine graduation tower is approximately 1.5 million PLN. This cost does not include the expenses of procuring brine, its subsequent disposal as waste, cleaning and disinfecting the installation, and maintenance and repair work on the facility, which can amount to over 100,000 PLN per year (<https://akcjaratunkowadlakrakowa.pl>; <https://www.czasbochenski.pl>). From an objective standpoint, these elements constitute a significant financial investment in the context of small-scale architectural projects, lacking any discernible therapeutic benefits. These facilities are intended exclusively for recreational use and to foster integration within the local community. Additionally, they function as tourist attractions. At present, there is an absence of scientific studies

that have been able to confirm the therapeutic nature of installations such as micro-graduation towers. Consequently, the allocation of public funds to such investments is a subject of scrutiny, particularly in light of the escalating fundamental needs of the populace, including but not limited to new roads, pedestrian pathways, childcare facilities, and public infrastructure.

## CONCLUSIONS

Brine graduation towers, whose history dates back to ancient times and is associated with salt extraction techniques, have become an integral component of health resort infrastructure and recreational spaces. Their origins were linked to the industrial concentration of brine. However, over time, the health-promoting properties of salt aerosol, reminiscent of the seaside microclimate, began to be appreciated. Today, health resort graduation towers primarily serve as inhalers, thereby facilitating the treatment of respiratory, cardiovascular, and immune system diseases. Numerous studies indicate that the microclimate in their vicinity is characterized by elevated air quality, a diminished presence of pathogenic microorganisms, and a favorable ionic composition. On the other hand, the operation of graduation towers (micro-graduation towers) in urban settings and with a closed brine circulation system introduces specific risks and has given rise to considerable controversy. The most significant of these include: increased concentration of particulate matter and aerosols in the mist, gradual degradation and salinization of soils, growth of algae and undesirable microorganisms on the surface of the structure, as well as the risk of pathogenic bacteria and antibiotic-resistant strains. In this context, the conducted research, which is among the first in Poland and Europe to systematically analyze the microbiological quality of brine and brine aerosol produced by graduation towers, is of particular importance. The published studies contain pioneering results and points to the need to develop sanitary standards for municipal brine graduation towers. In summary, brine graduation towers should be regarded as facilities of great health and social importance, which at the same time require responsible management and sanitary control. Their development, both in health resorts and in urban areas, should be conducted in a manner that is consistent with ongoing research

on user safety and the minimization of potential risks. It is necessary to develop nationwide legal regulations governing municipal graduation towers. The guidelines contained therein should concern the following: location of micro-graduation towers (in order to minimize their harmful impact on the environment), the methods by which they should be cleaned and disinfected, the frequency with which the brine should be replaced, the manner in which microbiological monitoring should be conducted to identify and eliminate potential hazards, and the modifications and safeguards that should be introduced to increase the effectiveness of disinfecting brine circulating in a closed cycle.

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