ROLES OF ENVIRONMENTAL CONDITIONS AND ULTRASONICATION IN RELEASING ORGANIC MATTER FROM BIOLOGICAL ACTIVATED CARBON

[*]Sri Anggreini[1], Ade Jaya Saputra[2], LQ Parulian Sanjaya S[3]
[1,2,3]Faculty of Civil Engineering and Planning, Universitas Internasional Batam, Batam, Indonesia
[*)] Email: sri.anggreini@uib.ac.id

Received: 28 November 2025 ; Revised: 1 Desember 2025 ; Accepted: 5 Desember 2025

ABSTRACT

Biological activated carbon (BAC) is widely used in drinking water treatment because it combines adsorption on activated carbon with biodegradation carried out by the attached microbial community. However, environmental shifts such as changes in pH, temperature, or physical disturbances may cause previously adsorbed organic matter (OM) to detach from the activated carbon. This phenomenon can increase dissolved organic carbon in treated water and potentially affect downstream processes. This study examined how pH, temperature, and ultrasonication influence the release of OM from BAC. The BAC was extracted using DOC-free tap water under different pH conditions (5.8, 7.0, and 8.6) and temperatures (5°C, 20°C, and 30°C), with and without the application of ultrasonication. After treatment, dissolved organic carbon (DOC) and UV absorbance at 260 nm (UV260) were measured to characterize the released OM. The results show that higher pH promotes OM detachment, with both DOC and UV_{260} values increasing markedly under alkaline conditions. Temperature also played a strong role; warmer conditions enhanced OM release, indicating that higher kinetic energy and increased molecular mobility facilitate detachment. Ultrasonication consistently intensified the release across all conditions, suggesting that the disruption of biofilms and the reopening of blocked pores contribute to this effect. The findings highlight the sensitivity of BAC to operational changes and underscore the importance of monitoring OM release to maintain the reliability of drinking water treatment systems.

Keyword: *Biological Activated Carbon; Organic Matter; Detachment; Ultrasonication*

1. INTRODUCTION

Biological activated carbon (BAC) plays a vital role in drinking water treatment because it combines the adsorption of organic matter (OM) with biological degradation carried out by microorganisms [1,2]. This material originally comes from granular activated carbon (GAC), which has long been used in water purification. Over time, microorganisms begin to colonize the surface and internal pores of the GAC, forming a biofilm [3]. As a result, the material gradually transforms into BAC, giving it a dual function, which includes adsorbing contaminants and breaking them down biologically.

During extended use, some of the previously adsorbed OM may be released back into the water, especially when environmental conditions shift, such as changes in pH, temperature, or physical disturbances. This detachment process can increase dissolved organic carbon (DOC) concentrations in the treated water, reducing filtration efficiency and potentially affecting the stability of the distributed water quality [4]. In drinking water systems, this is a significant concern because higher DOC concentrations can interfere with subsequent treatment stages and may contribute to the formation of disinfection by-products (DBPs), which pose public health risks [5,6].

Several environmental factors are known to influence the release of OM from BAC. Shifts in pH can alter the surface charge of the carbon and the degree of ionization of the organic molecules, affecting the strength of interactions between them [7,8]. Temperature changes can modify molecular kinetic energy and diffusion rates, potentially accelerating the release process [9,10]. Physical treatments such as ultrasonication may disrupt biofilm structures and open up clogged pores, making it easier for trapped organic matter to escape [11,12]. Liu et al. (2017) show that ultrasonication can help reopen larger pores and expose carbon surfaces [13]. Research on BAC specifically has revealed that ultrasonication can do more than renew the carbon's adsorptive capacity. In some cases, low-frequency ultrasonication trims down excess biomass while also making mid-sized and larger pores accessible again. Some bacteria are reduced in number, and blocked adsorption sites reopen, an observation that supports the idea that ultrasonication helps release OM that has been trapped within the biofilm or lodged inside the pore structure [13]. A study by Li et al. (2024) adds another perspective. They observed that low frequency ultrasonication not only cleans carbon pores but also influences the surrounding microbial community [14]. The treatment reduced dissolved organic nitrogen and the precursors of nitrogen-containing disinfection by-products, suggesting that ultrasonication reshapes the biofilm environment in ways that affect the character of the organics released [14].

Although many studies have examined adsorption processes and biological regeneration of BAC [15–19], systematic comparisons of how pH, temperature, and ultrasonication collectively influence OM detachment remain limited. Taken together, the literature shows that although ultrasound-based regeneration of BAC has been

explored extensively, most studies focus on how well adsorption capacity recovers or how microbial communities shift afterward. What remains less understood is the nature of the OM that comes off the carbon, especially when changes in pH, temperature, or ultrasonic exposure occur at the same time.

This study is important because the release of OM from BAC can directly affect treatment performance, the quality of water delivered to consumers, and associated health risks. In many water treatment plants, detachment is rarely monitored, as operational attention typically focuses on adsorption and biodegradation. OM release can still occur unexpectedly when operating conditions shift, highlighting the need for a clearer understanding of the factors that control this behavior.

Therefore, this study aimed to investigate how variations in pH, temperature, and ultrasonication influence the detachment of OM from the pores of BAC when exposed to DOC-free tap water. The characteristics of the released OM were evaluated using ultraviolet absorbance at 260 nm and dissolved organic carbon analyses. The findings are expected to provide a more comprehensive understanding of OM stability within BAC and to support the development of strategies that minimize its release in drinking water treatment systems.

2. MATERIALS AND METHODS

Sample Preparation

The BAC was taken from a drinking water treatment plant located in Central Japan. The plant supplies clean water to the surrounding area and produces around 220,300 m^3 of treated water each day. DOC-free tap water was prepared by continuously passing tap water through a granular activated carbon (GAC) column (F400 type) until the effluent turbidity reached a stable value. Once the turbidity became constant, the treated water was immediately used to extract OM from the BAC. The use of GAC was intended to produce water free of DOC, while residual chlorine was expected to be removed through the adsorption process.

Detachment Experiment

The working solutions were prepared by adjusting the pH of DOC-free tap water to 5.8, 7.0, and 8.6 using 0.1 M hydrochloric acid or 0.1 M sodium hydroxide. Subsequently, 100 mL of the pH-adjusted DOC-free tap water and 10 g of BAC were added to a 300 mL reactor. Some samples were subjected to ultrasonication, while others were not. Ultrasonic treatment was applied at 40 kHz for 5 minutes, following the procedure described in previous studies [20,21]. After ultrasonication, all samples were shaken at 5°C, 20°C, or 30°C. The shaking process was performed at 100 rpm for 180 minutes to simulate different environmental conditions. Samples at 5°C were maintained in a cooling unit, whereas samples at 20°C and 30°C were kept in an incubator set to the respective temperatures.

Following shaking, the samples were filtered through a 0.2 µm cellulose acetate membrane. Water-quality analyses were then conducted, including the measurement of dissolved organic carbon (DOC) using a TOC analyzer and UV absorbance at 260 nm (UV260) using a spectrophotometer. Specific ultraviolet absorbance (SUVA) was calculated by dividing the UV260 value by the DOC concentration. SUVA is commonly used as an indicator of the aromaticity and hydrophobicity of organic matter (OM). Higher SUVA values generally indicate a greater proportion of aromatic, conjugated carbon structures, while lower SUVA values suggest the presence of more aliphatic or simpler organic compounds [6].

3. RESULTS AND DISCUSSION

Effect of pH on OM Release from BAC

The effect of pH on the release of OM from BAC, reflected in both DOC and UV260 concentrations, is shown in **Fig. 1**. The results clearly indicate that pH has a strong influence on the release of OM from BAC. As the pH of the test solution increases from 5.8 to 8.6, both the DOC and the UV260 concentrations rise significantly. As shown in **Fig. 1a**, in the ultrasonicated samples at pH 8.6, DOC reached its highest level (2.3 mg L^{-1}), whereas at pH 5.8 it was much lower (1.45 mg L^{-1}). A similar trend is observed in UV_{260}, where the concentration increases from 1.7 m^{-1} at pH 5.8 to over 3.2 m^{-1} at pH 8.6 under ultrasonic treatment, as displayed in **Fig. 1b**. This pH-dependent behavior suggests that under more alkaline conditions, the BAC releases more OM. At higher pH, the deprotonation of acidic functional groups on organic compounds (e.g., carboxyls or phenolics) enhances their solubility, making them more likely to detach from the activated carbon structure [22,23]. In addition, at higher pH there may be repulsive electrostatic forces (due to deprotonated groups) that weaken the interaction between OM molecules and the BAC surface, further promoting detachment [24]. The observed pH-dependent increase in

both DOC and UV260 is consistent with previous study that desorption from carbonaceous media is strongly influenced by pH solution [21].

Interestingly, even without ultrasonication, the non-sonicated samples show the same upward trend in DOC and UV260 with increasing pH. However, the absolute values are lower than with ultrasonication, which suggests that pH and ultrasonic treatment act synergistically, higher pH makes OM more mobile, and ultrasound further accelerates its release.

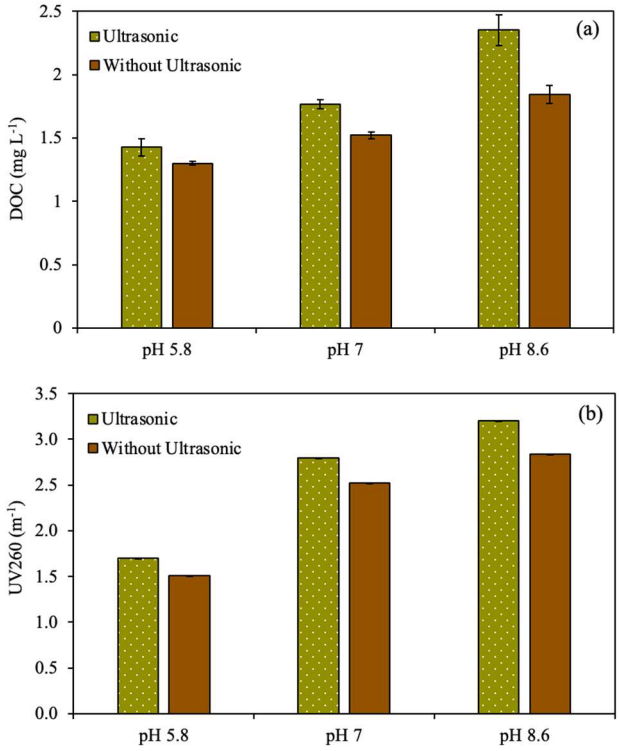

Fig 1. Changes in the release of OM from BAC based on the DOC (a) and UV260 (b) concentrations measured at different pH levels at 20°C.

These findings align with earlier studies showing that biochar materials often exhibit greater release of OM when exposed to higher pH conditions [25]. Under alkaline environments, aromatic and humic-like structures become more prone to detachment. Liu et al. (2022) also reported that increases in pH influenced the release of humic-like from biochar, supporting the pattern observed in this study [25].

Effect of Temperature on OM Release from BAC

The results show that temperature plays a critical role in regulating the concentration of OM released from BAC. As illustrated in the **Fig. 2**, both DOC and UV_{260} values increased gradually as the temperature rose from 5°C to 30°C. At 5°C, the release of DOC remained relatively low for both treatments. However, when the temperature was increased to 20°C and further to 30°C, the concentration of OM released became noticeably higher. This trend was consistent in both DOC and UV260 concentrations, indicating that higher temperatures promote the detachment of organic compounds from BAC surfaces.

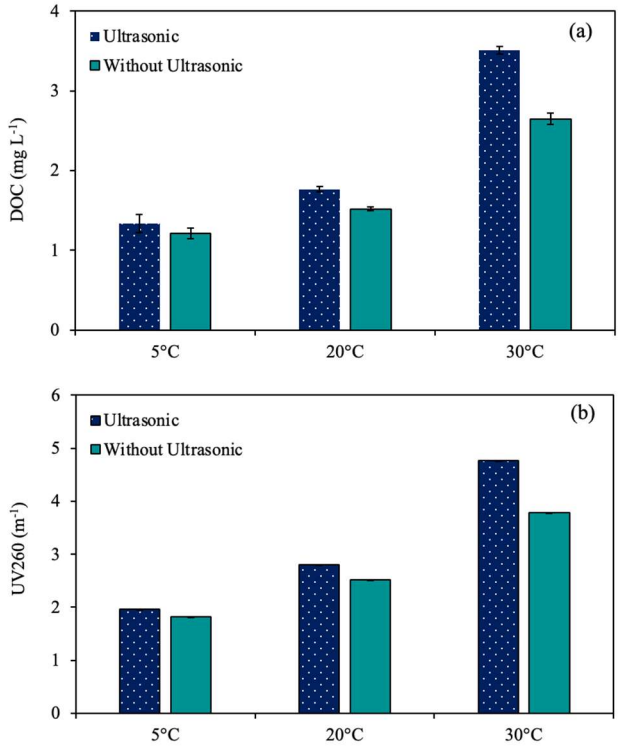

Fig 2. Changes in the release of OM from BAC based on the DOC (a) and UV260 (b) concentrations measured at different temperatures at pH 7.

The samples that received ultrasonication consistently released more OM compared with those processed without ultrasound. This difference became more pronounced at elevated temperatures, suggesting that ultrasound and temperature act in a complementary manner. Higher temperatures are known to enhance molecular mobility, reduce solution viscosity, and increase the flexibility of biofilm structures, which collectively facilitate the breakdown and release of trapped organic components [26]. These mechanisms help explain why the combination of ultrasonication and warmer conditions yielded the highest DOC and UV260 values in this study.

Previous studies indicate that temperature notably affects the behavior of BAC. Warmer conditions tend to accelerate microbial metabolism within biofilms and alter the extracellular polymeric matrix in ways that reduce structural cohesion, thereby making trapped organic matter more likely to be released [27]. Investigations focused on carbonaceous adsorbents further show that increasing temperature enhances molecular mobility and mass transfer, which in turn promotes faster diffusion of organic molecules within porous media and raises detachment rates from activated carbon surfaces [28]. These findings provide a scientific basis that aligns well with the temperature-dependent release patterns observed in the present work.

Effect of pH and Temperature on The Aromaticity of OM

Fig. 3 shows that both pH and temperature significantly influence the aromatic content of the OM released from BAC. As shown in **Fig. 3a**, the SUVA values obtained at different temperatures show a clear but nuanced pattern. At pH 7, SUVA tends to increase from 5°C to 20°C for both treatments, suggesting that a moderate temperature enhances the release of more aromatic fractions from the BAC. This trend aligns with the understanding that higher temperatures can promote detachment and slightly increase microbial activity at the BAC surface, allowing more chromophoric organic matter to be released. Taken together these mechanisms explain why SUVA rose with moderate warming in our experiments and are consistent with observations reported in recent studies of BAC and other carbon-based adsorbents [29].

However, when the temperature rises to 30°C, SUVA decreases for both ultrasonic and without ultrasonic conditions. This decline may indicate that excessive temperature promotes the release of organic matter that is less aromatic, or that the BAC surface becomes less efficient in maintaining its biofilm structure at higher thermal stress. Research on activated carbon under elevated temperatures also reports that the detachment of non-aromatic, lower-molecular-weight compounds becomes more dominant as the system warms [30], which supports the pattern observed here.

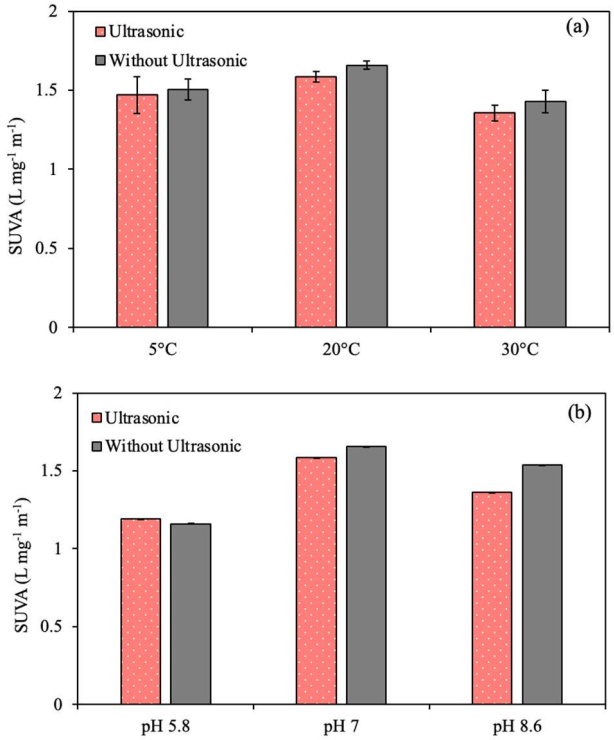

Fig 3. SUVA of OM released from BAC under different temperatures at pH 7 (a) and under different pH conditions at 20 °C (b).

The SUVA values measured at 20 °C show a clear dependence on pH, and this dependence also differs depending on whether ultrasonication was applied, as shown in **Fig. 3b**. For samples treated with ultrasound, SUVA rises from approximately 1.2 L mg^{-1} m^{-1} at pH 5.8 to 1.6 at pH 7.0, then decreases to 1.4 at pH 8.6. In the without ultrasonicated samples, a similar pattern emerges, SUVA is about 1.2 at pH 5.8, increases to 1.7 at pH 7.0, and then declines to 1.6 at pH 8.6. This trend suggests that neutral pH (7.0) favors the release or presence of more aromatic or conjugated organic molecules, as indicated by the higher SUVA. Aromatic compounds, which have extensive π-conjugation, tend to absorb UV strongly, and SUVA captures this behavior when normalized to DOC. The drop in SUVA at both lower (5.8) and higher (8.6) pH indicates that the nature of the released organic matter might shift away from strongly aromatic moieties toward more aliphatic or less conjugated structures when the pH moves away from neutrality.

Mechanistically, at acidic pH (5.8), protonation of acidic functional groups in organic compounds may reduce their solubility or alter their conformation, limiting the release of highly aromatic structures. On the other hand, at more alkaline pH (8.6), deprotonation may change the molecular interactions, increased negative charge could enhance repulsive forces, making the more-conjugated, UV-absorbing components less stable in solution, or favor the release of more polar, less aromatic substances [31].

Interestingly, the influence of ultrasonication seems to be modest in terms of SUVA, while ultrasound clearly helps mobilize organic matter, it does not always lead to the highest SUVA values, especially at the highest of pH. At pH 7.0, the without ultrasonicated samples show a slightly higher SUVA than the ultrasonicated ones. This could mean that ultrasound preferentially releases less-aromatic, possibly more labile, organic fractions that are loosely bound to the BAC, while the more strongly aromatic molecules may remain more tightly associated, especially under certain pH conditions. This behavior aligns with findings in the literature. For example, a review on the optical properties of DOC highlights that pH can strongly influence molecular structure and light-absorbing behaviors, because changes in protonation affect the conformation and thus the UV-visible characteristics of organic compounds [32].

4. CONCLUSIONS

This study shows that changes in pH, temperature, and ultrasonication strongly affect how organic matter (OM) detaches from biological activated carbon (BAC). Higher pH consistently led to greater DOC and UV_{260} values, indicating that alkaline conditions weaken the interactions between OM and the carbon surface, making the

compounds easier to release. Ultrasonication further increased this release, demonstrating that chemical conditions and physical disturbance can work together to mobilize OM that is trapped inside BAC pores or biofilm layers.

Temperature also played an important role. As the water warmed from 5°C to 30°C, more OM was released, reflecting faster molecular movement and reduced biofilm integrity at higher temperatures. The combined effect of heat and ultrasonication produced the highest detachment rates. The SUVA results revealed that both pH and temperature shape not only the amount of OM released but also its aromatic character. Moderate conditions (20°C and pH 7) favored the release of more aromatic compounds, whereas more extreme pH values and higher temperatures shifted the release toward less-aromatic, lighter organic fractions.

Overall, the findings highlight that OM stability in BAC is sensitive to even small changes in operational conditions. Understanding these influences is essential for maintaining BAC performance and preventing unexpected increases in OM that could affect downstream treatment processes and drinking water quality.

REFERENCES

[1] Wang, L., Li, W., Song, L., Liu, X., Zheng, K., Zhang, L., Minhing, T. (2024). "Removal of dissolved organic matter via a combination of UV/persulfate oxidation and biological activated carbon (BAC) process". Separation and Purification Technology, Vol. 337, 126376. https://doi.org/https://doi.org/10.1016/j.seppur.2024.126376.

[2] Kaiser, T., Picioreanu, C., Lackner, S. (2025) "Modeling interactions between the adsorption of dissolved organic carbon and biological activity on granular activated carbon". Water Research, Vol. 287, 124304. https://doi.org/10.1016/j.watres.2025.124304.

[3] Kajjumba, G.W., Washington, C.M.M., Mohan, A., Yu, Z.L.T., Schimmoller, L., Gonzalez, J., Summers, R.S., Dickenson, E.R.V. (2025) "Application of granular and ozone-biological activated carbon treatments for the mitigation of organic chemical peaking events in potable water schemes". Water Research X, Vol. 29, 100389. https://doi.org/10.1016/j.wroa.2025.100389.

[4] Gamage, S.M.K., Sathasivan, A. (2017) "Potential of a biologically activated carbon treatment to remove organic carbon from surface waters". International Biodeterioration & Biodegradation, Vol. 124, 82–90. https://doi.org/https://doi.org/10.1016/j.ibiod.2017.05.025.

[5] Larasati, A., Bernadet, O., Gaglianio, M.C. (2025) "Implications of biological activated carbon (BAC) filters for pharmaceutical removal from municipal wastewater: A review on its properties, operational factors, and biofilms". Journal of Water Process Engineering, Vol. 79, 108974. https://doi.org/https://doi.org/10.1016/j.jwpe.2025.108974.

[6] Anggreini, S., Rosadi, M.Y., Yamada, T., Hudori H., Deng, Z., Li, F. (2023) "Characteristics of organic matter released from drinking water treatment sludge under different storage conditions: Evaluation based on activated carbon adsorbability". Chemosphere, Vol. 339, 139679. https://doi.org/https://doi.org/10.1016/j.chemosphere.2023.139679.

[7] Sun, Y., Peng, B.-Y., Wang, X., Li, Y., Wang, Y., Yanan, Z., Xia, S., Zhao, J. (2023) "Adsorption and desorption mechanisms of oxytetracycline on poly(butylene adipate-co-terephthalate) microplastics after degradation: The effects of biofilms, Cu(II), water pH, and dissolved organic matter". Science of The Total Environment, Vol. 863, 160866. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.160866.

[8] Li, Z., Liang, J., Li, J., Ma, X., Lang, Y., Li, H., Qiu, H., Cao, X., Zhao, L. (2025) "Thermal desorption coupled with persulfate oxidation for removing soil organic pollutants: Key role of soil organic matter passivation". Journal of Hazardous Materials, Vol. 500, 140382. https://doi.org/https://doi.org/10.1016/j.jhazmat.2025.140382.

[9] Shan, Y., Zhou, B., Liu, Z., Li, L., Zhou, K., Wang, Z., Wu, B., Feng, W., Xue, H., Wang, Z. (2025) "In situ ultrasonic-backwash regeneration of upflow activated carbon filters for improved removal of organics from drinking water". Process Safety and Environmental Protection, Vol. 198. https://doi.org/10.1016/j.psep.2025.107188.

[10] Chern, J.-M., Wu, C.-Y. (2001) "Desorption of dye from activated carbon beds: effects of temperature, pH, and alcohol". Water Research, Vol. 35, 4159–65. https://doi.org/https://doi.org/10.1016/S0043-1354(01)00127-0.

[11] Ghorbani, P., Siavashi, M. (2025) "Experimental investigation of the effect of particle size of granular activated carbon in a packed bed on methanol adsorption/desorption". Applied Thermal Engineering, Vol. 284, 128997. https://doi.org/https://doi.org/10.1016/j.applthermaleng.2025.128997.

[12] Yang, F., Wang, X., Li, J., Li, Z., Wang Z. (2025) "Preparation of Zr-doped MXene@MIL-125(Ti) composite to mediate the ultrasonic removal of organic dyes and microplastics". Journal of Molecular Liquids, Vol. 437, 128450. https://doi.org/https://doi.org/10.1016/j.molliq.2025.128450.

[13] Liu, C., Sun, Y., Wang, D., Sun, Z., Chen, M., Zhou, Z., Chen, W. (2017) "Performance and mechanism of low-frequency ultrasound to regenerate the biological activated carbon". Ultrasonics Sonochemistry, Vol. 34, 142–53. https://doi.org/https://doi.org/10.1016/j.ultsonch.2016.05.036.

[14] Li, C., Liu, C., Shan, Y., Lan, T. (2024) "Effects of low frequency ultrasound treatment on dissolved organic nitrogen removal by biological activated carbon: Critical insights into molecular characteristics, microbial traits, and metabolism". Water Research, Vol. 260, 121924. https://doi.org/https://doi.org/10.1016/j.watres.2024.121924.

[15] Ciotola, E., Koch, K., Sottorff, I., Esposito, G., Cesaro, A. (2025) "Removal of trace organic compounds in anaerobically digested sludge by ultrasonic treatment". Chemical Engineering Journal, Vol. 522, 167356. https://doi.org/10.1016/j.cej.2025.167356.

[16] Ajaz, S., Radke, M., Hassan, A,A,, Kaparaju, P., Michael, R.N., Leusch, F.D.L. (2025) "Integrated assessment of biological activated carbon filters with UV/peracetic acid pretreatment for the mitigation of organic micropollutants and toxicity". Journal of Water Process Engineering, Vol. 78, 108774. https://doi.org/10.1016/j.jwpe.2025.108774.

[17] Sari, Y.A., Pamadi, M. (2019) "Current Situation of Wastewater Treatment Plant for Sewage in Batam City". Journal of Physics: Conference Series, Vol. 1351. https://doi.org/10.1088/1742-6596/1351/1/012109.

[18] Anggreini, S., Saputra, A.J., Sanjaya, L.P. (2025) "Characteristics of organic matter released from water treatment sludge in water treatment facilities". Journal of Civil Engineering and Planning, Vol. 6, 2746-6299. https://doi.org/10.37253/jcep.v6i1.10441.

[19] Chen, H., Wang, J., Xu, L., Zhou, P., Graham, N.J.D., Yu, W. (2025) "Role of granular activated carbon's physical properties and surface chemistry in sustaining biological activated carbon performance". Chemical Engineering Journal, Vol. 524, 169173. https://doi.org/https://doi.org/10.1016/j.cej.2025.169173.

[20] Wu, B., Zhou, B., Liu, Z., Li, L., Zhou, K., Wang, Z., Shan, Y., Feng, W., Shao, Z., Xue, H., Wang, Z. (2024) "Adsorption characteristics of used granular activated carbon regenerated by ultrasonic backwashing". Arabian Journal of Chemistry, Vol. 17. https://doi.org/10.1016/j.arabjc.2024.105704.

[21] Gao, S., Wang, Z., Jia, Y., Xu, N., Liao, L., Wang, Z., Wu, B., Feng, W., Shan, Y., Hu, L., Xue, H. (2024) "Regeneration of activated carbon by combined ultrasound and persulfate treatment". Arabian Journal of Chemistry, Vol. 17, 105929. https://doi.org/10.1016/j.arabjc.2024.105929.

[22] Xu, Y., Yu, X., Xu, B., Peng, D., Guo, X. (2021) "Sorption of pharmaceuticals and personal care products on soil and soil components: Influencing factors and mechanisms". Science of the Total Environment, Vol. 753, 141891. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.141891.

[23] Cooray, P.L.I.G.M., Chalmers, G., Chittleborough, D. (2025) "A review of properties of organic matter fractions in soils of mangrove wetlands: Implications for carbon storage". Soil Biology and Biochemistry, Vol. 201, 109660. https://doi.org/10.1016/j.soilbio.2024.109660.

[24] Reddy, Y.S., Rotte, N.K., Hussain, S., Srikanth, V.V.S.S., Chandra, M.R. (2023) "Sustainable mesoporous graphitic activated carbon as biosorbent for efficient adsorption of acidic and basic dyes from wastewater: Equilibrium, kinetics and thermodynamic studies". Journal of Hazardous Materials Advances, Vol. 9, 100214. https://doi.org/10.1016/j.hazadv.2022.100214.

[25] Liu, M., Zhao, Z., Lu, Q., Yu, W. (2022) "Release of dissolved organic carbon from biochar and formation of humic-like component during photoreaction: Effects of Ca2+ and pH". Water Research, Vol. 219, 118616. https://doi.org/https://doi.org/10.1016/j.watres.2022.118616.

[26] Ahmad, J.I., Dignum, M., Liu, G., Medema, G., Hoek J.P.V.D. (2021) " Changes in biofilm composition and microbial water quality in drinking water distribution systems by temperature increase induced through thermal energy recovery". Environmental Research, Vol. 194, 110648. https://doi.org/10.1016/j.envres.2020.110648.

[27] Lin, Y.-T., Wang, Y.-C., Xue, Y.-M., Tong, Z., Jiang, G.-Y., Hu, X.-R., Crittenden, J.C., Wang, C. (2024) "Decoding the influence of low temperature on biofilm development: The hidden roles of c-di-GMP". Science of the Total Environment, Vol. 927, 172376. https://doi.org/https://doi.org/10.1016/j.scitotenv.2024.172376.

[28] Abdelhak, S., Menard, Y., Artigas, J. (2023) "Effects of global change on the ability of stream biofilm to dissipate the herbicide glyphosate". Environmental Pollution, Vol. 324, 121406. https://doi.org/https://doi.org/10.1016/j.envpol.2023.121406.

[29] Zusman, O.B., Kummel, M.L., Rosa, J.M.D.L., Mishael, Y.G. (2020) "Dissolved organic matter adsorption from surface waters by granular composites versus granular activated carbon columns: An applicable approach". Water Research, Vol. 181, 115920. https://doi.org/https://doi.org/10.1016/j.watres.2020.115920.

[30] Ma, X., Wang, L., Hou, Y., Zhou, L. (2022) "Adsorption/desorption characteristics of low-concentration semi-volatile organic compounds in vapor phase on activated carbon". Journal of Environmental Management, Vol. 305, 114360. https://doi.org/https://doi.org/10.1016/j.jenvman.2021.114360.

[31] Banc, C., Gautier, M., Blanc, D., Lupsea-Toader, M., Marsac, R., Gourdon, R. (2021) "Influence of pH on the release of colloidal and dissolved organic matter from vertical flow constructed wetland surface sludge deposits". Chemical Engineering Journal, Vol. 418, 129353. https://doi.org/https://doi.org/10.1016/j.cej.2021.129353.

[32] Xu, Y., Zhang, Y., Qiu, L., Zhang, M., Yang, J., Ji, R., Davide, V., Chen, Z., Gu, C. (2024) "Photochemical behavior of dissolved organic matter in environmental surface waters: A review". Eco-Environment and Health, Vol. 3, 529–42. https://doi.org/10.1016/j.eehl.2024.06.002.