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Residue-free alkali-treated aluminum foil for water disinfection: A novel supernatant $Mg(OH)_2$ fabrication method

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Abstract

This study presents a novel approach to fabricate alkali-treated aluminum (ATA) foil for point-of-use (POU) water disinfection, addressing the residue issue associated with conventional production methods. Traditional ATA foil production leaves a residual layer that hinders practicality in use. To cope with it, a supernatant $Mg(OH)_2$ solution was employed, resulting in residue-free ATA foil. Two variants, conventional ATA foil (ATA foil-1) and supernatant-treated ATA foil (ATA foil-2), were fabricated and analyzed. Surface characterization revealed that ATA foil-2 had a smoother surface with fewer cracks while maintaining *E. coli* removal efficiency and methyl orange adsorption capacity similar as ATA foil-1. Maximum *E. coli* adsorption capacities were found at 572,967 CFU/cm^2 for ATA foil-1 and 561,513 CFU/cm^2 for ATA foil-2. Both foils achieved over 84% methyl orange removal, indicating adsorption as the primary removal mechanism. The findings demonstrated that the supernatant $Mg(OH)_2$ method successfully produced residue-free ATA foil with comparable disinfection performance, thus eliminating the need for a washing step and enhancing its suitability for point-of-use water treatment applications.

Keywords: Alkali-treated aluminum foil; water disinfection; *E. coli* removal; pathogen adsorption

1. Introduction

Access to clean drinking water is a fundamental human right, yet it still remains a critical challenge worldwide. As released by the World Health Organization, 1.7 billion people lack access to safely managed drinking water services with water contamination that has caused millions of deaths annually, primarily due to diarrheal diseases [1]. This global health crisis underscores an urgent need for effective, affordable, and accessible water disinfection technologies, particularly at the point of use (POU) where individuals consume water [2,3]. POU water treatment focuses on providing clean drinking water at household level, especially in regions without centralized treatment facilities or with water quality issues [4 – 6].

Conventional POU disinfection methods—including boiling, chlorination, and filtration—face limitations in cost, efficiency, and accessibility [3,7]. Boiling requires fuel and time, while chlorination, despite its effectiveness, produces an unpleasant taste and potentially harmful residual chlorine [8,9]. Filtration units, though effective, are often costly and require a regular maintenance, making them impractical for many communities [10]. Solar disinfection is a promising alternative but remains weather-dependent and slow [11]. The development of alternative, cost-effective, and efficient water disinfection technologies, therefore, is deemed crucial for improving access to safe drinking water, particularly in low-resource settings.

One promising approach is the use of alkali-treated aluminum (ATA) foil for POU water disinfection. It offers a simple and effective means of removing harmful pathogens, reducing the incidence of waterborne diseases, particularly in the vulnerable populations of low-income communities. The technique involves immersing aluminum foil in $Mg(OH)_2$ solution, producing a surface with enhanced antimicrobial properties. Recent studies have demonstrated that ATA foil effectively removes bacteria and viruses from contaminated water [12]. The antimicrobial properties of ATA foil are attributed to the positively charged $Mg(OH)_2$ coating, which attracts and adsorbs any negatively charged bacteria. Additionally, the release of Mg^{2+} ions from the coating can contribute to bacterial inactivation by disrupting cell membranes or interfering with essential cellular processes. However, a significant drawback has been observed: the formation of a white powder residue on the foil surface, requiring washing or wiping before use. This additional step then reduces convenience, effectiveness, and practicality for

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POU applications.

This research aims to address a critical limitation of conventional ATA foil technology: the formation of a white powder residue necessitating a washing or wiping step before use. To overcome this, we introduce a novel fabrication method by employing a supernatant solution of $Mg(OH)_2$. This is contradicting with previous protocols [12] that directly used a 1% $Mg(OH)_2$ suspension, resulting in the deposition of residual $Mg(OH)_2$ particles on the foil surface. In our method, the supernatant solution was obtained by allowing $Mg(OH)_2$ to settle, followed by carefully siphoning off the clear liquid to minimize the presence of these particles. This modification is expected to eliminate the white powder residue while maintaining the antimicrobial efficiency of ATA foil, thereby enhancing its suitability for POU water disinfection.

The study evaluated the effectiveness of ATA foil fabricated using two methods to remove *Escherichia coli* (*E. coli*), a widely recognized fecal contamination indicator. The first approach followed the conventional $Mg(OH)_2$ treatment method [12], while the second one employed the supernatant $Mg(OH)_2$ solution, a novel refinement. Additionally, methyl orange adsorption was analyzed to investigate the underlying bacterial removal mechanism.

By addressing a key limitation of ATA foil technology, this study contributes to advancing practical and scalable water disinfection solutions. The elimination of pre-use washing/wiping improves user convenience, increasing the potential for wider adoption in regions lacking access to safe drinking water. This novel approach by making POU water treatment more efficient, user-friendly, and accessible to vulnerable communities has a potential to enhance public health.

2. Materials and Methods

Aluminum foil, 20-µm-thick, was purchased from Yumico (Best Fresh), Indonesia. $Mg(OH)_2$ powder and chemical reagents were obtained from Merck KGaA, Germany.

2.1. Preparation of $Mg(OH)_2$ solution and fabrication of ATA foil

A stock solution of $Mg(OH)_2$ was prepared by adding 10 g of $Mg(OH)_2$ powder to 1 L of distilled water. After vigorously stirring using a magnetic stirrer for 30 min, it was allowed to settle at room temperature for 8 h. The supernatant was carefully decanted from the settled precipitate and used for the fabrication of ATA foil-2.

In this study, two types of ATA foil were fabricated: ATA foil-1 and ATA foil-2. ATA foil-1 was prepared by soaking 25 cm^2 pieces of aluminum foil in 100 mL of a 1% (w/v) $Mg(OH)_2$ solution prepared by dissolving 1 g of $Mg(OH)_2$ powder in 100 mL of distilled water for 24 hours at room temperature under static conditions. A similar procedure was prepared for ATA foil-2 but, instead of the 1% $Mg(OH)_2$ solution, it used 100 mL of the $Mg(OH)_2$ supernatant solution. After 24 hours, both types of foils were removed from their respective solutions, rinsed with distilled water, and air-dried.

2.2. Surface characterization of ATA foil

The fabricated ATA foils' surface morphology and elemental composition (ATA foil-1 and ATA foil-2) were analyzed by means of scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX). The SEM-EDX analysis, meanwhile, was performed using Carl Zeiss SEM with EDX EVO 10.

2.3. Disinfection experiments

E. coli was used as a model microorganism to evaluate the disinfection performance of the ATA foils. The bacteria were cultured in nutrient broth at 37°C for 24 hours. This solution was then diluted with water to achieve a concentration of approximately 100000 CFU/mL. To prepare a test solution with a roughly 1000 CFU/mL concentration, 1 mL of the diluted solution was mixed with 99 mL of water in a 250-mL bottle. Disinfection experiments were conducted in triplicate using 250 mL sterile sample bottles. Three experimental groups were set up: (1) Control: 100 mL of contaminated water without ATA foil; (2) ATA foil-1: 100 mL of contaminated water with ATA foil-1 (25 cm^2); and (3) ATA foil-2: 100 mL of contaminated water with ATA foil-2 (25 cm^2). The bottles were placed on a reciprocal shaker operating at 80 rpm and incubated at room temperature (25 ± 2°C) for 24 hours. Samples were collected from each bottle at 0, 1, 3, and 24 hours of incubation. The viable count of *E. coli* in each sample was determined through the dilution plate method by spreading 1 mL of the sample onto nutrient agar plates and incubating the plates at 37°C for 24 hours. The number of colony-forming units (CFUs) was then counted.

To investigate the *E. coli* removal mechanisms from the ATA foils, methyl orange (MO) was used as a model pollutant to assess the adsorption capacity of ATA foil-1 and ATA foil-2 in order to figure out if adsorption plays an important role in the removal of *E. coli* from the ATA foils. Adsorption experiments were conducted by adding a 25-cm^2 ATA foil to 10 mL of a 5 mg/L methyl orange solution in 50 mL polypropylene containers. The containers were placed on a reciprocal shaker operating at 100 rpm and shaken for 10 hours at room temperature (25 ± 2°C). The solutions, after being shaken for 10 h, were then filtered through a 0.45 µm membrane filter to remove any suspended particles. Meanwhile, the residual concentration of MO in the filtrate was determined using a UV-Vis spectrophotometer at a characteristic absorption wavelength of 464 nm (Shimadzu UV-1900i, Japan).

2.4. E. coli adsorption isotherm modeling

To determine the maximum adsorption capacity (q_m) of ATA foil-1 and ATA foil-2, the bacterial adsorption data obtained from the disinfection experiments were fitted to the Langmuir isotherm model, which is expressed as $q_e = (q_m * K_L * C_e) / (1 + K_L * C_e)$ where q_e represents the amount of *E. coli* adsorbed per unit area of ATA foil (CFU/cm^2), q_m is the maximum adsorption capacity (CFU/cm^2), K_L is the Langmuir constant related to the affinity of the binding sites (mL/CFU), and C_e is the equilibrium concentration of *E. coli* in the solution (CFU/mL). The Langmuir isotherm parameters (q_m and K_L) were determined by nonlinear regression analysis using Ms. Excel 2019.

3. Results and Discussion

3.1. Characterization of ATA foil

The immersion of aluminum foil in various treatment solutions can create structural changes in the aluminum oxide layer, forming aluminum hydroxide. This has been seen through various studies performed on the interaction of aluminum with different chemical environments [13 – 15]. When aluminum foil is plunged into a dilute alkaline solution, such as a suspension of magnesium hydroxide, there will be no immediate changes. After some tens of seconds, however, bubble formation on the surface becomes is visible, indicating a sequence of reactions. First, the thin layer of aluminum oxide reacts with hydroxide ions in the aqueous solution to dissolve it. Once the aluminum oxide layer has been dissolved, the metallic aluminum underneath reacts with the alkaline solution, causing further dissolution and hydrogen gas evolution.

After the removal of ATA foil from the magnesium hydroxide suspension, a white residual powder of the biocompatible magnesium hydroxide still remains on the surface. The ATA foil itself then shows a brownish discoloration, the intensity of which will increase proportionally with the concentration of magnesium hydroxide in the suspension. This color change is an important observation that requires further clarification. While the discoloration might be attributed to oxidation of the aluminum surface, several other possibilities exist. The alkaline environment of the $Mg(OH)_2$ solution could induce the formation of various aluminum oxides or hydroxides with different stoichiometries, potentially contributing to the color change. It is also possible that the color change involves the formation of intermetallic compounds or other reaction products between aluminum and trace elements in the solution.

Understanding a precise mechanism behind this color change is beyond the scope of the current study. Further research employing techniques such as UV-Vis spectroscopy and X-ray photoelectron spectroscopy (XPS), however, would be highly valuable. UV-Vis spectroscopy is capable of analyzing the optical properties of the foil surface and identifying specific compounds based on their absorption spectra. XPS would provide detailed information about the elemental composition and chemical states of the elements on the foil surface, enabling to distinguish between different oxides, hydroxides, or intermetallic species.

To investigate the effect of the fabrication method on the properties of the ATA foil, surface morphology and elemental composition were determined using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) for ATA foil-1 and ATA foil-2. Fig. 1(a) and 1(b) illustrate the SEM images for both ATA foils.

These SEM images show a clear difference in the morphological characteristics of the surfaces for both foils. While ATA foil-1 was rough with many cracks and crevices on its surface (Fig. 1(a)), ATA foil-2 had a smooth surface with a minimum number of cracks (Fig. 1(b)). This morphology was also ascribed to the undissolved $Mg(OH)_2$ particles in the 1% $Mg(OH)_2$ solution utilized to generate ATA foil-1. The particles may have disturbed the smooth deposition of $Mg(OH)_2$ on the aluminum foil surface, resulting in the rough morphology. On the other hand, the supernatant $Mg(OH)_2$ solution utilized to generate ATA foil-2 lacked undissolved particles, leading to a smoother and more uniform coating.

EDX analysis was performed to determine the elemental composition of both ATA foils. In contrast to our expectations, the EDX analysis did not detect any magnesium (Mg) in either ATA foil-1 or ATA foil-2 (see elements tables in Fig. 1(a) and 1(b)). This finding indicated that the magnesium-aluminum layered double hydroxide (LDH) identified in our previous study [14,15] was not formed in this instance. The lack of LDH formation was likely due to the low magnesium concentration in the aqueous phase of the magnesium hydroxide suspension at approximately 0.5 mmol/L. This concentration may be insufficient to enable the formation of the LDH structure.

The absence of a magnesium signal in the EDX analysis requires further discussion.

1. Low Concentration/Thin Coating

   It is possible that the $Mg(OH)_2$ coating formed on the aluminum foil surface is too thin to be detected by the EDX technique. EDX has some limitations in detecting the very thin layers or low concentrations of elements. The signal from the underlying aluminum substrate might overwhelm the signal from the coating.

2. Amorphous Structure

   While we initially expected crystalline $Mg(OH)_2$ or LDH, the actual structure of the coating might be amorphous or poorly crystalline. Amorphous materials can sometimes yield weak or no clear EDX signals for certain elements due to the lack of long-range order.

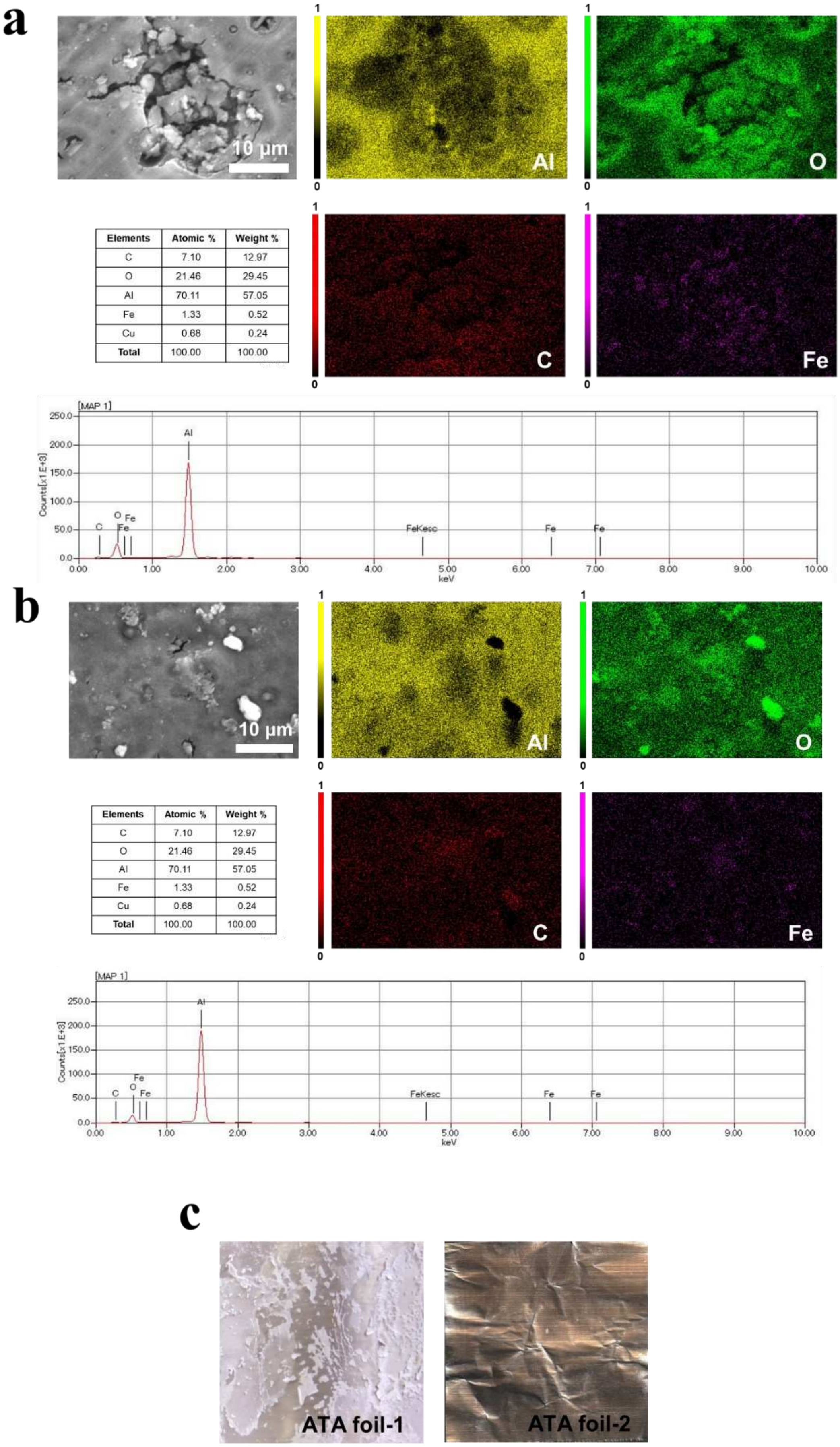
3. Alternative Magnesium Compounds

   It is also conceivable that magnesium is present in a form that is not easily detectable by EDX in this specific configuration. For instance, it might be incorporated into the aluminum oxide/hydroxide layer in a way that does not provide a distinct Mg signal.

4. Surface Sensitivity of EDX

   EDX is a surface-sensitive technique. If the magnesium is distributed unevenly or is present primarily at the outermost surface, it might not be consistently detected across the analyzed area.

The photographs in Fig. 1(c) provide a visual comparison of the appearance of ATA foil-1 and ATA foil-2. ATA foil-1 had a visible white powder residue on its surface, which necessitated washing or wiping before use. In contrast, ATA foil-2 appeared free from any residue, highlighting the advantage of the supernatant $Mg(OH)_2$ fabrication method in eliminating this undesirable feature.



Elements	Atomic %	Weight %
C	7.10	12.97
O	21.46	29.45
Al	70.11	57.05
Fe	1.33	0.52
Cu	0.68	0.24
Total	100.00	100.00

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Total	100.00	100.00

Fig. 1. Characteristics of ATA foil. Surface morphology and elemental analysis of ATA foil. Scanning electron microscopy (SEM) images and energy dispersive X-ray spectroscopy (EDS) element mapping of (a) ATA foil-1, and (b) ATA foil-2 (c) Photographs of ATA foil-1 (with white powders and should be wiped before used in experiments) and ATA foil-2

3.2. Disinfection abilities

Fig. 2 shows the disinfection efficacy of ATA foil-1 and ATA foil-2, evaluated by monitoring the removal of *E. coli* from contaminated water over 24 hours. Though ATA foil-1 and ATA foil-2 demonstrated an ability to remove *E. coli*, their performance was found different, particularly after 24 hours.

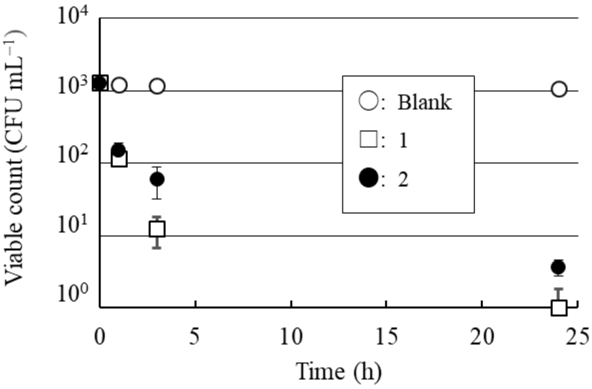

Fig. 2. Change in viable cell counts of E. coli at various time intervals after agitation with ATA foils, starting with an initial viable count of approximately 1000 CFU/mL. Error bars represent the standard deviation calculated from experiments conducted in triplicate

The *E. coli* concentration drastically dropped in the first hour of contact with ATA foil-1 to give a count of 117 CFU/mL, indicating relatively rapid disinfection. While, during the first hour of interaction with *E. coli*, the bacterial decline appeared gradual with ATA foil-2, reaching 153 CFU/mL. Eventually, ATA foil-1 showed effectiveness against *E. coli* as low as 1 CFU/mL after a 24-hour interaction. However, ATA foil-2 was still effective, and it resulted in a final *E. coli* count of 4 CFU/mL. This difference in the final *E. coli* count between the two products suggests that ATA foil-1 probably provided a slightly better disinfection performance compared to ATA foil-2 after the 24-hour contact.

This might also be in view of the rougher surface morphology of ATA foil-1, providing a larger surface area for bacterial attachment and inactivation. Conversely, the smoother surface topography of ATA foil-2 can provide advantages in terms of reducing biofilm formation and cleaning during long-term use. The antimicrobial nature of the ATA foil observed agrees well with literature. Previous studies have demonstrated the effectiveness of ATA foil in removing *E. coli* from contaminated water [12]. However, the differences in disinfection kinetics and final *E. coli* counts between ATA foil-1 and ATA foil-2 indicated that some fabrication methods are able to determine final material properties and performances. A full investigation is deemed necessary to understand the longer-term disinfection performance of these two types of ATA foil and any trade-offs there may be between rapid initial disinfection and biofilm prevention.

3.3. Maximum adsorption of E. coli

The bacterial adsorption data obtained by disinfection experiments were fitted to the Langmuir isotherm model to estimate the maximum adsorption capacity (q_m) of ATA foil-1 and ATA foil-2 for *E. coli*. The Langmuir isotherm model is a theoretical model that explains the adsorption of a solute on a solid surface under the assumptions of monolayer adsorption, homogenous adsorption sites, and no interaction between adsorbed molecules [16]. The model has been widely used to investigate the adsorption processes in numerous fields, including water treatment [17].

Fig. 3(a) and 3(b) depict the Langmuir isotherm plots and corresponding linearized plots for ATA foil-1 and ATA foil-2, respectively. These plots show the correlation between the equilibrium concentration of *E. coli* in solution (Ce) and *E. coli* adsorbed per unit surface area of ATA foil (qe). The curvature of the isotherm curves is the characteristic of favorable adsorption in which the quantity of *E. coli* adsorbed increases with the rising concentration of *E. coli* up to the saturation point.

The model fitted the experimental data well, as reflected by the high R^2 values of 0.9981 and 0.9986 for ATA foil-1 and ATA foil-2 (Fig. 3(c) and 3(d)), indicating that the model explained over 99% of the variability in the data. The maximum adsorption capacities obtained were 572,967.4 CFU/cm^2 for ATA foil-1 and 561,513.8 CFU/cm^2 for ATA foil-2. These values represented the maximum amount of *E. coli* that could be adsorbed per unit area of ATA foil. Table 1 presents the summary of the Langmuir parameters.

Table 1. Langmuir isotherm parameters for *E. coli* adsorption

ATA Foil	qm (CFU/cm^2)	K_L (mL/CFU)	R^2
ATA foil-1	572,967.4	5.74E-06	0.9981
ATA foil-2	561,513.8	5.02E-06	0.9986

The high adsorption capacities observed for both types of ATA foil suggest that adsorption significantly contributes to the removal of *E. coli* from contaminated water. These findings highlight the potential of ATA foil as an effective and practical solution for point-of-use water disinfection.

It is important to consider the validity of the Langmuir model assumptions in the context of bacterial adsorption on ATA foil. The Langmuir model assumes a perfectly homogeneous surface with identical adsorption sites. However, as shown in the SEM images in Fig. 1, ATA foil-1 had a rough surface with many cracks and crevices, indicating significant heterogeneity. While ATA foil-2 had a smoother one; it was unlikely to be perfectly homogeneous at the bacterial scale.

Furthermore, the Langmuir model assumes no interaction between adsorbed molecules. In reality, bacterial cells might interact with each other, especially at higher concentrations, potentially determining their adsorption behavior. Despite these deviations from ideal Langmuir conditions, the model still provided a good fit to the experimental data, as evidenced by the high R^2 values. This suggests that while the Langmuir model may not perfectly represent the complex interactions occurred on the foil surface, it can still be a useful tool for quantifying and comparing the adsorption capacities of the ATA foils.

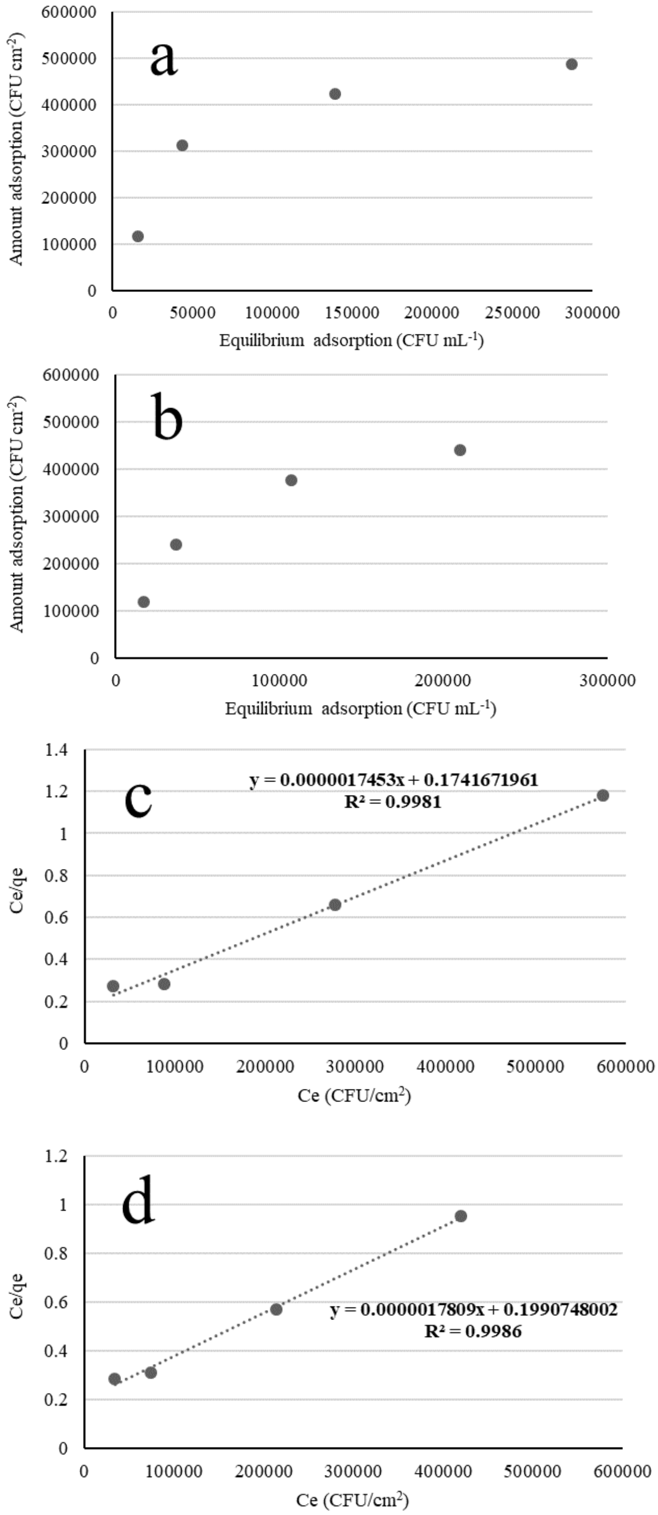

Fig 3. Adsorption isotherm of E. coli on (a) ATA foil-1, (b) ATA foil-2, and (c) and (d) Langmuir plots of the data for ATA foil-1 and ATA foil-2, respectively

3.4. MO removal efficiency and E. coli removal mechanisms

MO was used as a model pollutant to further investigate the *E. coli* removal mechanisms of the ATA foils. Even though it was expected that the foils might not perfectly adsorb MO at a concentration of 5 ppm due to the limited surface area of the 25 cm^2 double-sided lead foil, both ATA foil-1 and ATA foil-2 showed high removal efficiencies, achieving 85.29% and 84.26%, respectively (Fig. 4).

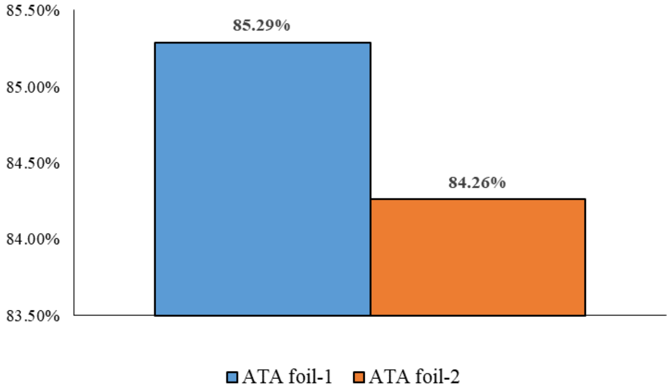

Fig. 4. Removal rates of methyl orange for ATA foil-1 and 2

These results, in conjunction with the high maximum adsorption capacities for *E. coli*, as discussed in Section 3.3, indicated the significant participation of the adsorption mechanism in the removal of contaminants using ATA foils. Perhaps the positively charged $Mg(OH)_2$ coating from ATA foils attracts and subsequently adsorbs the negatively charged *E. coli* cell and MO molecules leading to their removal from water [18,19].

However, the exceptionally high MO removal efficiency with limited surface area indicates that other mechanisms are at play rather than simple adsorption. The possible mechanisms could be:

1. Ion exchange: The $Mg(OH)_2$ coating provides a medium for ion exchange between MO molecules and hydroxyl ions on the surface for the removal of MO from the solution.
2. Chemical degradation: Although MO is commonly considered stable, it might undergo some degrees of chemical degradation in the presence of the activated aluminum surface, hence leading to a decrease in concentration. This degradation could involve several pathways. Aluminum, particularly in its oxidized forms, can act as a Lewis acid catalyst, potentially facilitating the cleavage of the azo bond (-N=N-) in MO. This cleavage would result in the formation of smaller aromatic compounds. Additionally, the alkaline environment provided by the $Mg(OH)_2$ coating might contribute to the degradation of MO as azo dyes, under certain conditions, can be susceptible to alkaline reduction. Further studies should identify the specific degradation products and the exact mechanisms involved.
3. Precipitation: The interaction between MO and the $Mg(OH)_2$ coating could result in the formation of insoluble complexes precipitating out of the solution. Specifically, Mg^{2+} ions released from the $Mg(OH)_2$ coating can interact with the sulfonate groups ($-SO_3^-$) of the MO molecules. This interaction can lead to the formation of magnesium salts of methyl orange, which have lower solubility in water compared to the original MO. These less soluble salts may then precipitate out of the solution.

Therefore, a more in-depth research is required to outline the exact contribution of each of these different mechanisms to the overall MO removal efficiency.

Other than adsorption, several other mechanisms may be responsible for *E. coli* removal:

1. Mg_2 ions, which may be released from the $Mg(OH)_2$ coating, have been reported to exhibit antimicrobial properties. These ions could inactivate *E. coli* cells by disrupting their cell membranes or interfering with essential cellular processes.
2. The rough surface of ATA foils with its cracks and crevices, could potentially trap and physically remove *E. coli* cells from the water.

It is important to acknowledge that while our data strongly suggest that adsorption plays a significant role, we cannot definitively rule out other contributing mechanisms. For instance, the alkaline pH of the $Mg(OH)_2$ solution could contribute to bacterial inactivation. Additionally, though not directly measured in this study, the possibility of the formation of reactive oxygen species (ROS) on the ATA foil surface, known to be potent antimicrobial agents, cannot be entirely excluded and warrants further investigation.

It thus seems probable that the mechanism of removing *E. coli* by ATA foils is highly complex, comprising adsorption, inactivation, and even physical removal. The relative contribution of each mechanism could be based upon some factors, such as the fabrication method, surface morphology of the foil, and the nature of the water to be treated. Further microscopic analyses of the foil surface after contact with *E. coli* are then required. A complete elucidation of this interaction will require further investigation of mechanisms, including the analysis of the water for released Mg^{2+} ions, and the viability of the adsorbed *E. coli* cells.

3.5. Future challenges

Most of the work in this study focused on batch experiments to evaluate the performance of ATA foil. Future research should apply ATA foil in continuous flow systems to further advance this technology toward real-world water treatment applications. Investigating the long-term stability and reusability of ATA foils is crucial for practical use. Further, studying the efficiency of ATA foil against other waterborne pathogens, especially viruses and protozoa, can provide a complete insight into its disinfection potential. Additionally, the risk of leaching of aluminum or magnesium from the ATA foil to the treated water should be studied to guarantee its suitability for drinking water treatment. Finally, the field studies of the performance of ATA foil under real-world conditions, especially in communities without access to safe drinking water, would yield valuable information on its practical feasibility and potential impact on public health.

4. Conclusion

This work demonstrated, for the first time, a novel approach to fabricate ATA foil using a supernatant $Mg(OH)_2$ solution, which eliminated the need for a washing step. This improved scalability and reduced potential residue in the treated water. The current work overcame the issue related to the formation of white powder residue that always appears in the conventional method by using a 1% $Mg(OH)_2$ solution during fabrication. Thus, ATA foil-2 fabricated with the supernatant solution showed relatively superior disinfection and adsorption compared to ATA foil-1 obtained from a conventional fabrication approach. In comparison, the SEM-EDX analysis showed that ATA foil-2 had a smoother surface with fewer cracks and lower Mg content compared to ATA foil-1. However, these surface characteristic differences did not significantly influence *E. coli* removal efficiency and methyl orange adsorption capacity. Both types of ATA foils were effective in removing *E. coli* from contaminated water in less than 24 hours and showed high adsorption capacities for methyl orange, indicating that adsorption is a critical mechanism for the removal of contaminants.

The results of this study demonstrated that the supernatant $Mg(OH)_2$ solution method holds a great promise for the fabrication of more practical and user-friendly ATA foil. This novel fabrication method is able to facilitate the broader use of ATA foil for point-of-use (POU) water disinfection, especially in communities with limited access to safe drinking water since washing or wiping the white powder residue before use is no longer required. Therefore, the study provides an important insight in developing better and more convenient water disinfection technologies. The successful use of the supernatant $Mg(OH)_2$ solution method opens a new avenue for the optimization of ATA foils fabrication for better performance in water treatment applications.

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