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Research Paper

The Effectiveness of Polysilicone Coated Chitosan-Nanosilver as a Disinfectant in Drinking Water Treatment Processes

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Abstract
The need for clean and safe drinking water is increasing, so innovative disinfection methods are needed. This study evaluates the effectiveness of Polysilicone coated with Chitosan-Nanosilver (PCAg) as a disinfectant for drinking water treatment. The synthesis process involves the reduction of silver nitrate ($AgNO_3$) with sodium citrate, which is then combined with chitosan in an acetic acid solution to produce a stable mixture of nanoparticles. This solution was then impregnated into polysilicone foam to create a functional filter media. The experimental results showed that the PCAg were able to effectively remove bacterial contaminants, including *Escherichia coli* and Total Coliform, from the distilled drinking water samples from 4 CFU/100mL to 0 CFU/100 mL, as per the quality standard of the Ministry of Health of the Republic of Indonesia number 2 of 2023. Analysis of the SEM-EDX characterization method showed an evenly distributed Chitosan-Nanosilver coating on the polysilicone surface, evidenced by the detection of 1.31% Nanosilver and an increase in carbon percentage from 40.16% to 44.98%. In addition, analysis of the FTIR characterization method showed the presence of peaks indicating alkane vibrations, aromatic rings, ester groups, and amine groups typical of chitosan. This indicates that chitosan has been coated on polysilicone. This study concludes that the coating process enables optimal interaction between chitosan, silver nanoparticles, and polysilicone, thus enhancing the antibacterial properties of the material. Thus having a significant ability to eliminate bacteria.

Keywords
Chitosan, Disinfectant, Nanosilver, Polysilicone

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1. INTRODUCTION

Human water needs are not only limited to quantity but also quality in meeting the need for clean water that is suitable for drinking. Environmental health quality standards for drinking water include physical, microbiological, chemical, and radioactive parameters (Ministry of Health of Indonesia, 2023). One of the main parameters that must be met is microbiological quality, which directly impacts health. Drinking water must be free of total coliform (0 CFU/100 mL), the presence of coliform bacteria in drinking water indicates contamination that has the potential to cause human illness (Djafar et al., 2024).

Generally, refillable drinking water treatment in Indonesia still relies on simple filtration methods that only physically purify water, such as removing large particles or sediment, but are ineffective in removing microbiological contaminants such as pathogenic bacteria. Bacteria such as *Escherichia coli* (*E. coli*) and coliform are often still contained in drinking water. The study showed that coliform bacteria were found in refill drinking water samples at 29 CFU/100 mL (Wardani et al., 2024). High levels of bacterial contamination can pose a threat to the local community and cause waterborne diseases (Khan et al., 2020).

The use of disinfectants is the most common method to reduce the risk of cross-contamination and the spread of bacteria, as they are able to reduce the number of bacteria effectively (Bai et al., 2022). As technology develops, various water disinfection methods have been developed, including chemical and physical methods. One of the compounds that shows high antibacterial potential is chitosan, which contains a positively charged amino group, so it is functionally active and plays a role in antibacterial and fungal activity (Guarnieri et al., 2022). One of these microbes is coliform bacteria, which are Gram-negative rod-shaped microbes that do not form spores (Sasidharan et al., 2022). The positively charged amino groups in chitosan, will electrostatically bind to the negatively charged components in the microbial membrane, resulting in an antimicrobial effect (Yan et al., 2021).

Silver nanoparticles are known to have strong antimicrobial properties (Bruna et al., 2021). Nanoparticle-silver with a smaller size has a larger surface area, which increases reactivity and interaction with pathogens, thereby enhancing antimicrobial effectiveness (Menichetti et al., 2023). The mechanism of antimicrobial activity occurs when silver nanoparticles are able to penetrate the bacterial cell wall, disrupt the cell membrane structure, and even cause cell death (Yin et al., 2020). The shape and size of silver nanoparticles determine their optical, electrical, magnetic, catalytic, and antimicrobial properties, with smaller particle sizes producing stronger antimicrobial effects (Yanti et al., 2021). Chitosan is rich in hydroxyl and amino groups that play a role in binding heavy metal ions, such as silver, which increases its antimicrobial effectiveness (Zhang et al., 2021). The combination of chitosan and silver nanoparticles is expected to produce a disinfectant that effectively eliminates bacteria from water.

Polysilicone foam is used as a support medium for coating chitosan and silver nanoparticles because it is widely found in everyday life, such as dish sponges. In addition, polysilicone is waterproof and stable, and can be surface modified. The attachment of silver nanoparticles to polyurethane foam provides good adhesion strength and facilitates phase separation (Centenaro et al., 2017).

Although various studies have explored the use of silver nanoparticles and chitosan as antibacterial agents, most still focus on the characterization of solution or polymer-based membranes without considering the effectiveness of applications on porous filtration media such as polysilicone foam. In addition, studies regarding the distribution and structural characterization of silver nanoparticles after the foam coating process are still limited. Therefore, this study aims to develop and characterize Polysilicone Coated with Chitosan-Nanosilver (PCAg) as an antibacterial filtration material for drinking water, with an emphasis on the distribution of silver nanoparticles, effectiveness in the elimination of pathogenic bacteria, and structural characterization using SEM-EDX to confirm the successful coating and dispersion of nanoparticles in the polysilicone foam substrate. The combination of these materials is expected to be an effective additional solution in water filtration systems, which not only serves to purify water, but also kills the bacteria in it.

2. EXPERIMENTAL SECTION

2.1 Materials

The main materials used were polysilicone were provided by dr. Shine, chitosan were provided by Aldrich, silver nitrate ($AgNO_3$) were provided by Emsure, acetic acid (CH_3COOH) were provided by Emsure, sodium citrate ($Na_3C_6H_5O_7$) were provided by Emsure, sodium hydroxide (NaOH) were provided by Emsure, and distilled water were provided by Sari Kimia Bekasi. In the manufacturing process, using laboratory equipment and tools such as balance sheet, thermometer, pH meter, Scanning Electron Microscope (SEM) JEOL JSM 6510 LA, and Spectrometer Jasco FT/IR-4600.

2.2 Methods

Silver nanoparticles were prepared using the ratio in Table 1. Weigh $AgNO_3$, then dissolve it per 500 mL into a glass beaker. Stir $AgNO_3$ at 85°C for 13 minutes (Yanti et al., 2021), then drop 1% sodium citrate (7 mL) obtained by dissolving 1 g sodium citrate per 100 mL. Cool the silver nanoparticle solution before storing it in the bottle.

Before making the chitosan solution, dissolve 5 mL of acetic acid per 500 mL. Weigh and put the chitosan into a glass beaker. Stir at 40°C (Sasidharan et al., 2022) for 30 minutes (Kalaivani et al., 2018). Mix the ratio of chitosan and $AgNO_3$ according to Table 1.

Table 1. Material Ratio

Description	Chitosan	$AgNO_3$
PCAg-1	1	12
PCAg-2	1	6
PCAg-3	1	3

The coating process begins by mixing a solution of silver nanoparticles and chitosan. The mixture was stirred at 90°C for 5 hours. Check the pH of the solution. If the pH is too acidic, drop NaOH and then check the pH periodically until normal. If the time required is sufficient, stop the dissolution process and then cool it down. The prepared polysilicone foam was soaked in silver nanoparticle chitosan solution for 24 hours (Sasidharan et al., 2022), then rinsed with distilled water and dried.

3. RESULT AND DISCUSSION

3.1 Manufacturing Analysis

Sodium citrate in $AgNO_3$ solution, used as a chemical reduction method and stabilizer, will form silver nanoparticles characterized by yellow discoloration as shown in Figure 1. The color change occurs due to collective oscillations of electrons in the conduction band, known as surface plasmon oscillations (El-Nour et al., 2017). Research conducted by Yanti et al. (2021) shows that 7 mL of sodium citrate is the optimum volume. Figure 1 shows that the greater the concentration of $AgNO_3$, the darker the color of the solution.

Figure 1. $AgNO_3$ Solution

$AgNO_3$ dissolution is heated at 85°C, which is the optimum temperature (Yanti et al., 2021). Heating temperature plays a role in regulating the speed of silver nanoparticle size formation. Heating takes 13 minutes to obtain a solution with a stable yellow color. Long stirring duration can cause the solution's color to become darker, which indicates aggregation. The initial yellow solution will turn purple, then finally grey (Badiah et al., 2019).

Figure 2 shows the chitosan, which was previously shaped like lumps of cotton, changing its texture to jelly-like, until it finally dissolved completely. The resulting solution appears slightly viscous, proving that the chitosan was successfully dissolved in acetic acid.

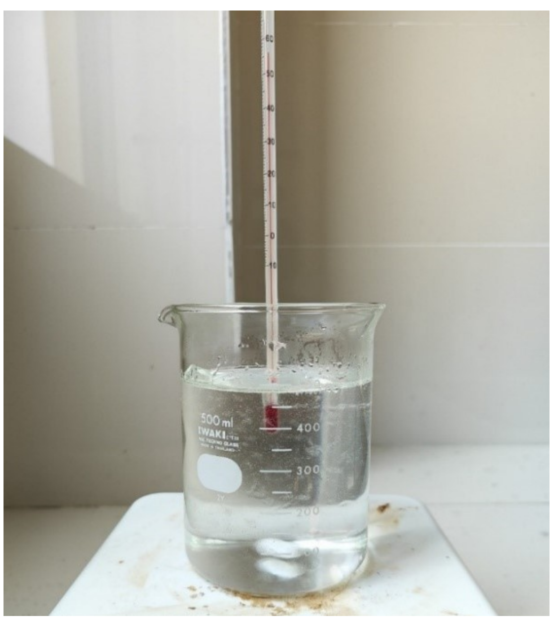

Figure 2. Chitosan Solution

The amino group on chitosan is weakly alkaline and difficult to dissolve in neutral or alkaline water. Acetic acid is a weak acid capable of protonating the amine group on chitosan into ammonium ions. Other studies have shown that chitosan has better solubility at a certain level of deacetylation in acetic acid solution because it has more amino groups that can be protonated (Nguyen et al., 2022). The concentration of acetic acid between 0.2% to 1.0% affected the rheological characteristics of the chitosan solution, which means that acetic acid played an important role in dissolving the chitosan (Sobral et al., 2022). A temperature of 40°C helps accelerate chitosan dissolution without damaging its molecular structure. At high temperatures, chitosan will undergo heat degradation characterized by dehydration, depolymerization, and decomposition of acetyl groups and deacetylation units in its polymer structure (Sikorski et al., 2021). A time of 30 minutes was sufficient to dissolve the chitosan evenly (Kalaivani et al., 2018).

Figure 3. Polysilicone Foam Coating

The mixture of silver nanoparticles and chitosan will produce a darker brownish-red solution (Figure 3). These two solutions were mixed into one glass beaker, so the volume became 1000 mL. This process was carried out for 5 hours with a temperature of 90°C. A high temperature of about 90°C is effective for maintaining the stability of silver nanoparticles during the mixing process, without the risk of chitosan degradation (Kalaivani et al., 2018). Sufficient time in the mixing process between chitosan and silver nanoparticles results in a more even dispersion of nanoparticles and enhances their antimicrobial effectiveness (Sasidharan et al., 2022).

The pH regulation during the mixing process is crucial to ensure the successful synthesis of silver nanoparticles stabilized by chitosan. Chitosan has amine groups that are protonated under acidic conditions, thus affecting the interaction between chitosan and silver ions. Therefore, pH adjustment by adding NaOH solution is required to achieve optimal pH conditions. Fan et al (2012) in Az Zahra et al. (2024) conveyed that the pH of chitosan solution conducive to the formation of silver nanoparticles is around 4.7-4.8. At this pH, chitosan can function optimally as a silver nanoparticle stabilizer.

The coating is done by embedding the polysilicone foam in the Nanosilver chitosan solution as shown in Figure 3. Ensure the polysilicone foam is fully submerged so all parts can be impregnated perfectly. The coating process was carried out for 24 hours under closed conditions.

The 24-hour time provides sufficient time for the Chitosan-Nanosilver solution to penetrate thoroughly into the pore structure of the polysilicone foam. The amine and hydroxyl groups on chitosan can form hydrogen (Li et al., 2018), bonds with oxide or hydroxyl groups that may be present on the polysilicone surface. This allows the chitosan-AgNPs to adhere to the surface effectively. In addition, the immersion process of the foam for 24 hours allows the solution to be absorbed into the foam's pores. This process involves the diffusion of the solution into the small pores of the foam, ensuring an even coating. Undersealed conditions, evaporation of the acetic acid solution and water from the chitosan can be minimized, keeping the solution concentration stable during the coating process. It also helps maintain the temperature and humidity around the foam.

The impregnated foam shows a fine luster due to silver nanoparticles attached to the surface and pores, this is in line with research Wigati et al. (2018) which shows that there are white spots on the luffa cylindrica sponge. These visual changes are shown in Figure 4.

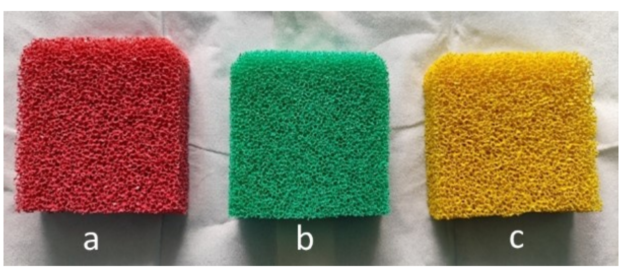

Figure 4. Chitosan-Nanosilver Coated Polysilicone Foam (a) PCAg-1 (b) PCAg-2 (c) PCAg-3

After the coating process is complete, the polysilicone foam is rinsed with distilled water to remove any residual solution. Then, the foam is dried at 100°C in an oven to remove the moisture content. Polysilicone coated Chitosan-Nanosilver (PCAg) is ready to be used as a medium to remove bacteria.

3.2 Water Testing Analysis

Drinking water quality standards that are suitable for consumption, set by Ministry of Health of Indonesia (2023) require the parameters of *Escherichia coli* and total coliform in water to be at the level of 0 CFU/100 mL. This means drinking water must be free from pathogenic bacterial contamination to ensure safe consumption and prevent the risk of waterborne diseases.

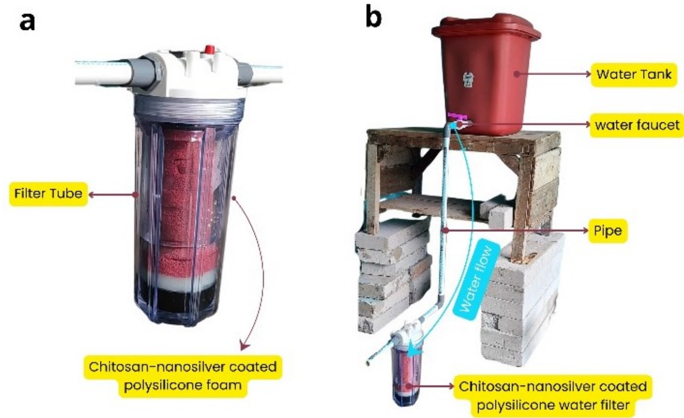

Figure 5. PCAg in Filter Tube (a) and Testing Circuit of Water Filter (b)

Testing of Nanosilver Chitosan-coated Polysilicone foam was carried out using a series of water filter tubes, where a stream of sample water was passed through the filter can be seen in Figure 5. The water sample used was distilled refilled drinking water.

The sample water was placed in a higher water tank, utilizing gravity to push it out. The water discharge was set at 100 mL/min with a small flow, so that the water could pass through the Nanosilver chitosan foam slowly to maximize its disinfectant function.

Table 2. Water Test Results

	Parameters	Results (CFU/100 mL)
Before	*Escherichia coli*	Negative
	Total Coliform	4
PCAg-1	*Escherichia coli*	Negative
	Total Coliform	Negative
PCAg-2	*Escherichia coli*	Negative
	Total Coliform	Negative
PCAg-3	*Escherichia coli*	Negative
	Total Coliform	Negative

Based on Table 2 the results of filtration testing with Nanosilver chitosan filter media, it was found that the water before the filtration process contained 4 colonies of Total Coliform, which indicated that the distilled drinking water was unsuitable for consumption. After the filtration process with three variations of materials, all parameters showed negative results for *Escherichia coli* and Total Coliform. This shows that only the PCAg-1 concentration was able to eliminate 4 colonies of bacteria. Although all variations

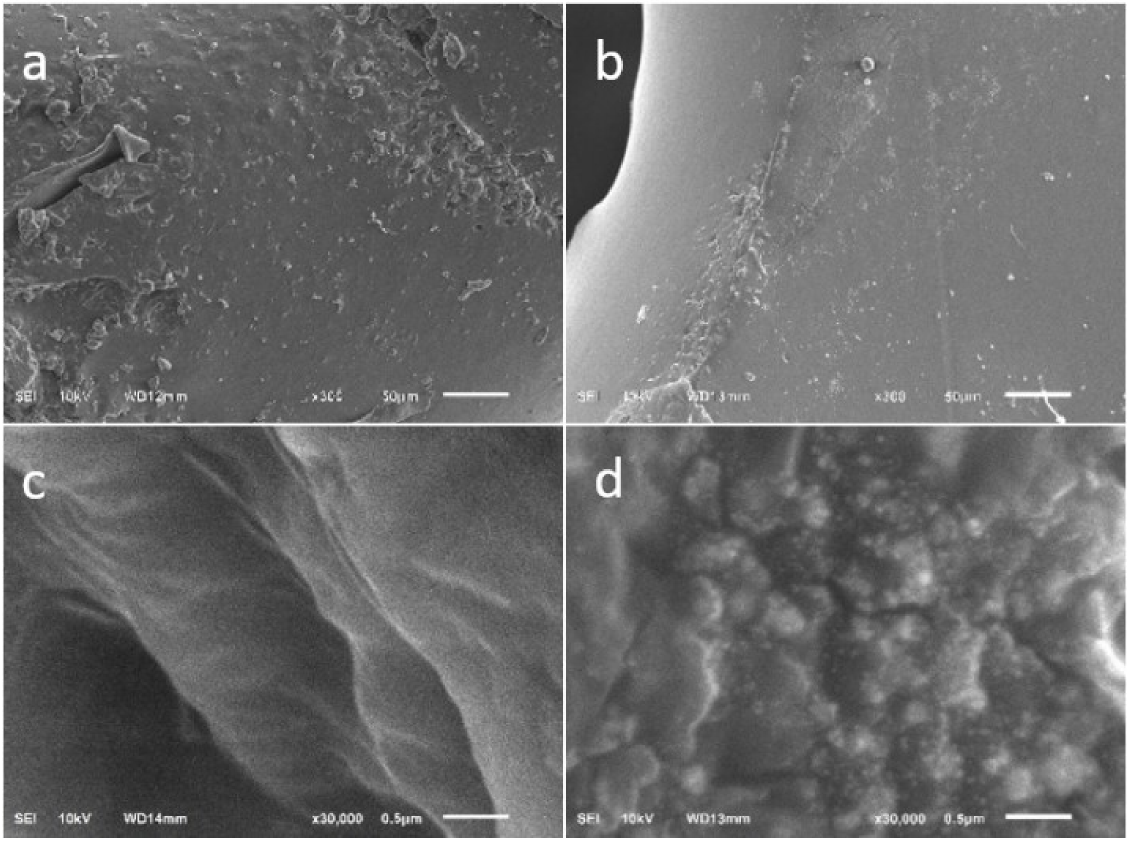

Figure 6. Zoom in 300× Before (a), 300× After (b), 30.000× Before (c), and 30.000× After (d)

successfully removed bacteria, this study selected the PCAg-1 variation with chitosan: $AgNO_3$ ratio of 1:12 as the best composition. This selection was based on the effectiveness of disinfection, where despite having the lowest $AgNO_3$ concentration, this variation was still able to completely remove *Escherichia coli* and Total Coliform colonies down to 0 CFU/100 mL. In addition, SEM-EDX analysis showed that the PCAg-1 variation still produced an even distribution of silver nanoparticles on the foam surface with no significant indication of agglomeration.

This antibacterial effectiveness combines chitosan that kills bacteria through electrostatic interactions that disrupt membrane permeability (Chandrasekaran et al., 2020). In addition, Nanoparticles and silver ions are able to attach to the bacterial cell wall, thus causing damage (lysis) and cell death. Positively charged silver ions interact with bacterial DNA, which can disrupt the replication process. The antibacterial mechanism of silver involves various factors, including damage to the cell envelope and membrane proteins, leading to membrane depolarization and disruption of homeostasis (Vasilev et al., 2024).

3.3 SEM Analysis

Scanning Electron Microscope (SEM) analysis was performed to observe the structure, morphology, particle distribution of nanoparticles, and pore characteristics on the surface of Polysilicone coating Chitosan-Nanosilver, which are important for filtration effectiveness. Figure 6 shows the SEM difference between polysilicone before and after being coated by Chitosan-Nanosilver.

SEM test results with 300× magnification show that the surface becomes more closed and smooth, indicating that the polysilicone is successfully coated with Chitosan-Nanosilver as seen in Figure 6(b). In addition, the results of SEM testing with a magnification of 30.000× after in Figure 6(d) show the addition of Chitosan-Nanosilver as seen from the areas with brighter colors.

Table 3. SEM-EDX Result

Element	Before Mass (%)	After Mass (%)
Carbon (C)	40.16	44.98
Nitrogen (N)	4.20	4.57
Oxygen (O)	3.89	4.68
Alumunium (Al)	0.79	-
Silicon (Si)	50.96	44.46
Silver (Ag)	-	1.31
Total	100.00	100.00

Table 4. Comparison of Disinfectant Methods

Disinfection Method	Excellence	Disadvantages
Chlorination	- Effective at killing a wide range of pathogens	- May produce harmful by-products such as trihalomethanes
	- Low operational cost	- Decreased effectiveness against some protozoa
Ozonization	- Powerful oxidizer that effectively kills microorganisms	- High installation and operational costs
	- Removes unwanted odors and tastes	- Leaves no protective residue, so recontamination is possible
PCAg (This Study)	- Combination of chitosan and silver nanoparticles provides synergistic antibacterial effect	- Further research to confirm durability and potential release of silver into water
	- Does not require an external energy source to operate	

EDX analysis using ZAF Method Standardless Quantitative Analysis was performed to see the atomic composition of the sample surface. At 30.000× magnification (d), the brighter color difference indicates the Nanosilver attached after the coating process. This is supported in Table 3, which shows that the mass content of Nanosilver (1.31%) was detected after coating Nanosilver chitosan, while before coating there was no visible Ag marked with (-). SEM-EDX analysis also showed an increase in carbon content from 40.16% to 44.98% after the coating process. This increase indicates that chitosan was successfully impregnated on the surface of the polysilicone foam. Because chitosan is an organic polymer which contains carbon (Li et al., 2020), the increase in carbon content can be attributed to the successful coating of the material.

SEM-EDX results confirm the successful coating of silver nanoparticles, where particle distribution and adhesion play an important role in their effectiveness. Research conducted by Centenaro et al. (2017) conveyed that the use of chitosan-coated polyurethane foam as an adsorption medium, the SEM results in this study showed a more homogeneous distribution of nanoparticles. Another study by Sasidharan et al. (2022) also reported that coating silver nanoparticles on porous substrates such as foam can improve nanoparticle adhesion and prevent agglomeration, which can reduce antibacterial effectiveness. This even distribution of nanoparticles on polysilicone foam significantly ensures effectiveness in the water disinfection process.

To strengthen the impact of this study, the effectiveness of Polysilicone Coated with Chitosan-Nanosilver (PCAg) compared to other disinfection methods is summarized in Table 4.

PCAg offers an innovative solution in drinking water disinfection. It combines the antibacterial effectiveness of chitosan and silver nanoparticles in a polysilicone foam-based filtration system. This technology has the potential to be a more stable, energy-efficient and applicable alternative to conventional methods.

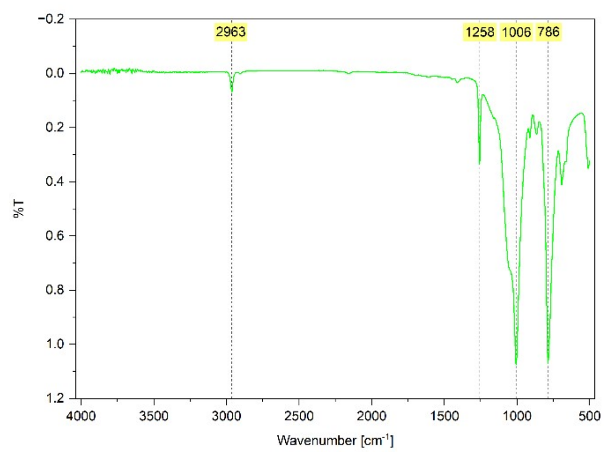

Figure 7. Result FTIR

3.4 FTIR Analysis

In this study, the analysis was carried out by utilizing FTIR to identify the functional groups contained in the sample. Polysilicone-coated Chitosan-Nanosilver (PCAg) was analyzed using FTIR Spectrometer Jasco FT/IR-4600, in Figure 7 showed that at the peak wave number of 2963 cm^{-1} there is an alkane chain vibration (C−H) belonging to chitosan, 786 cm^{-1} shows the vibration of the aromatic ring of chitosan, 1006 cm^{-1} shows the presence of ether functional groups (−C−O−C⁻) in the aromatic ring of chitosan, 1258 cm^{-1} shows the presence of amine groups (NH_2) belonging to chitosan. This indicates that the chitosan was successfully coated on the polysilicone.

4. CONCLUSIONS

The results showed that the Chitosan-Nanosilver was effectively coated on the polysilicone surface. The experimental results showed that the PCAg were able to effectively remove bacterial contaminants, including *Escherichia coli* and total coliform, from the distilled drinking water samples from 4 CFU/100mL to 0 CFU/100 mL, as per the quality standard of the Ministry of Health of the Republic of Indonesia number 2 year 2023. SEM-EDX analysis showed an evenly distributed Chitosan-Nanosilver coating on the polysilicone surface, evidenced by the detection of 1.31% Nanosilver and an increase in carbon percentage from 40.16% to 44.98%. Furthermore, tests showed that PCAg (Polysilicone coated Chitosan-Nanosilver) had a significant ability to eliminate bacteria. FTIR analysis showed peaks indicating alkane vibrations, aromatic rings, ether groups, and amine groups typical of chitosan. This suggests that chitosan has coated the polysilicone. This study only shows the antibacterial effectiveness against *Escherichia coli* and total coliform, while its effectiveness against other types of bacteria or other pathogenic microorganisms has not been studied further. In addition, the long-term durability of the material and the possibility of silver nanoparticles leaching into water have not been analyzed in depth. As a recommendation for future research, it is recommended thoat the material's durability be tested under repeateduse and the possibility of silver nanoparticle detachment during the filtration process be measured. In addition, evaluation of effectiveness against various types of pathogenic bacteria and viruses must ensure that PCAg can be widely used in safer and more efficient drinking water treatment applications.

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