Study of fabrication for antibacterial water filter by loading silver nanoparticles on activated carbon

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Abstract The aim of this study was to evaluate the use of nitric acid treatment of activated carbon, and observe whether it can increase the amount of silver adsorption. We used vacuum condition to investigate if we could synthesize higher loading silver nanoparticles. Furthermore, we explored a zero-waste manufacture process and tested its antibacterial activity.

1. Research Status
Activated carbon is widely used in the purification of domestic water[1], but microorganisms in water are easily adsorbed and multiplied inside it. After the ordinary activated carbon water purifier is used normally at room temperature for a period of time, the bacteria content in the water will increase by 4 orders of magnitude. If the activated carbon is antibacterially modified to have the ability of killing microorganisms adsorbed on it surfaces, the content of microorganisms in filtered drinking water can be effectively controlled[2][4].

Silver ions are widely used to inhibit or kill bacteria, viruses[3], algae, and fungi because of their advantages such as broad-spectrum antibacterial properties, antibacterial durability, antibacterial efficiency, and do not lead to microbial resistance[6].

Research results show that the main reaction mechanism of activated carbon-modified silver is reduction adsorption[7][8]. Related studies have shown that the surface of activated carbon has good reducing power and can reduce silver ions to elemental silver[9].

2. Method

2.1. Acid treatment
Adsorption of silver ions by activated carbon is closely related to the pore structure and surface chemical structure of activated carbon[10]. We use nitric acid to oxidize and modify activated carbon, and observe whether it can increase the amount of silver adsorption.

2.2. Vacuum condition
The vacuum technology is applied to remove the moisture and gas on or inside activated carbon before introducing the silver nitride and to reduce the interference on the process of nanosilver particles crystallization, enhancing the usability of silver nitride in process and reducing the consumed energy, and to improve the nanosilver adhesion on the surface of activated carbon.
2.3. Zero-waste process
To explore a zero-waste manufacture as an environmentally friendly and green process.

3. Experiment

3.1. Activated carbon pretreatment
The activated carbon was washed with deionized water, and then charged into flask of rotary evaporator. Vacuum dry up the activated carbon at 95°C for 1 hour and stored in a sealed container until use.

3.2. Modification by Nitric Acid
20g of granular activated carbon added to 200ml of 1M nitric acid solution. This was vibrated and reacted for 1 hour in the oscillator at 30°C, filtered and boiled in hot water. This was then washed to neutral, dried up for 1 hour in a vacuum at 95°C and then sealed and stored for future use.

3.3. Zero-waste preparation of silver loaded activated carbon
20g of nitric acid modified activated carbon was put into 24ml of 300 ppm silver nitrate solution at room temperature. This was stirred till all silver nitrate was adsorbed by activated carbon, and dried up for 1 hour in a vacuum at 95°C, then in an vacuum oven set at 300°C for 2 hours, and the surface morphology was observed.

3.4. Antibacterial test
After 30 minutes of ultrasonic vibration at room temperature, the silver loaded activated carbon was filtered and dried, and sent to SGS test, a notary testing unit in Taiwan. SGS laboratory prepared test water for testing. The test water flowed through the silver loaded activated carbon at a fixed flow rate of 0.3l/min for 10 minutes, and the water samples before and after treatment were respectively taken for antibacterial test.

4. Results and Discussion

4.1. Characterization test

![Image 1. Activated carbon without modification by nitric acid](image1.png)  
![Image 2. Activated carbon treated with nitric acid](image2.png)
SEM images in above show the morphologies of nitric acid modified and unmodified activated carbon. Comparing the surface morphology of the primitive activated carbon, it can be found that nitric acid has a strong elution and oxidation ability. After going through nitric acid treatment, the activated carbon appears loosen in structure, and the surface is not as uniform as the primitive activated carbon. The results may be due to the strong oxidation of nitric acid, which led to the partial oxidation of reducing groups on the surface of activated carbon. It is enhanced the adsorption capacity of activated carbon and leaded to the increase of necessary nuclei sites for the growth of silver particles.

**Chart 1. Elemental analysis of activated carbon EDS without nitric acid treatment**

| Element | Weight% | Atomic% |
|---------|---------|---------|
| C K     | 99.79   | 99.94   |
| Ca K    | 0.21    | 0.06    |
| Totals  | 100.00  | 100.00  |

**Chart 2. EDS elemental analysis of silver-loaded activated carbon without nitric acid treatment**

| Element | Weight% | Atomic% |
|---------|---------|---------|
| C K     | 96.07   | 99.42   |
| Al K    | 0.15    | 0.07    |
| Ca K    | 0.40    | 0.12    |
| Ag L    | 3.38    | 0.39    |
| Totals  | 100.00  | 100.00  |
Table 1. SGS antibacterial test report

| Test Item              | Unit   | Before processing | After processing | Elimination ratio(%) |
|------------------------|--------|-------------------|------------------|----------------------|
| E. coli                | CFU/mL | 7.1X10^5          | <1               | >99.9                |
| Staphylococcus aureus  | CFU/mL | 6.8X10^5          | <5               | >99.9                |
| Total Plate Count      | CFU/mL | 8.1X10^5          | <5               | >99.9                |

The antibacterial test was performed on the water flow after 10 minutes. The prepared nanosilver activated carbon can reduce the number of *E. coli*, *Staphylococcus aureus* and total microorganism count by more than 99.9%.

5. Conclusion
In this study, a zero-waste vacuum reduction method was used to prepare silver-loaded activated carbon. The silver content in the silver-loaded activated carbon solution made from 300 ppm silver nitrate was measured by ICP to be 120 ppm.

Since the adsorption of activated carbon to silver ions is closely related to the pore structure and surface chemical structure of the activated carbon, the functional groups are actually active adsorption sites for silver ions. In this case the nitric acid modification did increase the activated carbon's surface functional groups as expected and increased the silver content on the activated carbon surface. Whether the porosity and pore size can be improved requires further studied.

Although it has a good sterilization effect, we hope to further reduce the silver content in the solution and enable it to achieve the same sterilization effect. In addition, although the antibacterial results are satisfactory, the persistency of the nanosilver loaded activated carbon produced by our method needs to be further confirmed.

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