Microbial Risks in Household GAC Filters Increased with Residence Time

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Abstract. The research studied microbial contamination in household GAC filters with residence time. Initial GAC effluents were collected and stored in different circumstances (glass cup, silver cup and new GAC), Bacterial growth in GAC effluents and stored samples were detected during the 3-day residence time simultaneously. Besides, microbiome diversities in the GAC unit were measured for one month. Three main conclusions were found: (1) the maximum microbial counts were higher in storage water than in GAC filters. (2) The growth rates were faster in filters than those in storage water in a shorter residence time and the microbial risks were apparent initially. (3) The pH level decreased with residence time and the oxidation properties increased due to the desorption of GAC. The research provided useful information for optimizing household purifiers usage.

1. Introduction
Water purifiers has been more applied in residents’ houses and in the public to satisfy the pursue for high quality drinking water [1]. The purifier can remove disinfection residuals, heavy mental and disinfection by-products. Granular activated carbon (GAC) unit acts as an important role in removing hazardous substance and assimilable organic carbon (AOC) [2]. Besides, the taste of drinking water can be improved after the GAC process. However, house-hold purifiers dose not run continuously, so microbial pollution and biological risks are important concerns [3].

GAC has both absorption function and biodegradation function. GAC provides comfortable circumstance for microbial communities. Under the condition of continuously operation, GAC can keep relatively biologically stable. Due to work schedule, vacation leave and other reasons, water stagnation is a common phenomenon in water purifiers [4,5]. Ling studied the microbial changes in buildings induced by water stagnation, and reported that bacterial community assembly was highly reproducible and biological risks increased [5,6]. Besides, as one kind of small-scale water supply systems, water purifiers did not earn enough attentions and supervisions [7]. GAC is more suitable for bacterial growth, compared with the building pipes, so the biological risks deserved more attentions.

This paper studies the microbial contamination during 3-d residence time. GAC effluents at different residence time were collected to detect bacterial regrowth and microbial communities. The purpose of this study is to explore the microbial abundance changes and to analyze the biological risks in GAC.
induced by water stagnation, which can provide information for drinking water biosafety for consumers at the last meter of water supply systems.

2. Materials and Methods

2.1. Experimental plants
An experimental water treatment plant was applied in this study. The plant consists of sand filtration (SF) unit, GAC unit and a set of ultrafiltration membrane unit, as shown in Fig. 1. Tap water from the drinking water distribution system (DWDS) was used as the influent of the plant, and a pipe was connected to collect GAC effluents for sampling.

![Figure 1. Schematic of household drinking water treatment plant](image)

2.2. Parameters and detection methods
In this study, heterotrophic plate counts (HPC), pH, oxidation-reduction potential (ORP), UV254, OD600 and 16s-RNA were measured. HPC was detected on R2A agar. ORP and pH was detected by measured through ORION 4-Star (Thermo, USA). 16s-RNA was measured on Illumina high-throughput sequencing platform. Intact cells concentration (ICC) and total cells concentration (TCC) were measured through flow cytometry (FCM).

2.3. Pilot design
SF unit and GAC unit were first backwashed before operation. The whole plant ran continuously for 24 h and then the plant was powered off. Effluents of GAC were collected at the time of 0, 3, 6, 12, 24, 36, 48, 60, and 72 h after power off, the sample was marked as GE. Besides, Trible 500-mL GAC Effluents were collected at the time of 0. The first one was stored in glass cup (marked as SG) and the second one was stored in silver cup (marked as SS), to compare the microbial contamination. The third one was store in glass cup with washed new GAC (marked as SN) to compare the impact of the microbiome age. All stored water samples were sealed with membrane to prevent new bacteria invading. Besides, microbial abundances in GAC were measured at the time of 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} week after power off. HPC, ORP, OD600 and pH were all detected in all samples.
2.4. Data processing
The experimental data was processed using Origin 9.1, ggplot2 and SPSS version 20.0.

3. Results and Discussion

3.1. Microbial counts
The value of HPC ranged from $7 \times 10^1$ to $7.4 \times 10^5$ cfu/mL and ICC ranged from $1.9 \times 10^1$ to $3.92 \times 10^7$ cells/mL, as shown in Fig. 3. The maximum microbial counts followed the descending order: EG>ES>EW. The level of ICC/TCC was 10-78%, which increased with residence time.

Although GAC could provide additional nutrients for bacterial growth, yet the microbiome and biofilms in the unit were mature. The environment could ensure bacterial growth steadily, but the quorum sensing (QS) played the balance role in preventing crazy growth.

3.2. Range of the growth phase.
Bacterial growth experienced lag phase, exponential phase and stationary phase in this study, as shown in Fig. 3.

The lag phase in the SS sample was the longest one, as the silver material might played the role in refraining bacterial growth. This indicated that anti-bacterial material could keep the water safe in a short residence time. However, the lag phase in the GE sample was less than 6 h. This phenomenon indicated filters such as GAC would be polluted in short residence time. Although the bacterial counts
in the GE sample did not grow vastly in the following residence time, yet it held the highest risk in the first 24 h. The phenomenon might support that GAC unit was the major biological pollution sources in household treatment plant.

Bacteria in the GE sample was the first sample to entered the exponential phase, as the water environment in GAC was more suitable for growth. The GAC unit had systematic microbiome, so it held the capacity of resisting interference. This could explain that bacteria in the GE sample first entered the stationary phase. However, the differences between long-time used GAC and the new GAC were obvious. The new GAC has well absorption performance and bacteria prefer to grow in sediment phase or biofilm phase, so that bacterial growth was not so apparent in the bulk water phase. Therefore, the SN sample was the last one detected to enter the exponential phase.

3.3. Generation time and growth rate.

In the exponential phase, bacterial cells grew exponentially, as shown in the equation (1), and the generation time ($t_g$) could be calculated as the equation (2).

$$N=N_0 \times 2^n$$  \hspace{1cm} (1)

$$t_g=\frac{\Delta t}{n}$$  \hspace{1cm} (2)

In which, $N$ and $N_0$ respectively represented the end and the start values of HPC during the exponential phase; $n$ and $\Delta t$ bacterial were respectively the generations and the duration of the exponential phase.

To evaluate the average growth rate, the equation (3) was introduced.

$$N=N_0 \times (1+p)\Delta t$$  \hspace{1cm} (3)

in which, $p$ was the average growth rate in per hour.

![Figure 4. Generation time and the average growth rate](image)

The growth rate followed the order: SN>SS>SG>GE. Although the nutrients in the GE sample was more abundant, yet the competition decrease the growth rate due to the QS effect. The growth rate in the SS sample was the highest. The possible reason was that the anti-bacterial material stimulated the microbial resistance to the unfavourable growth environments induced by the material. The resistance included that the generation time decreased so that they could copy quickly to survive. When the resistant communities adapted themselves to the anti-bacterial environments, they would grow more quickly. Therefore, the generation time was very short and the average growth rate was high in the ES sample. This give guidelines that anti-bacterial material could support disinfection optimization through decreasing disinfection demands and expanding the disinfection duration.

3.4. Chemical changes with time

The values of pH ranged from 5.77 to 8.15. They changed apparently during the first 12 hour, then they gradually oscillated in small ranges. pH followed the descending order: GE>SG>SS>SN. The values of ORP ranged from -97.5 to 78.8. ORP followed the descending order: SN>SS>GE>SG. ORP in SG and GE samples decreased initially and then increased. ORP in the SS sample slightly increased and then
decreased. The possible reason was that silver iron was released into the bulk water phase, which was consistent with the HPC trends. The differences between GE and SN samples were obvious.

![Figure 5. Changes of pH and ORP with residence time](image)

4. Conclusion

The research studied microbial contamination in household GAC filters with residence time in three days, and compared the microbial contamination in storage water. There were three findings:

1. The maximum microbial counts were higher in storage water than in GAC filters.
2. The growth rates were faster in filters than those in storage water in a shorter residence time and the microbial risks were apparent initially.
3. The pH level decreased with residence time and the oxidation properties increased due to the desorption of GAC.

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