Verification of New GAC with Consideration to Environmental Impact in Large-scale Advanced Water Treatment Facilities

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Abstract: At Tokyo Waterworks, with the 100% introduction of advanced water treatment in the purification plants of the Tonegawa River system in FY2013, a problem has developed where the amount of renewed granular activated carbon (GAC) has surged to around three times when compared to five years ago. The renewal period of GAC is four years for the sake of supplying high quality water that is safe and potable, and as around 16,000m^3 needs to be renewed throughout the year, the costs and burden on the environment are increasing. Therefore, in order to establish a more effective method of operation that also considers the environment, testing is taking place with a view to introduce plant-based activated carbon and recycled coal. In the verification results up until now of organic matter indicators UV260 and TOC as well as physical property tests, it has been confirmed that, when compared to coal-based activated carbon that has been used thus far, there is no great difference in water treatment properties or operation manageability in both plant-based activated carbon and recycled coal.

Keywords: Granular activated carbon; plant-based activated carbon; recycled coal; environmental load reduction; carbon neutral; advanced water treatment

1. Introduction

The water resources of Tokyo are 80% dependent on the river surface water of the Tonegawa and Arakawa River systems, and around half of that is intake from Edogawa River. Although the catchment area of Edogawa River saw rapid development of housing construction as Tokyo's commuter town from 1965 onwards, the water quality of Edogawa River suddenly deteriorated due to such things as delays in sewerage improvement.

Due to this, the Kanamachi Purification Plant, which used Edogawa River as its source, became to receive many complaints and inquires from around 1972 regarding the "musty odor of the tap water", with the complaints surmounting close to 1,000 in one year (Figure 1).

The musty odor was caused from 2-Methylisoborneol which was created from cyanobacteria that had occurred in great quantity along with the rise in temperature in the Sakagawa River, a branch of Edogawa River where pollution had advanced leading to eutrophication. Also, ammonia nitrogen within the raw water that creates a chlorine-like odor became highly concentrated even in winter.

Due to this situation, it was decided to begin investigating the introduction of an advanced water treatment method with the goal of reducing ammonia nitrogen and also safely and effectively removing the causative agent of the musty odor, of which sufficient removal was difficult through normal treatment. In general, advanced water treatment includes ozonation, activated carbon treatment and biological treatment, and through these a treatment flow was verified that combined ozonation treatment and biological activated carbon(hereinafter referred to as "BAC treatment"), which are effective in removing the musty odor.

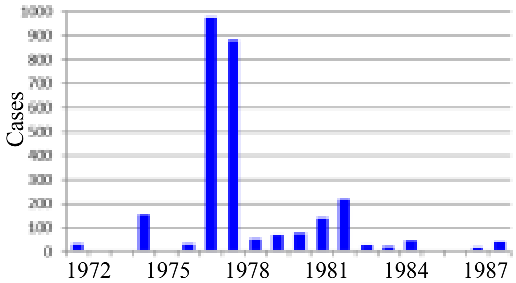


Figure 1: Amounts of complaints of musty odor in the areas supplied by Kanamachi

Table 1: Advanced water treatment facilities

Purification Plant	Water Resource	Facility Capacity (m^3 per day)	Scale of introduction (m^3 per day)
Kanamachi	Edogawa River, Tonegawa River Source	1,500,000	1st stage: 260,000
			2nd stage: 260,000
			3rd stage: 980,000
Misato	Edogawa River, Tonegawa River Source	1,100,000	1st stage: 550,000
			2nd stage: 550,000
Asaka	Arakawa River, Tonegawa River Source	1,700,000	1st stage: 850,000
			2nd stage: 850,000
Misono	Arakawa River, Tonegawa River Source	300,000	300,000
Higashi-Murayama	Arakawa River, Tonegawa River Source	880,000	880,000
Total	Tonegawa River Source	5,480,000	5,480,000

With the larger goal of commercializing new water treatments, a preliminary laboratory experiment was conducted in FY1983, and between FY1984 and FY1988 experiments were enforced that spanned six years including preliminary experiments. From this, the conclusion was reached that an advanced water treatment system that combines ozonation treatment and BAC treatment was effective. In June 1988 at Kanamachi Purification Plant it was decided to introduce a new water treatment that incorporated ozonation and BAC treatments in between the normal treatments of coagulation sedimentation and sand filtration.

In doing this, the introduction of advanced water treatment at all purification plants that were sourced from the Tonegawa River system proceeded sequentially. Construction of the advanced water treatment facilities began at Kanamachi Purification Plant in 1989, total advanced water treatment was 100% achieved in all purification plants sourced from the Tonegawa River system in FY2013 (Table 1).

Although having achieved 100% advanced water treatment and attaining a certain result regarding the goal of supplying safe and potable high-quality water, currently in total there are 206 BAC ponds. As activated carbon needs to be renewed every four years, the extremely huge amount renewed in a year was a problem, and it was expected to reach 16,000m^3 in FY2017 (Figure 2).

Due to this, a new verification was necessary that included costs and environmental burden, and so a verification was enforced concerning such things as the water treatment properties of plant-based activated carbon and recycled coal [1].

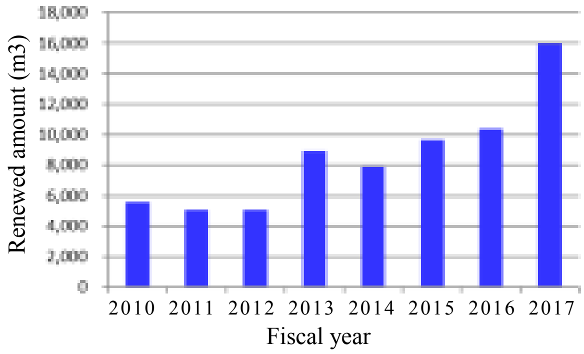


Figure 2: Amounts of granular activated carbon renewal

2. The approach to the adoption progress and renewal period of granular activated carbon

2.1 The approach towards the beginning of introduction

In activated carbon used in water treatment, there exists mainly two types: coal-based, and plant-based made from coconut shell.

In preliminary surveys at the beginning of introduction of advanced water treatments, Tokyo Waterworks is using coal-based activated carbon, of which the treatment is superior compared to plant-based activated carbon that uses coconut shell (pulverized coal). Furthermore Tokyo Waterworks uses activated carbon with a pitch diameter of 0.7mm at Asaka and Misono Purification Plants, where sand filtration is conducted in the first part of advanced water treatment. Then at Kanamachi, Misato and Higashi-Murayama Purification Plants, which don't conduct sand filtration in their first parts, activated carbon with a pitch diameter of 1.2mm is used.

At Kanamachi Purification Plant, of which Tokyo Waterworks first put into operation, on investigating the organic matter indicators UV260 and TOC, the decreasing rate of UV260 is practically 0% in the roughly seven years since water conduction began, and TOC became uniform, moving from 20% to 30% in around five years.

Additionally, ammonia nitrogen and anion surfactant after around seven years gain a higher frequency of leakage in winter, making them affect water treatment.

Based on these results, as a renewal policy for BAC ponds, in FY2000 it was decided when renewing with new charcoal to make the standard 7 to 8 years, as it is the period when adsorption ability remains.

Also, when granular activated carbon is recycled, the recycled coal standards of iodine adsorption at the time (over 850 mg/g) are able to be satisfied when it has been recycled/used up to five years. If longer than that, the degradation of activated carbon due to ozonation treatment will cause the yield when recycling to worsen and the recycling costs will increase. From this surveyed result, the usage period for new charcoal has been made around five years.

2.2 Changes in the renewal period

Within these circumstances bromate, which is a byproduct of ozonation treatment, was newly added to the water quality standards in their revision. From this, it became necessary to lower the ozone dosage, so BAC treatment became more important than ever before. Due to this, in situations where the renewal period is 7 to 8 years, it is feared whether the response is complete or not in regards to matter that requires risk reduction via adsorption capacity of granular activated carbon, such as pesticides and bromate.

On top of this, due to the heightened needs of customers for safe and palatable water, measures are needed in view of the reduction of residual chlorine concentration in water taps.

However, in the results of Asaka and Misato Purification Plants, that started operation of advanced water treatment after Kanamachi Purification Plant, the decreasing rate of UV260 within 4 to 5 years since water conduction began has mainly been 0%. Also the decreasing rate of TOC has seen gradual reduction and it transitioned to around 20-30% on the whole after the fifth year. In other words, it is inferred that up until four years of treatment by adsorption and biological degradation is possible, but from the fifth year treatment capacity of adsorption mainly disappears and only matter that can biologically degrade is able to be treated.

In order to reduce chlorine dosage at purification plants whilst securing necessary residual chlorine concentration in all water taps, it is necessary to reduce TOC as much as possible within water treatments as it is the cause of chlorine consumption. TOC was added to the water quality standard items from FY2004, and due to these points, in FY2009 the renewal period of granular activated carbon was made four years, before the complete disappearance of the adsorption capacity.

Furthermore, it was decided that when recycling granular activated carbon, the renewal period will be decided after obtaining knowledge regarding the usage period up until recycling, recycling yield and water treatment properties.

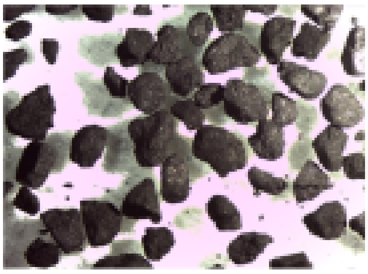
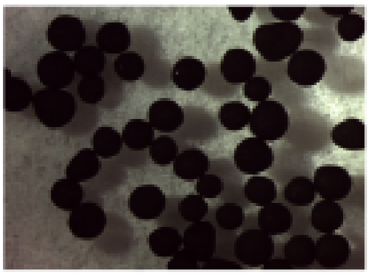
3. Plant-based activated carbon

3.1 The merits of introduction

From the viewpoint of carbon neutral, when produced, plant-based activated carbon discharges only 1/4 [(2)] of the CO_2 that coal-based activated carbon does, allowing it to contribute to reduced environmental burden.

Additionally, plant-based activated carbon has higher levels of “hardness” in its physical properties when compared to coal-based activated carbon, and has the possibility to gain excellent yield when recycled. Enforcing the recycling of granular activated carbon also contributes to reduction in waste volume and renewal costs (Table 2).

Table 2: Coal-based and plant-based activated carbon

Coal-based (pulverized coal)	Plant-based (granulated coal)
2-50mm pores develop and adsorb matter of a wide range of molecular weight. 	Pore distribution is close to coal-based activated carbon, so equivalent treatment is expected. 

Furthermore, unlike coal-based activated carbon, plant-based activated carbon has no risk of elution of heavy metals such as arsenic, and also as coconut shell, its raw material, is a non-depleting resource, it is possible to produce consecutively, and risk reduction at time of procurement is possible by using in combination with a coal-type. These are some of the many merits attributed to the introduction of plant-based activated carbon.

3.2 Trial introduction at Higashi-Murayama Purification Plant

In the beginning, after verifying the water treatment properties and physical properties of plant-based activated carbon through the experimental facilities from FY2007, it was confirmed that plant-based activated carbon was mostly equivalent to coal-based activated carbon [3].

So in order to verify the introduction into actual facilities, plant-based activated carbon had a trial introduction at one of the BAC ponds at Higashi-Murayama Purification Plant in FY2010. The standard of plant-based activated carbon has the pitch diameter at 1.2mm, the same as coal-based, and the uniformity coefficient less than 1.3.

The transitions of the removal rate of TOC from when it began water conduction is shown in Figure 3, and those of UV260 are in Figure 4.

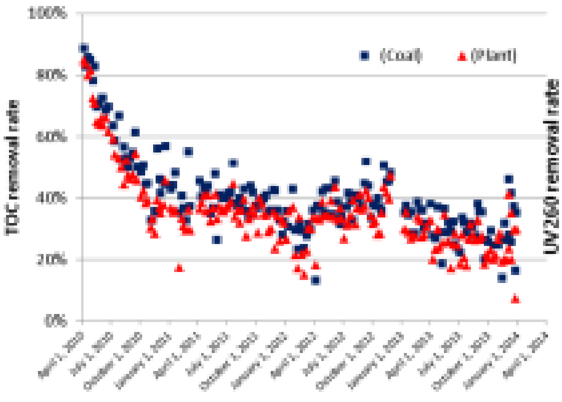


Figure 3: Treatment of organic matter (TOC)

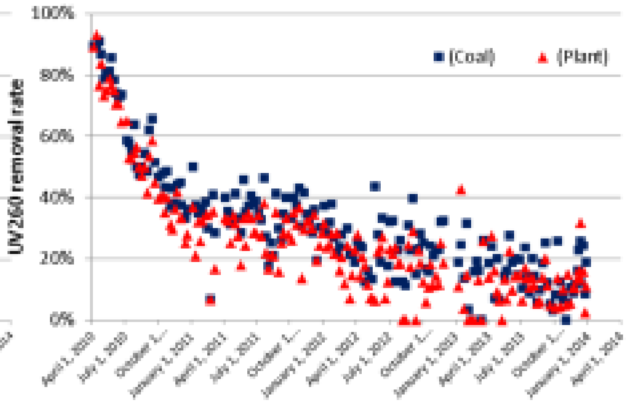


Figure 4: Treatment of organic matter (UV260)

For both of them the removal rate suddenly declined around one year after water conduction began. However, because not only TOC's function of adsorbing activated carbon but also its biological decomposing removal is effective, the removal rate after a year is inferred to be higher than UV260. From these results, it was confirmed that even in actual facilities the treatment of both TOC and UV260 has no large differences between coal-based and plant-based activated carbon.

In addition, in terms of the transition of ammonia nitrogen removal rate both at the beginning of activated carbon introduction and after the prechlorination stoppage from the second year onwards, the results from comparing plant-based and coal-based are shown in Figure 5. The conversion to BAC at the beginning of introduction was around a month earlier in plant-based activated carbon compared to coal-based activated carbon, but after the prechlorination stoppage both immediately showed ammonia removal, and from the second year onwards that trend was not able to be seen.

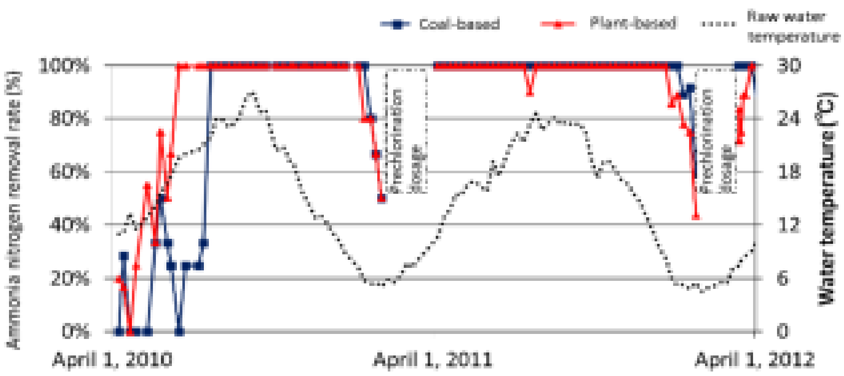


Figure 5: Treatment of ammonia nitrogen

Furthermore, the survey results of physical property changes of coal mining every year since beginning of water conduction are shown in Table 3. Moreover, testing of each item was enforced conforming to testing methods of activated carbon [4]. Iodine adsorption and methylene blue number, that are indicators that show adsorption capacity, outperform in plant-based activated carbon directly after water conduction begins, however are 22 months they become equivalent to coal-based activated carbon.

Table 3: Results of physical property tests

	Unit	New charcoal standards: Coal-based	New charcoal standards: Plant-based	Coal-based				Plant-based			
Elapsed time	months	-		0	10	22	34	0	10	22	34
Pitch diameter	mm	1.2±0.05		1.2	1.1	1.0	1.0	1.2	1.1	1.1	1.0
Uniformity coefficient	-	Below 1.3		1.3	1.4	1.4	1.4	1.3	1.4	1.4	1.4
Particle size	%	0.85-2.00mm Over 90 mass fraction %		96.4	97.9	97.0	97.3	99.1	98.9	99.5	98.2
Hardness	%	Over 90	Over 95	97	94	93	90	97	96	95	94
Packing density	g/mL	0.4-0.5		0.45	0.47	0.49	0.52	0.43	0.44	0.47	0.51
Iodine adsoprtion	mg/g	1,000	1,100	1,040	740	640	540	1,200	880	630	450
Methylene blue number	mL/g	180	200	190	160	150	110	250	190	160	120

On top of this, based on the status of operation management (the conditions of rising head loss of water and the expansion rate when washing) at Higashi-Murayama Purification Plant, it was confirmed that there were no problems in the plant's operation, and from this the verification of other purification plants was begun. Trial introductions were begun at Kanamachi Purification Plant from FY2012, at both Misato and Asaka Purification Plants from FY2013, and at Misono Purification Plant from FY2015. Yet at Asaka and Misono Purification Plants, where sand filtration was conducted before advanced water treatment, as the pitch diameter of coal-based activated carbon was 0.7mm and the uniformity coefficient was below 1.7, it was technically difficult to produce granulated coal of the same size, and so the pitch diameter of plant-based activated carbon was made 0.9mm and its uniformity coefficient was made below 1.5.

At the end of FY2017, BAC ponds that had trial-introduced plant-based activated carbon included 5 ponds at Higashi-Murayama Purification Plant (including ponds that introduced recycled coal), 7 ponds at the Kanamachi plant, 5 ponds at the Misato plant, 7 ponds at the Asaka Purification plant, and 2 ponds at the Misono Purification plant. From now, as well as the water treatment and maintenance after four years, further verification will be carried out concerning the first part of filtration and the effects of differing raw water quality.

4. Recycled coal

4.1 Trial introduction at Higashi-Murayama Purification Plant

For the efficient use of resources and the reduction of renewal costs, the verification for the full-scale introduction of recycled coal has begun.

First the two BAC ponds where it was introduced at Higashi-Murayama Purification Plant in FY2010 (1 coal-based pond and 1 plant-based pond) were recycled in FY2014, and the treatment of organic matter and the operation manageability was investigated along with two BAC ponds of new coal (1 coal-based pond and 1 plant-based pond) .

4.2 Results of trial introduction

From when it began water conduction, the treatment of TOC and UV260 had no difference between 4 ponds.

In addition, for the transition of the removal rate of ammonia nitrogen of new charcoal in FY2010, as mentioned before in Figure 5, the conversion to BAC of plant-based was around a month early, but for recycled coal the removal rate achieved 100% mainly at the same time.

Furthermore, the survey results of physical property changes of aged coal and recycled coal (both coal-based and plant-based), which began water conduction four years ago, in regards to both coal-based and plant-based, a hearing with makers took place based on the standards of the Japan Water Works Association, and they satisfy the criteria of the recycling standards of Tokyo Waterworks. Moreover, for the recycling yield, coal-based was 71% and plant-based was 75%, with plant-based slightly outperforming.

Upon receiving these results, because it was confirmed that recycled coal had no big difference when compared to new charcoal, trial introductions at other purification plants were also sequentially expanded, and there were 4 ponds for FY2015, 6 for FY2016, and 8 for FY2017.

5. Conclusion

As mentioned above, in verifying the results of UV260, TOC and physical property tests, it was confirmed that there are no big differences in water treatment and operation manageability in both plant-based activated carbon and recycled coal when compared with coal-based activated carbon.

Based on the heightening of customer needs in water quality and appropriate response to raw water quality, Tokyo Waterworks has also thus far actively accelerated the introduction of new technologies, such as introducing advanced water treatment in all purification plants sourced from the Tonegawa River system.

From here on as well, in order to fulfill the fundamental mission of the business of stably supplying high quality water that is safe and palatable, Tokyo Waterworks will promote proper actions that fulfill the needs of the times.

After trial introductions at Higashi-Murayama Purification Plant in FY2010, in the operation of plant-based activated carbon at actual facilities, and so far it has been introduced at 26 ponds, which is around 10% of BAC ponds.

Also for recycled coal, after trial introductions at Higashi-Murayama Purification Plant in FY2014, it has been introduced in 20 ponds so far. From here on as well, data gathering and analysis will be conducted, and verification for full-scale introduction from now is going to be pushed.

From now, in order to establish an operation method for granular activated carbon that is more effective and also considers the environment, the decision of full-scale introduction of both plant-based activated carbon and recycled coal will be comprehensively decided upon based on production cost, supply capacity, as well as the improvement of recycling technology.

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