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Improvement of Water Quality by using Wood–Based Activated Carbon Fibers

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This study was examined the preliminary safety of water specimens from the water source of the purification plant first by Ames test and then used the Wood–Based Activated Carbon Fibers (WACFs) as an absorbent with two water purification methods to evaluate the water quality improvement. The water specimens' safety showed that neither cytotoxicity nor mutagenicity toward *Salmonella typhimurium* TA98 and TA100 with or without S9 mixture had no any cytotoxicity and mutagenicity. The turbidity and total hardness of the water improved by prepared WACFs were 0.37–1.60 NTU and 292.00–136.68 mg/L as $CaCO_3$, respectively, meeting the quality standard for drinking water in Taiwan. The pH value in water was increased by WACFs filtration or standing in solution, and after processing was about 9.55–10.02. The maximum percent removal of sodium nitrite standard solution 0.1 μg/mL at 2 hours of standing time after processing with WACFs was about 34.5%. The total bacterial count, and *Escherichia coli* and coliform group were achieved the drinking water standards in Taiwan by microbiological analysis with the standing method for over 30 min. It is suggested that the WACFs; therefore, can be as the absorbent of water purification for the water quality improvement.

Key words: Wood–Based Activated Carbon Fibers (WACFs), Ames Test, Water Quality Improvement

INTRODUCTION

Activated carbon (AC) is one type of good adsorbent for gaseous and liquid adsorption and is widely applied in purification, de–colorization, removal of toxic substances, and treatment of waste water (Liu, 1998; Manocha, 2003; Yorgun *et al*., 2009; Sun and Jiang, 2010). This is because AC is a porous adsorbing material with nonpolar surface and is effective in adsorbing organic matter from water solution (Tomaszewska and Mozia, 2002; Przepiorski, 2006; Villacan *et al*., 2006). Moreover, AC is effective on the turbidity and chromaticity of the physical standards for drinking water (Anu *et al*., 2006), and has inhibitory effect on total bacterial count and coligroup in water (Ogawa *et al*., 2011). In general, AC is classified into 5 types by size (dimension), shape (appearance), and purpose (Liu, 1998). Among all, activated carbon fibers (ACFs) are regarded as the fibrous and porous material with a large specific surface area, a high adsorption capacity, and the ability to regenerate through absorption/desorption (Asakura *et al*., 2004).

Previous work established that Wood–Based Activated Carbon Fibers (WACFs) could be prepared by physical methods with steam activation from Nadelholz/Laubholz Unbleached Kraft Pulps and cardboard from recycled cartons. The iodine values and methylene blue adsorption value of WACFs were 635.45–1077.72 mg/g and 268.33–504.03 (mg/g), respectively, which can be prepared into AC with multiple mesopores, and used as functional water purifying material (Huang *et al*., 2010). Lin *et al*. (2015a) reported that the biological action of WACFs was evaluated by *Salmonella* mutagenesis assay (Ames test), indicating that the WACFs had no cytotoxicity or mutagenicity in the test range (1.0–5.0 mg/plate of WACFs). The antimutagenicity against strains for the WACFs also suggested the safety of the WACFs used primarily as a material for food use. Furthermore, Lin *et al*. (2015c) reported that WACFs produced no systematic poison for the experimental animals in a 28–day feeding study of Sprague–Dawley rats, and the atoxic dose was higher than 5.0 g/kg, suggesting WACFs prepared from wood pulps and recycled cartons can be a potential type of food moisture–proof material and a potential type of material for water purification.

In Taiwan, tap water is from groundwater, reservoirs, and rivers (Shiu, 2000), and all water sources must conform to the Water Quality Standard for Drinking Water Sources (EPA, 1997), before it can be used as a water source of tap water. If the raw water of tap water is severely polluted, there may be mutagenicity increasing the probability of cell mutation. In general, gene mutation caused by chemical substances can be tested by the Ames Tests (Ames *et al*., 1975; Maron and Maron, 1983). Monarca *et al*. (1983) and Marguerite *et al*. (1986) also reported that AC could reduce the mutagenicity of water

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to different extents. The water source of tap water then has to be purified by waterworks and conform to the water quality standard for drinking water, as specified by the Environmental Protection Administration (EPA) of Executive Yuan (2013c), before it is supplied as domestic water for the public.

This study used the WACFs, prepared with the conditions of physical activation with steam at an 850°C activation temperature with 60 min of activation time from Laubholz Unbleached Kraft Pulp (Huang *et al*., 2010; Lin *et al*., 2015a; Lin *et al*., 2015b), to evaluate the application in water quality improvement because the WACFs have better porosity and adsorption ability as seen from previous results (Lin *et al*., 2015a). The preliminary safety of cytotoxicity and mutagenicity of the Ames Test for water quality before processing was also investigated. Hopefully, the WACFs prepared from the study can be as the absorbent of water purification for the water quality improvement.

MATERIALS AND METHODS

Specimen

Wood–Based Activated Carbon Fibers (WACFs)

The precursor, 20 g of absolute dried Laubholz Unbleached Kraft Pulps (LUKP, a wood pulp, paperboard was provided by the Hou–li Mill, Cheng Loong Corporation in Taiwan) specimen, was prepared in a closed container of super–high temperature vacuum carbonization activation equipment (Chi–How Heating Co., Ltd.). The prepared WACFs code was 850 LUKP WACFs and the preparation conditions and the characteristics of 850 LUKP WACFs refer to (Lin *et al*., 2015a).

Source of water specimen

The raw water from the water source of the Kinmen County Ronghu purification plant, and the slow filter water in front of the activated carbon filter (slow filter) following the water purification procedure of the Ronghu purification plant were used as the blank group (Blank). The raw water and the slow filter water were obtained on May 27, 2014.

Test strains

Salmonella typhimurium, including TA98 and TA100, was bought from the Bioresource Collection and Research Center, Food Industry Research and Development Institute.

Rat liver mixture

The rat liver mixture (S9 mix) (Organ Teknika Co., Switzerland) was prepared from Sprague–Dawley male rats treated with Aroclor 1254.

Methods

Preliminary safety test for water quality

Referring to the Ames Test, as proposed by Ames *et al*. (1975), Waleh *et al*. (1982), the *Salmonella typhimurium* TA98 and TA100 were used as test strains. The phosphoric acid buffer solution was used as the blank group (Control), and each water specimen before improvement by WACFs was repeated to calculate the colony counts. The test details and the result evaluations of cytotoxicity testing and mutagenicity test refer to (Lin *et al*., 2015a).

Water purification methods

Filtration with only 400 mesh screening net (with only 400 mesh) was as a control to compare with two methods as follow.

Standing method: the WACFs and the water specimens of raw water or slow filter water were mixed by a weight ratio of 1: 10 (wt%), and kept still for 30, 60, and 120 min, respectively (Zhou and Lu, 2010; Lin *et al*., 2015b), before water testing;

Filtration method: the WACFs was placed in a glass funnel, the raw water or slow filter water flowed from the top to the bottom under gravity, and were controlled by valve; the flow velocity was 10±2 mL/min (Ogawa *et al*. 2011), 20±2 and 30±2 mL/min. The weight ratio of WACFs to raw water or slow filter water was 1: 10 (wt%) (Lin *et al*., 2015b).

Water tests

Turbidity is caused by the suspended substances in water, including fine colloidal particles to coarse and dispersed suspended particles (Shi, 2003). The turbidity was tested by the water turbidity detection method – turbidimetric method, as published by EPA (NIEA W219.52C, 2005).

The pH value specified by the water quality standard for drinking water is 6.0–8.5 in Taiwan. The pH value was measured by the inwater hydrogen ion concentration measuring method – electrode method, as published by EPA (NIEA W424.52A, 2008).

Taiwan's water quality standard for drinking water restricts the total hardness, and the value is 300 mg/L (calculated by $CaCO_3$). The total hardness was tested by the inwater total hardness detection method – Ethylenediaminetetracetic acid (EDTA) titration, as published by EPA (NIEA W208.51A, 2006). The equation was total hardness (represented by $CaCO_3$, mg/L) = $A \times B \times 1000/V$, where A is the titration volume of EDTA for water specimen titration minus titration volume of Blank; V is the water specimen volume (mL); B is the milligrams of $CaCO_3$ equivalent to 1 mL EDTA volumetric solution.

The nitrite nitrogen was tested by the inwater nitrite nitrogen detection method – spectrophotometry, as published by EPA (NIEA W418.52C, 2013b). The equation is nitrite nitrogen concentration (mg/L) = $A \times 50/V$, where A is the concentration value (mg/L) measured by calibration curve; V is the water specimen volume (mL). The sodium nitrite standard solution 0.1 μg/mL was used to discuss the changes in the content adsorbed by WACFs.

The total bacterial count was tested by the inwater total bacterial count detection method – mixed dilution method, as published by EPA (NIEA E204.55B, 2013a). The equation is total bacterial count (CFU/mL) = total colony counts in the selected culture dish/sum of actual volumes of water specimens in the selected culture dish.

The *Escherichia coli* (*E. coli*) and coliform group was tested by the commercial quick test method, namely, Chromocult coliform was used to quickly test the aerobic or facultative anaerobic, gram–negative, and asporulate

coliform group. The equation was count of *E. coli* and coliform group (CFU/100mL) = [(red colony + violet colony) × 100] / water specimen volume × extension rate.

Statistical analysis

The results are represented by mean (standard deviation). The statistical analysis was conducted using SPSS 12 (Statistical Product and Service Solutions) and Duncan's multiple range test ($\rho<0.05$). Different letters represent significant difference, while the same letter (same subset) represents no significant difference.

RESULTS AND DISCUSSION

Preliminary safety of water quality

Cytotoxicity

Ames *et al*. (1975) reported that for screening of environmental mutagens and carcinogens, the Ames test (Preliminary safety), a convenient method to evaluate mutagenic activities of these chemicals, has been developed, and McCann *et al*. (1975) and Shugimura *et al*. (1976) have suggested that the mutagenic activities of a number of chemicals correlate well with the carcinogenic activities. Waleh *et al*. (1982) indicated that the amount of residual bacteria of *Salmonella typhimurium* must be over 80% of the control group to determine that the test group has no cytotoxicity for *Salmonella typhimurium*.

The cytotoxicity of raw water and slow filter water specimens for *Salmonella typhimurium* TA98 and TA100 strains with either rat liver enzyme mixture (with S9 mix; an external metabolic activation system) or zero S9 mix (without S9 mix) was tested. The rat liver enzyme mixture is one of the enzymes in a rat liver mixture is the rat liver cell extract. This enzyme is added to simulate the intravital metabolism of organisms and used in the Ames tests of the water specimens. The results are as shown in Table 1. The bacterial count of Control without S9 mix was 1268 in TA98, 717 in TA100; the TA98 with S9 mix was 3658, TA100 was 2551. The bacterial count of raw water specimen without S9 mix was 1206 in TA98, and 1014 in TA100. Survival (residual bacteria rates, %) was 95–141%. The TA98 with S9 mix was 3360, and TA100 was 2611. Survival was 91–102%. Survival of slow filter water specimen without S9 mix was 104–105% in TA98 and TA100, while that with S9 mix was 95–102%. The Survival of the raw water and slow filter water specimens with either S9 or zero S9 mix is all higher than 80%. The water specimens; therefore, have no cytotoxicity.

Mutagenicity

The mutagenicity is analyzed by using the method proposed by Maron D. and Maron B. (1983). Ames *et al*. (1975) reported that the number of spontaneous revertants induced by the specimen is less than for the control group (Control) by more than two times; the specimen has no mutagenicity. The results of mutagenicity of raw water and slow filter water specimens are as shown in Table 2. The revertants of Control without S9 mix were 33 in TA98, 170 in TA100; the TA98 with S9 mix were 38, TA100 was 184. The revertants of raw water and slow filter water specimens without S9 mix were from 32 to 33 in TA98, and from 163 to 167 in TA100. For both water specimens, the TA98 and TA100 with S9 mix were from 34–186. The revertants of *Salmonella typhimurium* TA98 and TA100 induced by raw water and slow filter water specimens, with and without the S9 mix, had not exceeded two times the spontaneous revertants of Control, meaning the raw water and slow filter water had no mutagenicity.

In this study, the 850 LUKP WACFs (WACFs) were prepared from Laubholz Unbleached Kraft Pulp with the method of physical activation with steam. Lin *et al*. (2015a) reported that the Survival (%) for *Salmonella typhimurium* TA98 and TA100, with or without the S9

Table 1. Cytotoxicity of water specimen for raw water and slow filter water toward *Salmonella typhimurium* TA98, TA100 with or without S9 mixture

Water specimen	Number of bacteria/plate (Survival, %) [1]			
	TA98		TA100	
	Without S9 mix			
Control [2]	1268 ± 39	(100.0) [3]	717 ± 58	(100.0)
Raw water [4]	1206 ± 65	(95.1)	1014 ± 203	(141.4)
Slow filter water [4]	1319 ± 34	(104.1)	751 ± 212	(105.7)
	With S9 mix			
Blank	3658 ± 175	(100.0)	2551 ± 81	(100.0)
Raw water	3360 ± 572	(91.9)	2611 ± 44	(102.4)
Slow filter water	3733 ± 25	(102.1)	2424 ± 97	(95.0)

[1] Survival (%) = [(the bacterial count of test group / the bacterial count of control group)] * 100

[2] Control: only with phosphate buffer saline (control group)

[3] Each value is expressed as mean ± S.D. (n = 3); values in parentheses are percentages relative to Control (100%).

[4] The raw water and the slow filter water were obtained from the water source of the Kinmen County Ronghu purification plant on May 27, 2014

Table 2. Mutagenicity of water specimen for raw water and slow filter water toward *Salmonella typhimurium* TA98, TA100 with or without S9 mixture

Water specimen	His$^+$ revertants/plate (Mutagenicity ratio, MR) [1]			
	TA98		TA100	
	Without S9 mix			
Control [2]	33 ± 4	(1.00) [3]	170 ± 6	(1.00)
Raw water [4]	33 ± 3	(0.99)	163 ± 20	(0.95)
Slow filter water [4]	32 ± 4	(0.96)	167 ± 22	(0.98)
	With S9 mix			
Control	38 ± 3	(1.00)	184 ± 11	(1.00)
Raw water	34 ± 2	(0.91)	186 ± 6	(1.01)
Slow filter water	36 ± 3	(0.96)	183 ± 2	(0.99)

[1] MR (Mutagenicity ratio) = induced revertants per plate/spontaneous revertants per plate (Control)
[2], [3], [4] see Table 1

mix in the test range (1.0–5.0 mg/plate of WACFs), were all higher than those of a Blank (Control) by more than 80%, and the WACFs for TA98 and TA100 with or without S9 mix did not exceed spontaneous revertants by more than two times, indicating the WACFs had no cytotoxicity or mutagenicity. Lin *et al*. (2015b) also reported that the 850 LUKP WACFs is in the dose range (1.0, 2.5, and 5.0 g/kg/day) of biological safety assessment. The WACFs; therefore, has the function of water purification, and can be preliminarily regarded as a safe natural water purifying material.

Evaluation of water purification

Turbidity

Generally, the turbidity of a water specimen is determined by the ratio of the reference standard turbidity suspension of the water specimen to the intensity of specific scattered light, and the unit is Nephelometric Turbidity Unit (NTU) (EPA, 2013c). Table 3 showed the results of turbidity of the raw water and slow filter water purified by the filtration methods with WACFs. The raw water (Blank) turbidity was 3.42–3.43 NTU, and the slow filter water (Blank) was 0.72–0.74 NTU. The turbidity of the raw water was reduced to 1.84–1.34 NTU after the methods with 400 mesh only or the standing method with 30, 60 and 120 min; the turbidity of slow filter water was reduced to 0.66–0.37 NTU. The turbidity of raw water treated by the filtration method with 10, 20 and 30 mL/min was reduced to 1.82–1.42 NTU; the turbidity of the slow filter water was reduced to 0.64–0.39 NTU.

Table 3. Turbidity of water specimen for raw water and slow filter water after processing by standing and filtration method with wood–based activated carbon fibers

Water purification methods		Turbidity (NTU) [1]	
		Raw water [2]	Slow filter water [2]
Standing Method	Blank [3]	3.43 ± 0.14 [a 4)]	0.74 ± 0.09 [a]
	With 400 mesh only	1.84 ± 0.15 [b]	0.66 ± 0.13 [a]
	30 min	1.60 ± 0.05 [c]	0.62 ± 0.03 [a]
	60 min	1.58 ± 0.01 [c]	0.52 ± 0.03 [a]
	120 min	1.34 ± 0.03 [d]	0.37 ± 0.06 [a]
Filtration Method	Blank	3.42 ± 0.15 [a]	0.72 ± 0.09 [a]
	With 400 mesh only	1.82 ± 0.11 [b]	0.64 ± 0.14 [a]
	10 mL/min	1.59 ± 0.05 [c]	0.61 ± 0.01 [a]
	20 mL/min	1.60 ± 0.01 [c]	0.50 ± 0.04 [a]
	30 mL/min	1.42 ± 0.03 [d]	0.39 ± 0.06 [a]

[1] Turbidity of water quality standard for drinking water source is no standard; Turbidity of water quality standard for drinking water is 2.0 NTU (EPA, 2013c)
[2] The raw water and the slow filter water were obtained from the water source of the Kinmen County Ronghu purification plant on May 27, 2014
[3] Blank: water specimen is raw water or slow filter water that unprocessed with any WACFs
[4] Each value is expressed as mean ± S.D. (n = 3) by Duncan's multiple range tests, significant differences in data are represented by $p < 0.05$ between row sited by different alphabets

According to the results of Duncan's multiple range tests, the WACFS processed results of different standing periods had significant difference, but not for the filtration method with different filtration flow velocities. It is indicated that the WACFs is influenced by the standing method when purifying water, and the water turbidity decreases as the time extends decreases, but not for the flow velocity. The water quality standard for drinking water specifies turbidity as 2.0 NTU (EPA, 2013c). It is suggested that the raw water specimen is processed by WACFs the standing method with different standing periods can reach the water quality standard for drinking water.

pH value

The pH value increases because when the AC is heated, the carbon single bonding forms double bonding when the hydrogen atom is removed from the precursor surface (Zhu *et al*., 2012). The surface is likely to form multiple basic functional groups, such as the oxygen–containing functional group formed by the oxygen transfer of C–CO_2 or C–H_2O reaction, when the activation temperature is higher than 800°C (Park and Kim, 2001; Zhu *et al*., 2012). The results of pH value of raw water and slow filter water specimens after processing are as shown in Table 4. The raw water pH value (Blank) was 7.26–8.50, and the pH value after with 400 mesh only or WACFs he standing method with 30, 60 and 120 min increased to 7.30–9.55. The slow filter water pH value was 7.50–8.03, and the pH value after WACFs standing was 7.48–10.02. The pH value also increased after filtration by 400 mesh only or WACFs at different flow velocities. The pH value of the filtered raw water specimen was 8.50–9.73, that of the slow filter was 7.98–9.62. The pH value after the processing by WACFs in this test is higher than the water standard (6.0–8.5) in Taiwan. This is because the pH value after the process by the AC filter tank of the purification plant increases. Anu *et al*. (2006) reported that the subsequent process of the general water treatment plant can make water quality meet the standard.

Total hardness

Table 5 showed the total hardness of raw water was 217.07–249.76 mg/L and that of slow filter water was 206.99–229.25 mg/L. The total hardness of water specimens for this test is about in the range. The total hardness of raw water from various reservoirs in Kinmen is 58.1–248 mg/L (Construction and Planning Agency, 2005). Table 5 also shows the changes in the total hardness of raw water and slow filter water specimens purified by the standing method with WACFs or with 400 mesh only. The total hardness of raw water was reduced to 236.09–136.68 mg/L (calculated by $CaCO_3$), and the slow filter water had the same result, about 236.09–142.90 mg/L. The filtration method also reduced the raw water of total hardness to 203.17–137.84 mg/L, and the slow filter water had the same result, about 212.95–173.11 mg/L. It is suggested WACFs can soften water by the standing or filtration method. In general, the amount of multivalent metal cations of Ca^{2+}, Mg^{2+}, Sr^{2+} and Fe^{2+} in water is the factor determining water hardness, too hard water is inapplicable to industry, and it influences the taste of drinking water (Chang, 2006). McCafferty *et al*. (2000) and Lee *et al*. (2003) indicate that the inorganic substance is likely to exchange ions with the carbon surface functional groups, and form the complex for absorption. Therefore, when WACFs is prepared by a high temperature steam activation, due to the oxygen transfer of C–H_2O reaction and the formation of oxygen–containing and basic functional groups on the carbon surface, it can reduce the total hardness in water during water treatment. The basic functional groups on the surface increase with the activation temperature, which is helpful to reducing the total hardness of water.

Nitrite nitrogen

Nitrite nitrogen is listed as an unhealthy material in

Table 4. pH value of water specimen for raw water and slow filter water after processing by standing and filtration method with wood–based activated carbon fibers

Water purification methods		pH value [1]	
		Raw water [2]	Slow filter water [2]
Standing Method	Blank [3]	7.26 ± 0.08 [c 4]	7.50 ± 0.05 [c]
	With 400 mesh only	7.30 ± 0.20 [c]	7.48 ± 0.05 [c]
	30 min	9.92 ± 0.06 [a]	10.02 ± 0.06 [a]
	60 min	9.99 ± 0.02 [a]	9.97 ± 0.01 [a]
	120 min	9.55 ± 0.09 [b]	9.75 ± 0.09 [b]
Filtration Method	Blank	8.50 ± 1.24 [a]	8.03 ± 0.06 [c]
	With 400 mesh only	8.50 ± 1.29 [a]	7.98 ± 0.10 [c]
	10 mL/min	9.90 ± 0.06 [a]	9.85 ± 0.16 [a]
	20 mL/min	9.79 ± 0.02 [a]	9.75 ± 0.08 [ab]
	30 mL/min	9.73 ± 0.01 [a]	9.62 ± 0.12 [b]

[1] pH value of water quality standard for drinking water source is no standard; pH value of water quality standard for drinking water is 6.0–8.5 (EPA, 2013c)

[2), 3), 4)] see Table 3

Table 5. Total hardness content of water specimen for raw water and slow filter water after processing by standing and filtration method with wood–based activated carbon fibers

Water purification methods		Total hardness (mg/L as $CaCO_3$)[1)]	
		Raw water [2)]	Slow filter water [2)]
Standing Method	Blank [3)]	249.76 ± 03.73 [b]	229.25 ± 01.86 [b]
	With 400 mesh only	236.09 ± 2.15 [c]	236.09 ± 2.15 [a]
	30 min	292.00 ± 5.69 [a]	210.00 ± 2.15 [c]
	60 min	136.68 ± 8.61 [e]	142.90 ± 2.15 [c]
	120 min	180.17 ± 8.61 [d]	208.75 ± 3.73 [b]
Filtration Method	Blank	217.07 ± 7.78 [a]	206.99 ± 5.18 [b]
	With 400 mesh only	203.17 ± 0.47 [b]	212.95 ± 6.48 [a]
	10 mL/min	137.84 ± 6.48 [e]	173.11 ± 7.77 [d]
	20 mL/min	153.87 ± 5.18 [d]	178.60 ± 2.59 [c]
	30 mL/min	190.97 ± 9.07 [c]	207.45 ± 3.89 [b]

[1)] Total hardness content of water quality standard for drinking water source is no standard; Total hardness content of water quality standard for drinking water is under 300 mg/L as $CaCO_3$ (EPA, 2013c)
[2), 3), 4)] see Table 3

the water quality standard for drinking water. If it enters human body, it is rapidly reduced to nitrite and generates carcinogenicity. The nitrite nitrogen or nitric nitrogen; therefore, is regarded as a water pollution index, and drinking water quality standards have close restraints for nitrite nitrogen and nitric nitrogen (EPA, 2013c). The nitrite nitrogen concentration in the raw water and slow filter water of this study was not detected. Therefore, this study used sodium nitrite standard solution 0.1 μg/mL in the standing method to discuss the changes in the content adsorbed by WACFs. The results are as shown in Fig. 1. The sodium nitrite standard solution 0.1 μg/mL after standing filtration with 0 (control), 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 h was reduced to 0.08 μg/mL below. According to the results of Duncan's multiple range tests, the WACFS processed results of different standing periods had significant difference. It is said that WACFs can adsorb nitrite nitrogen, which is possibly due to the basic (alkaline) functional group (Cabal *et al.*, 2009; Nunell *et al.*, 2012).

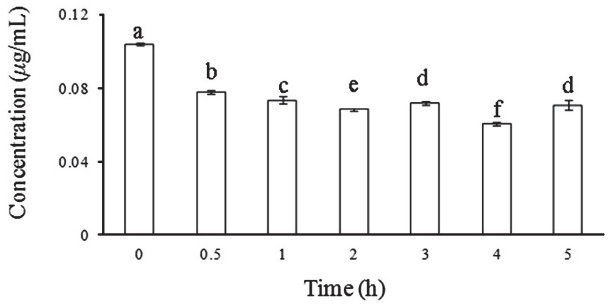

Fig. 1. Content change of sodium nitrite standard solution (0.1μg/mL) during different standing time after processing with wood–based activated carbon fibers.
Note Each value is expressed as mean ± S.D. (n = 3). Means with-different superscript letters are significantly different at $p < 0.05$.

Total bacterial count and E. coli and coliform group

Figure 2 showed the results of total bacterial count and *E. coli* and coliform group of raw water and slow filter water specimens, as filtered by the standing and filtration methods with WACFs. The total bacterial count of raw water was 38–39 CFU/mL, the total bacterial count decreased significantly after standing, and the total bacterial count in water was able to be reduced by 94.7–86.8% after 30 min WACFs standing for raw water and slow filter water. After 120 min WACFs standing the total bacterial count of raw water and slow filter water was 12 and 20 CFU/mL (upper left Fig. 2), conforming to the water quality standard for drinking water, 20 CFU/mL. For the filtration method, the total bacterial count of raw water was 22 CFU/mL, and slow filter water was 26 CFU/mL (upper right Fig. 2) that was able to be reduced by 35.2–25.6%. Uraki *et al.*, (2008) report that the AC filtration and standing process are effective methods to reduce the total bacterial count in water, because the active mechanism is that the strongly alkaline solution condition is presented in AC to cause bacteria death and the bacteria are adsorbed in the AC.

The *E. coli* and coliform group are 20 CFU/mL in the water quality standard for drinking water sources, and 0.06 CFU/mL in the water quality standard for drinking water (EPA, 2013c). The results (Fig. 2) of them in raw water and slow filter water for this test were 17 and 16 CFU/mL, respectively, for the method with 400 mesh only. The raw water and slow filter water filtered by WACFs and standing method was 0 CFU/mL (lower left Fig. 2). For the filtration method, the raw water and slow filter water was 27 and 45 CFU/mL, respectively; after WACFs filtration with 10, 20 and 30 mL/min was reduced to 0 CFU/mL for the raw water, but 20–26 CFU/mL for the slow filter water (lower right Fig. 2).

According to the above results, the standing or fil-

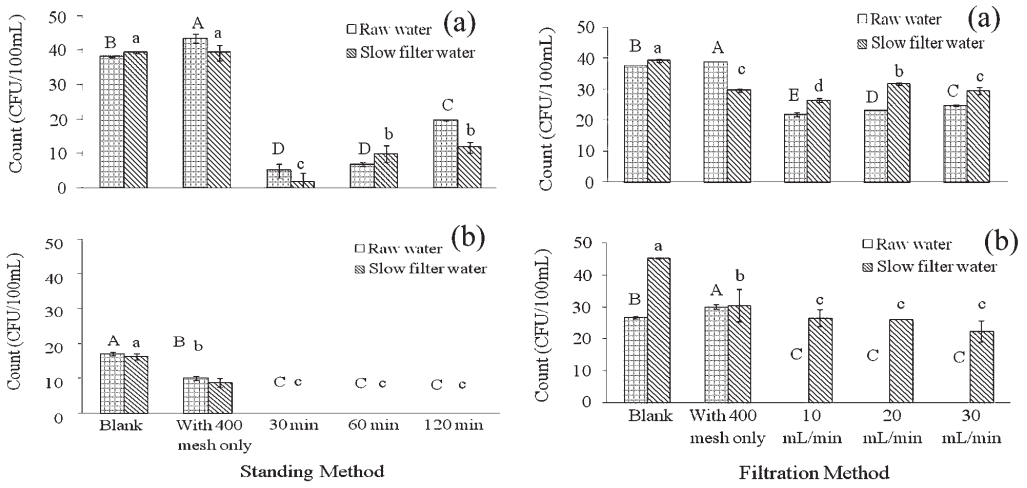

Fig. 2. Microorganism of water specimen for raw water and slow filter water after processing by standing and filtration method with wood–based activated carbon fibers.
Note (a) Total bacterial count (b) *E. coli* and coliform group.

tration method of WACFs showed that the total bacterial count and the *E. coli* and coliform group in water increased slightly with the WACFs contact time (standing time or filtration flow velocity). Liao *et al*., (2013) reported that the AC pores are adsorptive and developed; it is advantageous to the adhesion and growth of microorganisms, and the colonies increase in the activated carbon with the filtration or standing time. Therefore, the AC filter is mostly followed by the ozone sterilization procedure in order to control the quantity of aquatic microorganisms in the water purification procedure of the purification plant (Chen and Chang, 2005).

CONCLUSIONS

This study used LUKP as the precursor to prepare WACFs (850 LUKP WACFs) by physical activation with steam, in order to evaluate the water improvement and the preliminary safety of water quality before purification. The cytotoxicity test results of the Ames Test for the water specimens before standing or filtration by WACFs showed that the bacterial survival rate was higher than 80% of control group, meaning that there is no cytotoxicity. The mutagenicity results showed that the spontaneous revertants were not exceeded by over two times, suggesting no mutagenicity for both water specimens. In terms of water turbidity testing, the WACFs could reduce water turbidity to 0.37–1.60 NTU. The total hardness of the water improved by prepared WACFs was 292.00–136.68 mg/L as $CaCO_3$. Both results is met the quality standard for drinking water in Taiwan. The pH value in water was increased by WACFs filtration or standing in solution, and the pH value after processing was about 9.55–10.02. The nitrite nitrogen concentration could be reduced to 25.4–34.5% after processing by WACFs. The total bacterial count, and *Escherichia coli* and coliform group were achieved the drinking water standards in Taiwan by microbiological analysis, when the raw water and slow filter water were processed by using the standing method with over 30 min. The water processed by WACFs can improve the water quality. Therefore, the WACFs can be as the absorbent of water purification for the water quality improvement in purification plant.

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