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# A Study of Sorghum Distillery Residue Activated Carbon for Water Purification

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This study used fermentation waste–Sorghum Distillery Residue (SDR) as a precursor to prepare different kinds of Sorghum Distillery Residue Activated Carbon (SDRAC) by physical activation with steam, in order to evaluate the water purification and the preliminary safety of water quality before and after purification. The turbidity, total hardness, nitrite nitrogen, total bacterial count, and coliform of the water purified by prepared SDRAC were 0.12 NTU, 55.6 mg/L, 0.00 mg/L, 1 CFU/mL, and below 1.0 CFU/mL, respectively, meeting the quality standard for drinking water in Taiwan. The total organic carbon in water was reduced by 34.5%, at most. The cytotoxicity test results of the Ames Tests for the water specimens before and after filtration by SDRAC 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. The SDRAC; therefore, has functional value of water purification, and can be preliminarily regarded as a safe natural water purifying material.

**Key words**: Sorghum Distillery Residue Activated Carbon (SDRAC), Physical Activation with Steam, Water Purification, Ames Tests

## INTRODUCTION

Activated carbon 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). It has stable chemical properties, and is resistant to acid, alkali, high temperature, and high pressure, and is extensively applicable to the drinking water purification process (Jiang, 2010). As activated carbon has a developed pore structure, it can adsorb the trace amount of organic contaminants in water (Kihn *et al*., 2000; Andersson *et al*., 2001), and can significantly reduce the chemical oxygen demand and total organic carbon in water (Kunio *et al*., 2001; Seyed *et al*., 2004; Omri *et al*., 2013). It is effective on the turbidity and chromaticity of the physical standards for drinking water (Anu *et al*., 2006). In addition, the activated carbon has inhibitory effect on total bacterial count and coligroup in water (Ogawa *et al*., 2011), and it conforms to the biological criteria of water standards of the Environmental Protection Administration of Taiwan (EPA). It is obvious that activated carbon is important for water purification. A previous study (Lin *et al*., 2015) reported that the Sorghum Distillery Residue (SDR) is a type of fermentation waste, which can be prepared into activated carbon with multiple mesopores, and used as functional water purifying material. 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. The water has to be purified by waterworks and conform to the water quality standard for drinking water, as specified by the EPA of Executive Yuan (2013c), before it is supplied as domestic water for the public.

In modern life, the massive amounts of chemical substances, environmental accumulation, biological concentration, biotransformation, and chemical reaction pollutes the environment and causes hazards to human health, such as malignant tumors, impaired capacity to bear children, and gene mutation. Mutagenicity is a change in the hereditary property in the reproduction process of deoxyribonucleic acid storing gene information in biological somatocyte caused by toxic chemical substances. If there is biological mutagenicity, there is a high proportion with biological carcinogenicity. Therefore, if the raw water of tap water is severely polluted, there may be mutagenicity increasing the probability of cell mutation. If the chlorine dosage is too high in the tap water treatment process, there may be high carcinogenic risk. In addition, activated carbon reduces the mutagenicity of water to different extents (Monarca *et al*., 1983; Marguerite *et al*., 1986). Therefore, gene mutation caused by chemical substances can be tested by the Ames Tests, in order to evaluate the carcinogenecity to the human body (Ames *et al*., 1975; Maron and Maron, 1983).

This study attempted to use the SDRAC prepared by physical activation in a previous study (Lin *et al*., 2015) to evaluate its application to water purification, as well

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as the preliminary safety of water quality before and after purification. To reduce the economic cost of SDRAC, and use it locally, some reports indicate that the Kinmen County dam spring has high turbidity and high density coligroup, and the eutrophication of the reservoir increases the total organic carbon in water (Construction and Planning Agency, 2005). Therefore, this study used prepared SDRAC for Kinmen County water specimen purifying treatment and related water testing. The water specimen treated by the prepared activated carbon was used to evaluate the preliminary safety of cytotoxicity and mutagenicity of the Ames Tests. The activated carbon prepared by SDR is expected to conform to sustainable recycling of Kinmen distillery residue waste resource in order to purify local water, and such treated water is safe.

## MATERIALS AND METHODS

### Specimen

*Sorghum Distillery Residue Activated Carbon (SDRAC)*

The fermentation waste, Sorghum Distillery Residue (SDR), was used to prepare different kinds of SDRAC by physical activation with steam, and that with a yield above 17% and iodine value higher than 700 mg/g (T850–60–090–$H_2O$, T800–60–090–$H_2O$, T800–60–120–$H_2O$ and T800–60–150–$H_2O$) were selected for water testing. This study referred to Lin *et al*. (2015) for the codes, basic properties, and adsorption characteristics of SDRAC.

*Source of water specimen*

The raw water from the water source of the Kinmen County Ronghu purification plant, and the water specimen 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 was obtained on May 27, 2014, and the slow filter water was obtained on May 27, 2014.

### Methods

*Water purification methods*

Standing method: the SDRAC 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), before water testing;

Filtration method: the SDRAC 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 and 5±2 mL/min (Ogawa *et al*., 2011), and the weight ratio of SDRAC to raw water or slow filter water was 1: 10 (wt%). The abbreviations for water purification specimens are as shown in Table 1.

**Table 1.** Abbreviations of water specimen after processing by water purification with SDRAC[1)]

| Type of SDRAC [2)] | Method of water purification | Time of standing and flow velocity | Water specimen |
|---|---|---|---|
| T850–60– 90–$H_2O$ [3)] | Standing Method | 30 min | T850–60–090–030min [4)] |
| | | 60 min | T850–60–090–060min |
| | | 120 min | T850–60–090–120min |
| | Filtration Method | 10 mL/min | T850–60–090–10 mL/min |
| | | 5 mL/min | T850–60–090–05 mL/min |
| T800–60– 90–$H_2O$ | Standing Method | 30 min | T800–60–090–030min |
| | | 60 min | T800–60–090–060min |
| | | 120 min | T800–60–090–120min |
| | Filtration Method | 10 mL/min | T800–60–090–10 mL/min |
| | | 5 mL/min | T800–60–090–05 mL/min |
| T800–60–120–$H_2O$ | Standing Method | 30 min | T800–60–120–030min |
| | | 60 min | T800–60–120–060min |
| | | 120 min | T800–60–120–120min |
| | Filtration Method | 10 mL/min | T800–60–120–10 mL/min |
| | | 5 mL/min | T800–60–120–05 mL/min |
| T800–60–150–H2O | Standing Method | 30 min | T800–60–150–030min |
| | | 60 min | T800–60–150–060min |
| | | 120 min | T800–60–150–120min |
| | Filtration Method | 10 mL/min | T800–60–150–10 mL/min |
| | | 5 mL/min | T800–60–150–05 mL/min |

[1)] SDRAC: Sorghum Distillery Residue Activated Carbon
[2)] Type of SDRAC: see the paper – Lin *et al*. (2015)
[3)] T850–60– 90–$H_2O$: T (Activation temperature) – Activation duration – Flow rate – Activating agent (Steam)
[4)] T850–60– 90–030 min: T (Activation temperature) – Activation duration – Flow rate – Time of standing or flow velocity

*Water tests*

The turbidity was tested by the water turbidity detection method – turbidimetric method, as published by EPA (NIEA W219.52C, 2005a).

The pH value was measured by the inwater hydrogen ion concentration measuring method – electrode method, as published by EPA (NIEA W424.52A, 2008).

The total hardness was tested by the inwater total hardness detection method – EDTA (Ethylenediaminetetraacetic acid) titration, as published by EPA (NIEA W208.51A, 2006). The equation was total hardness (represented by $CaCO_3$, mg/L) = A × B × 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 × 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 $\mu$g/mL was used to discuss the changes in the content adsorbed by SDRAC.

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 coliform 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 bacteria. The equation was coliform count (CFU/100mL) = [(red colony + violet colony) × 100] / water specimen volume × extension rate.

The total organic carbon (TOC) was tested by the inwater TOC detection method – peroxy–pyrosulfate thermal oxidation/infrared mensuration, as published by EPA (NIEA W532.52C, 2005a).

*Preliminary safety test for water quality*

Referring to the Ames Tests, as proposed by Ames *et al*. (1975), Waleh *et al*. (1982), which indicated that if the sample is toxic for the strain, the bacterial count decreases, and the test result is likely to be misjudged. Therefore, the specimen cytotoxicity has to be tested before the mutagenicity test, in order to evaluate whether the growth of the strain is influenced. The mutagenicity can be implemented if there is no toxicity. In this study, the *Salmonella typhimurium* TA98 and TA100 were used as test strains. TA98 is the strain sensitive to frame shifting mutation, as caused by specific mutagens; TA100 is the strain for testing base substitution variation (Mortelmans and Zeiger, 2000). The phosphoric acid buffer solution was used as the blank group (Control), and each water specimen before and after purification by SDRAC was repeated to calculate the colony counts. After cytotoxicity testing, the residual bacterial count has to be higher than 80% of the residual bacterial count of Blank, meaning that the specimen has no toxic response to cells (Waleh *et al*., 1982). In the mutagenicity test, if the specimen induced by spontaneous revertants is higher than Control by two times, i.e. mutagenicity ratio above 2.0, it means the specimen has mutagenic-

**Table 2.** Turbidity [1] of water specimen for raw water and slow filter water after processing by standing method with SDRAC

Unit: NTU

| Water specimen [2] | Raw water [3] | Percent removal (%) [4] | slow filter water [3] | Percent removal (%) |
|---|---|---|---|---|
| Blank [5] | 20.60 (1.84)[b6] | – | 1.34 (0.39) [b] | – |
| T850–60–090–10 mL/min | 2.50 (0.26) [a] | 87.8 | 1.11 (0.24) [b] | 17.1 |
| T850–60–090–05 mL/min | 1.73 (0.16) [a] | 91.6 | 0.60 (0.06) [a] | 55.2 |
| T800–60–090–10 mL/min | 2.80 (0.29) [a] | 86.4 | 1.24 (0.26) [b] | 7.4 |
| T800–60–090–05 mL/min | 1.96 (0.03) [a] | 90.4 | 0.59 (0.15) [a] | 55.9 |
| T800–60–120–10 mL/min | 2.36 (0.36) [a] | 88.5 | 0.99 (0.24) [ab] | 26.1 |
| T800–60–120–05 mL/min | 1.90 (0.14) [a] | 90.7 | 0.61 (0.14) [a] | 54.4 |
| T800–60–150–10 mL/min | 2.36 (0.28) [a] | 88.5 | 0.94 (0.15) [ab] | 29.8 |
| T800–60–150–05 mL/min | 1.84 (0.06) [a] | 91.0 | 0.55 (0.04) [a] | 58.9 |

[1] Turbidity of water quality standard for drinking water source is no standard; Turbidity of water quality standard for drinking water is 2 NTU (Environmental Protection Administration, 2013c)

[2] Water specimen: see Table 1

[3] The raw water was obtained on May 27, 2014, and the slow filter water was obtained on May 27, 2014.

[4] Percent removal (%) = [ (turbidity of blank – turbidity of water specimen after processing with SDRAC) / turbidity of blank] * 100

[5] Blank: water specimen is raw water or slow filter water that unprocessed with any SDRAC.

[6] Mean (standard deviation) with the different superscripts are significantly different ( $\rho < 0.05$) by Duncan's multiple range tests

ity (Ames *et al.*, 1975).

*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

### Evaluation of water purification

*Turbidity*

Turbidity is caused by the suspended substances in water, including fine colloidal particles to coarse and dispersed suspended particles (Shi, 2003). 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). Table 2 showed the results of turbidity of the raw water and slow filter water purified by the filtration method with SDRAC. The raw water turbidity was 20.6 NTU, and the slow filter water was 1.34 NTU. The turbidity of the raw water was reduced to 2.50–1.73 NTU after filtration, the water turbidity was able to be removed by 87.8–91.6%; the turbidity of slow filter water was removed by 7.4–58.9%, i.e. 1.24–0.55 NTU. The turbidity of raw water treated by the standing method was removed by 84.4–87.0%, the turbidity was reduced to 3.02–2.67 NTU; the turbidity of the slow filter water was removed by 35.0–91.0%, i.e. turbidity was reduced to 0.87–0.12 NTU (results not shown in Table). According to the results of Duncan's multiple range tests, the SDRAC processed results of different standing periods and filtration flow velocities had significant difference. It is indicated that the SDRAC is influenced by them when purifying water, and the water turbidity decreases as the time extends and the flow velocity decreases. The water quality standard for drinking water specifies turbidity as 2 NTU. It is suggested that the raw water specimen is processed by SDRAC at a flow velocity of 5±2 mL/min can reach the water quality standard for drinking water.

*pH value*

The raw water pH value was subacid 5.86, and the pH value after SDRAC standing increased to 7.76–9.47. The slow filter water pH value was 6.56, and the pH value after activated carbon standing was 8.18–9.69. The pH value also increased after filtration by SDRAC at different flow velocities. The pH value of the filtered raw water specimen was 6.65–8.39, that of the slow filter was 7.04–8.43 (results not shown in Table). The pH value increases because when the activated carbon is heated, the carbon single bonding forms double bonding when the hydrogen atom is removed from the precursor surface. The activated carbon material bottom surface delocalization ($\pi$ electron) forms a Lewis Bases–like effect, and the activated carbon becomes alkaline (Zhu *et al.*, 2012). When the activation temperature is higher than 800°C, 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–$H_2O$

**Table 3.** Total hardness [1)] of water specimen for raw water and slow filter water after processing by standing method with SDRAC standing method with SDRAC

Unit: mg/L

| Water specimen [2)] | Raw water [3)] | Percent | slow filter water [3)] | Percent removal (%) |
|---|---|---|---|---|
| Blank [5)] | 115.5 (4.15) [e3)] | – | 116.6 (4.71) [g] | – |
| T850–60–090–030min | 63.3 (2.69) [a] | 45.1 | 64.4 (1.56) [b] | 44.8 |
| T850–60–090–060min | 58.9 (5.61) [a] | 49.0 | 56.7 (2.69) [a] | 51.4 |
| T850–60–090–120min | 57.8 (4.12) [a] | 50.0 | 55.6 (3.11) [a] | 52.3 |
| T800–60–090–030min | 84.2 (1.56) [d] | 27.0 | 85.3 (1.56) [f] | 26.8 |
| T800–60–090–060min | 82.0 (1.56) [cd] | 29.0 | 80.9 (1.56) [ef] | 30.6 |
| T800–60–090–120min | 79.8 (2.69) [bcd] | 30.1 | 77.6 (3.11) [de] | 33.4 |
| T800–60–120–030min | 79.5 (5.39) [bcd] | 31.2 | 82.0 (3.11) [ef] | 29.7 |
| T800–60–120–060min | 78.7 (1.56) [bcd] | 31.8 | 77.6 (1.56) [de] | 33.4 |
| T800–60–120–120min | 72.1 (1.56) [b] | 37.6 | 73.2 (0.00) [cd] | 37.2 |
| T800–60–150–030min | 79.8 (2.69) [bcd] | 30.9 | 78.7 (3.11) [de] | 32.5 |
| T800–60–150–060min | 78.7 (3.11) [bcd] | 31.8 | 76.5 (2.69) [cde] | 34.4 |
| T800–60–150–120min | 74.3 (4.12) [bc] | 35.6 | 71.0 (1.56) [c] | 39.1 |

[1)] Total hardness of water quality standard for drinking water source is no standard; Total hardness of water quality standard for drinking water is 300 mg/L (Environmental Protection Administration, 2013c)

[2), 3), 5), 6)] see Table 2

[4)] Percent removal (%) = [(total hardness of blank – total hardness of water specimen after processing with SDRAC) / total hardness of blank] * 100

reaction, where the higher activation temperature means the carbon surface contains more basic functional groups (Park and Kim, 2001; Zhu *et al*., 2012). The pH value specified by the water quality standard for drinking water is 6.0–8.5, the pH value after the treatment by SDRAC in this test is higher than the water standard. However, the pH value after the process by the activated carbon filter tank of the purification plant increases. The subsequent process of the general water treatment plant can make water quality meet the standard (Anu *et al*., 2006).

*Total hardness*

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. Taiwan's water quality standard for drinking water restricts the total hardness, and the value is 300 mg/L (calculated by $CaCO_3$). Table 3 showed the total hardness of raw water was 115.5 mg/L and that of slow filter water was 116.6 mg/L. The total hardness of raw water from various reservoirs in Kinmen is 58.1–248.5 mg/L (Construction and Planning Agency, 2005). The total hardness of water specimens for this test is in the range. Table 3 also shows the changes in the total hardness of raw water and slow filter water specimens purified by the standing method with SDRAC. The total hardness of raw water was reduced by 27.0–50.0%, the total hardness of T850–60–090–$H_2O$ was reduced to 57.8–63.3 mg/L, the total hardness decreases as the standing time extends, and the slow filter water had the same result. The filtration method also reduced the total hardness to 67.7–88.6 mg/L, the T850–60– 90–$H_2O$ had the maximum decreasing percentage (results not shown in Table). SDRAC can soften water by the standing or filtration method. 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 SDRAC is used for 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, SDRAC 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 ($NO_2$–N) is one of the forms of nitrogen dissolved in water. The other forms are ammonia nitrogen ($NH_3$–N), nitrate nitrogen ($NO_3$–N), organonitrogen (Org–N), and various forms in the aerobic state (Sawyer, 1967). Nitrite nitrogen is listed as an unhealthy material in the water quality standard for drinking water. It is carcinogenic to the human body, and affects human health and infant methemoglobinemia (Shi, 2003). 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, 2013). The nitrite nitrogen concentration in the raw water and slow filter water of this study was 0.01 mg/L. The slow filter water was 0.00 mg/L, which was lower than 0.1 mg/L of the water quality standard for drinking water, thus, nitrite nitrogen was not tested. Therefore, this study used sodium nitrite standard solution 0.1 $\mu$g/mL in the standing method to discuss the changes in the content adsorbed by SDRAC. The results are as shown in Table 4. The sodium nitrite standard solution 0.1 $\mu$g/mL after standing filtration was reduced to 0.089–0.021 $\mu$g/mL, and the percent removal was 11.0–79.0%. It is said that SDRAC can adsorb nitrite nitrogen, which is possibly due to the basic (alkaline) functional group (Cabal *et al*., 2009; Nunell *et al*., 2012).

**Table 4.** Content change of sodium nitrite standard solution 1) during different standing time after processing with SDRAC

Unit: CFU/mL

| Water specimen [2] | Raw water [3] | Percent removal (%) [4] |
|---|---|---|
| T850–60– 90– 30min | 0.065 (0.0)[5] | 35 |
| T850–60–90– 60min | 0.046 (0.0) | 54 |
| T850–60–90–120min | 0.021 (0.0) | 79 |
| T800–60–90– 30min | 0.089 (0.0) | 11 |
| T800–60–90– 60min | 0.065 (0.0) | 35 |
| T800–60–90–120min | 0.036 (0.0) | 64 |
| T800–60–120– 30min | 0.088 (0.0) | 12 |
| T800–60–120– 60min | 0.060 (0.0) | 40 |
| T800–60–120–120min | 0.033 (0.0) | 67 |
| T800–60–150– 30min | 0.064 (0.0) | 36 |
| T800–60–150– 60min | 0.050 (0.0) | 50 |
| T800–60–150–120min | 0.029 (0.0) | 71 |

[1] Sodium nitrite standard solution: 0.1 µg/mL
[2] see Table 1
[3], [5] see Table 2
[4] Percent removal (%) = [ (sodium nitrite standard solution (0.1 $\mu$g/mL) – sodium nitrite standard solution) / sodium nitrite standard solution (0.1 $\mu$g/mL) ] * 100

*Total bacterial count*

Table 5 showed that the total bacterial count of raw water and slow filter water specimens, as filtered by the standing method with SDRAC. The total bacterial count of raw water was 1539 CFU/mL, the total bacterial count decreased significantly after standing, and the total bacterial count in water was able to be reduced by 99.8–99.9% after 30 min SDRAC standing. The total bacterial count was 1–3 CFU/mL, and the total bacterial count increased with the standing time. The total bacterial count after 120 min SDRAC standing was 10–16 CFU/mL; that of slow filter water was 1025 CFU/mL, and the value was 1–28 CFU/mL after standing filtration. The total bacterial count was able to be reduced by 97.2–99.9%, thus, conforming to the water quality standard for drink-

**Table 5.** Total bacterial count [1] of water specimen for raw water and slow filter water after processing by standing method with SDRAC

Unit: mg/L

| Water specimen [2] | Raw water [3] | Percent | slow filter water [3] | Percent removal (%) |
|---|---|---|---|---|
| Blank [5] | 1539 (66.00) [b6] | – | 1025 (104.00) [b] | – |
| T850–60–090–030min | 3 (0.82) [a] | 99.8 | 1 (0.00) [a] | 99.9 |
| T850–60–090–060min | 4 (1.70) [a] | 99.7 | 5 (1.63) [a] | 99.5 |
| T850–60–090–120min | 16 (3.40) [a] | 98.9 | 25 (2.05) [a] | 97.6 |
| T800–60–090–030min | 1 (0.00) [a] | 99.9 | 1 (0.47) [a] | 99.9 |
| T800–60–090–060min | 4 (2.16) [a] | 99.7 | 2 (0.82) [a] | 99.8 |
| T800–60–090–120min | 10 (0.47) [a] | 99.3 | 12 (2.49) [a] | 98.8 |
| T800–60–120–030min | 2 (0.47) [a] | 99.8 | 1 (0.47) [a] | 99.9 |
| T800–60–120–060min | 4 (1.63) [a] | 99.7 | 5 (1.63) [a] | 99.5 |
| T800–60–120–120min | 15 (2.62) [a] | 99.0 | 28 (3.40) [a] | 97.2 |
| T800–60–150–030min | 1 (0.00) [a] | 99.9 | 1 (0.47) [a] | 99.9 |
| T800–60–150–060min | 2 (0.88) [a] | 99.8 | 3 (2.16) [a] | 99.7 |
| T800–60–150–120min | 13 (2.05) [a] | 99.1 | 20 (2.01) [a] | 98.0 |

[1] Total bacterial count of water quality standard for drinking water source is no standard; Total bacterial count of water quality standard for drinking water is 100 mg/L (Environmental Protection Administration, 2013c)

[2), 3), 5), 6)] see Table 2

[4] Percent removal (%) = [(total bacterial count of blank – total bacterial count of water specimen after processing with SDRAC) / total bacterial count of blank] * 100

ing water (100 CFU/mL). Ogawa *et al*. (2011) indicates that during standing in activated carbon, the total bacterial count in water varies with the activated carbon measure. The total bacterial count in water effectively decreases as the activated carbon measure is increased. Uraki *et al*. (2008) reported that the activated carbon filtration and standing process are effective methods to reduce the total bacterial count in water. The active mechanism is that the strongly alkaline solution condition is presented in activated carbon to cause bacteria death and the bacteria are adsorbed in the activated carbon.

In terms of filtration method (results not shown in Table), the total bacterial count in the filtered raw water was 381–436 CFU/mL; that in the slow filter water was 248–333 CFU/mL, and the total bacterial count increased as the filtration flow velocity decreased. According to the above results, the standing or filtration test of SDRAC showed that the total bacterial count in water increased slightly with the SDRAC contact time (standing time or filtration flow velocity). Because the activated carbon 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 (Liao *et al*., 2013). The increase of colonies with the activated carbon contact time is a common phenomenon in the activated carbon filter of a purification plant. General purification plants often set the sterilization procedure behind the activated carbon filter in order to increase sterilization efficiency. Many studies have reported that the Alphaproteobacteria extensively exists in the activated carbon filter for drinking water treatment (Ko *et al*., 2007; Magic–Knezev *et al*., 2009; Liao *et al*., 2012). Thus, in the water purification procedure of the purification plant, the activated carbon filter is mostly followed by the ozone sterilization procedure in order to control the quantity of aquatic microorganisms (Chen and Chang, 2005).

To sum up, in the standing or filtration treatment of SDRAC, its alkaline characteristics can effectively reduce the total bacterial count in water, but as the contact time extends, the developed pore structure is contrarily helpful to the adhesion and growth of microorganisms.

*Coliform*

Coliform often exists in human and homeothormous excreta, and is highly correlated with feces source pollution. It is a pollution index bacterium, and it is the fecal pollution level of drinking water. Thus, it is specified in the water quality standard for drinking water of Taiwan. It is 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, 1997; 2013c). The coliform in raw water and slow filter water for this test is 3 and 22 CFU/mL, respectively, meaning that the raw water of the Jinsha reservoir and the slow filter water of the Ronghu water process plant have no high fecal pollution, and conform to the water quality standards for drinking water sources and drinking water. The filtrate of raw water and slow filter water filtered by SDRAC and standing method or filtration method was below 1 CFU/mL (results not shown in Table). Therefore, SDRAC at a high activation temperature has better results in the water purification process for subsequent testing. The T850–

**Table 6.** Total organic carbon [1] of water specimen for raw water and slow filter water after processing by standing method with 2 types of SDRAC

Unit: mg/L

| Water specimen [2] | Raw water [3] | Percent | slow filter water [3] | Percent removal (%) |
|---|---|---|---|---|
| Blank [5] | 7.6 | – | 8.7 | – |
| T850–60–90–30min | 5.1 | 32.8 | 5.7 | 34.5 |
| T850–60–90–10mL/min | 5.6 | 26.3 | 6.6 | 24.1 |

[1] Total organic carbon (TOC) of water quality standard for drinking water source is no standard; TOC of water quality standard for drinking water is 100 mg/L (Environmental Protection Administration, 2013c)
[2], [3], [5], [6] see Table 2
[4] Percent removal (%) = [ (TOC of blank – TOC of water specimen after processing with SDRAC) / TOC of blank] * 100

60–90–$H_2O$ at an activation temperature of 850°C is used to assess the TOC in water and water safety.

*TOC*

The organic matter in water has adverse effect on the colority, smell, and taste of drinking water, and it influences the dosage of coagulant in the water purification procedure, interfering in advanced water process and heavy metals Fe and Mn in water form complex, thus, increasing the content of heavy metals, corrosion of distribution lines, and regrowth of microorganisms in water. In the chlorination procedure, it is likely to react with disinfector to produce the sterilization byproducts of haloform and halothane, affecting human health (Bull, 1982; Jacangelo *et al*., 1995). Therefore, the content of TOC is considered in the water purification procedure, and TOC in the standard of drinking water sources is 4 mg/L. Table 6 showed the changes in the TOC in water after filtration and standing of raw water and slow filter water by T850–60–090–$H_2O$. The TOC of raw water was 7.6 mg/L, after 30 min standing, the TOC removal rate was 32.8%, reduced to 5.1 mg/L. The percent removal of the filtration method was 26.3%, and the value decreased to 5.6 mg/L. There is adsorption effect on the TOC of slow filter water. The TOC of slow filter water was 8.7 mg/L. After SDRAC standing, the TOC in water was 5.7 mg/L; that of filtration method was 6.6 mg/L, the TOC percent removal was 24.1–34.5%. Anu *et al*. (2006) studied the bioactive carbon filter of the Finland purification plant, and evaluated the activated carbon filter treatment by different methods or conditions. They found that the natural organic matter in the raw water was removed by 53–95%, and the water was purified. It is suggested that the effect of SDRAC on removing or reducing TOC is related to the standing time and filtration flow velocity.

**Safety assessment of water quality**

*Cytotoxicity*

The cytotoxicity of water specimens after 30 min T850–60– 90–$H_2O$ standing and filtration method at the flow velocity of 10 mL/min for *Salmonella typhimurium* TA98 and TA100 strains was tested. The results are as shown in Table 7. The bacterial count of Control without rat liver enzyme mixture (S9 mix) was 1663 in TA98, 1979 in TA100; the TA98 with S9 mix was 1836, TA100 was 2140. The bacterial count of raw water without the S9 mix was 1715 in TA98, and 1983 in TA100. Survival was 100–103%. The TA98 with the S9 mix was 1875, and TA100 was 2250. Survival was 102–105%. Survival of slow filter water without the S9 mix was 101–104% in

**Table 7.** Cytotoxicity of water specimen for raw water and slow filter water after processing by standing and filtration methods with 2 types of SDRAC toward *Salmonella typhimurium* TA98, TA100 with or without S9 mixture

| Water specimen [1] | | without S9 mixture | | | | with S9 mixture | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | TA98 | Survival [2] (%) | TA100 | Survival (%) | TA98 | Survival (%) | TA100 | Survival (%) |
| Control [3] | | 1663 (44)[5] | 100 | 1979 (48) | 100 | 1836 (82) | 100 | 2140 (55) | 100 |
| raw water | Blank [4] | 1715 (45) | 103 | 1983 (26) | 100 | 1875 (53) | 102 | 2250 (90) | 105 |
| | T850–60–90–30 min | 1741 (29) | 104 | 2030 (32) | 102 | 1882 (54) | 102 | 2328 (66) | 108 |
| | T850–60–90–10 mL/min | 1844 (50) | 110 | 2036 (33) | 102 | 1963 (69) | 106 | 2340 (54) | 109 |
| slow filter water | Blank | 1738 (41) | 104 | 2010 (16) | 101 | 1878 (59) | 102 | 2192 (11) | 102 |
| | T850–60–90–30 min | 1746 (41) | 104 | 2031 (33) | 102 | 1891 (36) | 102 | 2233 (59) | 104 |
| | T850–60–90–10 mL/min | 1799 (56) | 108 | 2004 (37) | 101 | 1872 (30) | 101 | 2254 (37) | 105 |

[1] see Table 1
[2] Survival (%) = [(the bacterial count of test group / the bacterial count of control group)] * 100
[3] Control: only with 0.1 mL phosphate buffer saline
[4] see Table 2
[5] Mean (standard deviation)

**Table 8.** Mutagenicity of water specimen for raw water and slow filter water after processing by standing and filtration methods with 2 types of SDRAC toward *Salmonella typhimurium* TA98, TA100 with or without S9 mixture

| Water specimen [1] | | without S9 mixture | | | | with S9 mixture | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | TA98 | MR[2] | TA100 | MR | TA98 | MR | TA100 | MR |
| Control [3] | | 52 (4)[5] | 1.00 | 145 (4) | 1.00 | 53 (7) | 1.00 | 165 (10) | 1.00 |
| raw water | Blank [4] | 51 (7) | 0.98 | 141 (9) | 0.97 | 53 (6) | 1.00 | 167 (9) | 1.01 |
| | T850–60–90–30 min | 50 (8) | 0.96 | 147 (9) | 1.01 | 59 (8) | 1.11 | 168 (6) | 1.02 |
| | T850–60–90–10 mL/min | 53 (5) | 1.02 | 160 (4) | 1.10 | 55 (3) | 1.03 | 157 (5) | 0.95 |
| slow filter water | Blank | 51 (8) | 0.98 | 148 (5) | 1.02 | 53 (7) | 1.00 | 164 (5) | 0.99 |
| | T850–60–90–30 min | 46 (5) | 0.88 | 128 (6) | 0.88 | 52 (4) | 0.98 | 163 (5) | 0.98 |
| | T850–60–90–10 mL/min | 48 (6) | 0.86 | 146 (6) | 1.00 | 52 (7) | 0.98 | 165 (11) | 1.00 |

[1] see Table 1
[2] MR (Mutagenicity ratio) = induced revertants per plate/spontaneous revertants per plate (Control)
[3] Control: see Table 7
[4] see Table 2
[5] Mean (standard deviation)

TA98, while that with S9 mix was 102%. Therefore, the water specimens have no cytotoxicity. In order to guarantee the safety of water specimens processed by SDRAC, the cytotoxicity of the water specimens processed by SDRAC was tested. The same Table showed that after 30 min standing and filtration at flow velocity of 10 mL/min, the raw water processed by T850–60– 90–$H_2O$ was 1741–1844 in TA98 without the S9 mix, and Survival was 104–110%; that in TA100 was 2032–2036, Survival was 102%; that with the S9 mix was 1882–1963 in TA98, Survival was 102–106%; TA100 was 2328–2340, Survival was 108–109%. Survival of slow filter in TA98 and TA100, with or without the S9 mix, was 101–108%. It is said that that Survival of the processed water specimens in TA98 and TA100 strain tests is higher than 80% of Control, there is no cytotoxicity, and the mutagenicity can be carried out.

*Mutagenicity*

The results of mutagenicity are as shown in Table 8. The revertants of *Salmonella typhimurium* TA98 and TA100 induced by raw water and slow filter water, 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. The same Table also showed that, in the mutagenicity results of water specimens processed by SDRAC, the water specimens of raw water and slow filter water after 30 min standing and filtration at flow velocity of 10 mL/min in T850–60– 90–$H_2O$ had no mutagenicity, and did not exceed two times the spontaneous revertants of Control. It is said that that the raw and slow filter water before and after purification have no mutagenicity toward *S. typhimurium* TA98 and TA100.

## CONCLUSIONS

This study evaluated the feasibility of SDRAC for purifying water, and performed the Ames Tests to ensure the preliminary safety of water quality before and after purification. In terms of water turbidity testing, the SDRAC prepared in different conditions could reduce water turbidity by 7.4–91.6%. The value was 0.12–2.93 NTU. The pH value in water was increased by SDRAC filtration or standing in solution, and the pH value after processing was increased by 13.4–61.6 %. The total hardness of the raw water and slow filter water specimens processed by SDRAC was removed by 23.2–52.3%, and the value was 55.6–88.6 mg/L. The nitrite nitrogen concentration could be reduced after processing by SDRAC. After the SDRAC process, the total bacterial count in water was removed by 67.5–99.9%, and the percent removal of coliform was 99.9%. The water tests conform to the water quality standard for drinking water in Taiwan. SDRAC could remove 26.3–34.5% of TOC. The bacterial survival rate of cytotoxicity testing for water specimens before and after purification was higher than 80% of Control, meaning there was no cytotoxicity. The mutagenicity results showed that the spontaneous revertants were not exceeded by two times, thus, there were no mutagenicity. The water processed by SDRAC can meet the water quality standard for drinking water, and the preliminary safety of SDRAC can be guaranteed by the Ames Tests. Therefore, SDR may be used to prepare activated carbon, which can be prepared into SDRAC, and is more functional to purify water.

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