# ELECTRICITY-FREE PRODUCTION OF ACTIVATED CARBON FROM BIOMASS IN BORNEO TO IMPROVE WATER QUALITY

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Activated carbons (ACs) were prepared from biomass of Borneo island (wood charcoal, peat, and coconut husk) by using an electricity–free furnace, of which the energy source was exclusively wood charcoal. This furnace was comprised of two parts, an inner vessel equipped with water inlet for steam activation and an outer shell as a heating part for the inner vessel. The inside temperature of the inner vessel was able to reach over 1000 $^oC$. Peat and wood charcoal were converted to AC by carbonization followed by steam activation, and the specific BET surface areas of resultant ACs were 889 $m^2/g$ and 749 $m^2/g$, respectively. A mobile apparatus for water purification was newly designed and fabricated with the resultant AC, together with a white quartz sand, which is called keranggas in Kalimantan. The $COD_{OH}$ of both polluted creek water by the University of Palangka Raya and Kahayan River water were remarkably decreased by the purification with the designed apparatus from 20.0 mgO/L to 0.93 mgO/L, and 18.2 mgO/L to 0.74 mgO/L, respectively. Thus, the newly designed furnace and purification apparatus were shown to be highly effective tools to produce a promising agent for water purification and to produce clarified water without use of electricity, respectively.

*Keywords: Activated carbon; Chemical oxygen demand (COD); Electricity-free mobile furnace; Biomass in Borneo Island; Peat soil*

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## INTRODUCTION

Borneo, the third largest island in the world, is widely covered by peat swamps that are distributed among all three countries existing in the island. Indonesian Kalimantan, as a part of Borneo, possesses 6.4 to 9.2 million ha of lowland peat swamp forests. In Malaysia, 2.7 million ha of peat swamp lands in Borneo occupy 8% of the nation's total area, and Brunei Darussalam possesses approximately 10000 ha of peat swamps. Over the past 4500 years, peat has accumulated as high as 20 m of thickness in some areas (Phillips 1998). We, therefore, considered it as one of promising feedstock for production of organic materials, activated carbon (AC) in particular (Mudjijati et al. 2000; Efanov and Galochkin 2007; Uraki et al. 2008; Cojocar et al. 2011).

The populations of developing countries are significantly increasing, and concomitantly their demand on clean water for daily life is also expanding. Tap water in not only advanced countries but also developing countries, in south-east Asia in particular, is generally required to be further purified for drinking. Accordingly, the residents are forced to purchase drinkable water at a relatively high price for their daily lives. Taking water purification effectiveness and energy consumption of daily water purification into consideration, daily water should be produced in each area of consumption to maintain production cost as low as that of high population areas. In the purification of river water, AC is a key agent, because it is a well known adsorbent for removing organic substances from dirty water (Tekeuchi et al. 1991; Pollard et al. 1995; Spahis et al. 2008). It is, therefore, preferable that AC should be also produced near where the water is to be consumed.

There is another problem to produce purified water. Although there are water-purification plants in populated cities, it is difficult to construct such the plant in a small town or rural area. To overcome this problem, it is strictly required to develop simple and easy process (low cost plant) to produce both AC with high performance and a suitable water purification apparatus (Pollard et al. 1992). From these viewpoints, we have tried to prepare low-price AC from biomass, peat soil, and fibers of coconut husk in the Borneo area. It was found that AC with a comparable adsorption performance to commercial AC could be produced from peat soil as well as coconut husk by steam activation at 950 $^{o}$C using an electric furnace, suggesting that peat soil is a promising source for AC production (Uraki et al. 2008).

As a secondary trial, we designed and manufactured another furnace to produce AC without electricity, indicating that AC could be prepared everywhere. Wood charcoal was practically used as an energy source instead of electricity, because it can be readily produced anywhere without electricity due to the exothermic reaction, and it can generate a larger heating energy than wood. This furnace consisted of two parts; one is an inner vessel for production of AC, and the other one is outer shell to maintain a high temperature of the inner vessel, which was made of a steel drum (Uraki et al. 2008). Unfortunately, the furnace did not give AC with adsorption performance comparable to that of a commercial one, although the resultant AC had significant ability to purify the river water in Palangka Raya city. The reason why excellent AC could not be obtained could be attributed to a lower maximum temperature (ca 600 $^{o}$C) of the inner vessel. Effective steam activation requires at least 700 $^{o}$C (Wigmans 1989), and the activation is generally performed under the conditions of more than 800 $^{o}$C. (Pastor-Villegas and Duran-Valle 2002; Manocha et al. 2010). Therefore, we suppose that AC with satisfactory adsorption performance can be obtained when the steam activation is carried out at more than 800 $^{o}$C.

In this study, we designed and manufactured a new furnace again by modification of the first furnace. In the new furnace, firebricks were used to fabricate the outer shell to preserve heat inside the furnace. In addition, we also attempted to fabricate a mobile apparatus for the purification of river water with the resultant AC and materials obtained in Palangka Raya city. This study was carried out in February of 2011 in Palangka Raya, Indonesia, where no instruments are available for chemical analyses. Therefore, all analyses were performed exclusively by titrations.

## EXPERIMENTAL

### Materials

Peat soil was collected in Palangka Raya area, and it was completely dried at 105 $^{o}C$ before use. Wood charcoal was purchased from a local market. Chemicals for iodine adsorption analysis and COD analysis were purchased from Wako Chemicals, Osaka, Japan, and Sigma-Aldrich.

Water for purification test was collected from Kahayan River in Palangka Raya and a small creek by the University of Palangka Raya at $18^{th}$ and $23^{rd}$ of February in 2011.

### Manufacturing Electricity-Free Furnace and Preparation of AC

Real and outline images of electric-free furnace are shown in Fig. 1. The furnace mainly consisted of two parts, an outer shell and an inner vessel. The outer shell was manufactured with firebricks by Division of Administration and Supporting Unit, Research Center for Chemistry, Indonesian Institute of Science, PUSPIPTEK Serpong. The inner vessel (202 mm in diameter x 300 mm in height; 9.6 L) was made of iron equipped with a water inlet and a gas outlet for steam activation, and an inlet for thermocouple by Mechanic Lab. Faculty of Science, Hokkaido University. These two parts were assembled in Palangka Raya.

A sample in the weight range of 20 to 100 g was placed on a cylindrical basket (15 cm in diameter x 5 cm in height) made of 60 mesh of steel baskets. The four baskets were piled up and inserted into the inner vessel. The temperature of the inner vessel reached 1000 $^{o}C$ after 15 to 20 min of charcoal ignition. The temperature over 1000 $^{o}C$ was kept for about 30 min, and then water was introduced from a syringe into the vessel through an evaporation port for 20 to 50 min by hand pressure. About 10 kg of wood charcoal per a process of AC production was burned for energy supply. After cooling under ambient conditions overnight, the resultant AC was recovered and weighed to estimate yield based on dry raw sources.

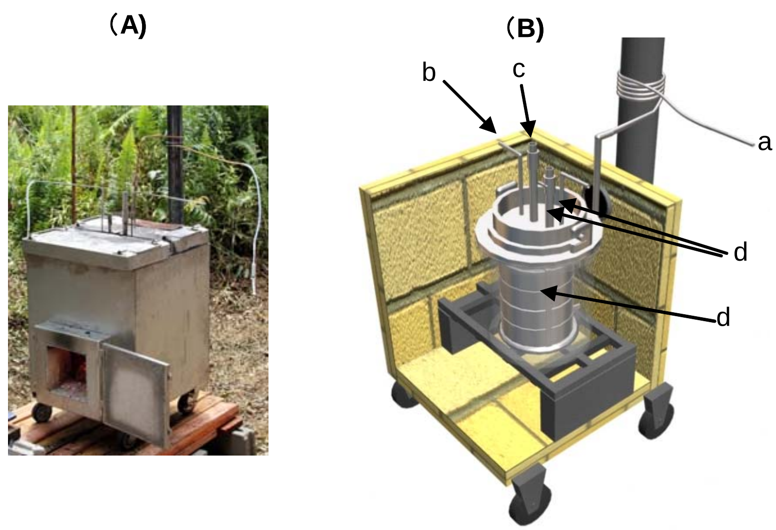



**Figure 1.** Real Image (A) and drawing image (B) of electric-free furnace for AC production. a, water inlet connected to bottom; b, water inlet connected to top; c, thermocouple tube; d, gas outlet; e, four layers of sample baskets.

### Evaluation of Adsorption Performance of AC

Iodine adsorption of AC was measured according to Japan Industrial Standard (JIS) K-1474. BET specific surface area of AC was measured on AUTOSORB-3, Yuasa Ionics, Co. Ltd., Japan, after drying samples at 200 °C overnight.

### Water Purification

The water purification ability of resultant ACs was conducted in two ways. At first, various amounts of AC, 1, 2, and 5 g, were added into 200 mL of water sample. The mixture was stirred for 20 minutes, and then filtered. The filtrate was analyzed with respect to chemical oxygen demand (COD) and colonization of bacteria.

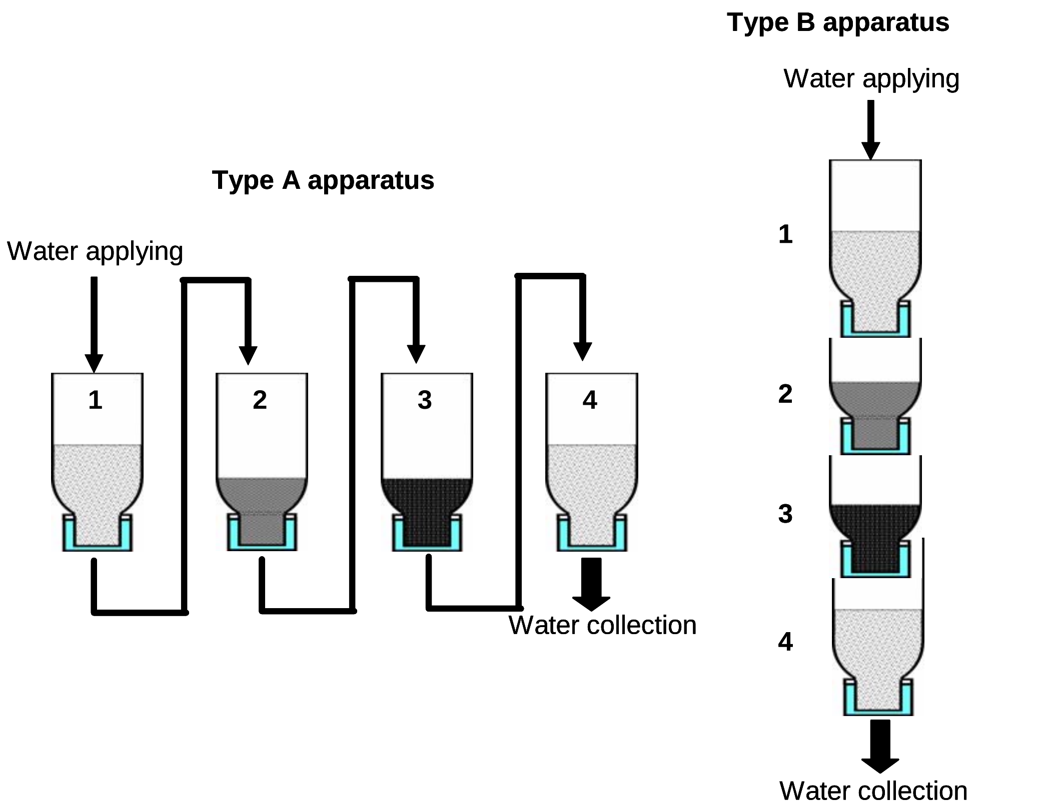



**Figure 2.** A mobile water-purification apparatus. In Type A, the purification was carried out stepwisely through 4 layers, and in Type B, layers of purification agents are directly connected.1, Keranggas as first layer (15 g and 25 g); 2, Wood charcoal as second layer (30 g and 15 g); 3, AC as third layer (20 g and 15 g); 4, Keranggas as final layer (15 g and 25 g). The first and second values in parenthesis of former sentence was weight of the agents in A and B, respectively.

The second way was to use a mobile apparatus newly fabricated for water purification, as shown in Fig. 2. This simple apparatus was fabricated with two materials, a suction part of PET bottle and filter paper for colander of domestic kitchen, which covered the suction part of PET bottle. This apparatus consisted of four adsorption layers (Fig. 2). The top and the bottom layer was local white quarts sand called keranggas in Kalimantan, which was washed with distilled water but not sterilized before use. The second layer from the top was wood charcoal that was purchased in the market of

Palangka Raya and also used as energy source for AC production. Finally, the resultant ACs were placed in the third layer. Water samples flowed from first layer at the top to the bottom by gravitational driving force. The water after each layer was collected and evaluated in terms of the degree of water purification, COD, and colonization of bacteria. The COD was measured according to the alkaline COD method ($COD_{OH}$) in JIS K-0102, and its unit was mgO/mL. The bacterial colonization was observed by using an easy detection kit (Petan Check, Eiken Chemicals, Tokyo, Japan) after 2-days culture of inoculant (0.3 mL) from river water with and without purification.

## RESULTS AND DISCUSSION

### Furnace and AC Production

A furnace to establish high-temperature condition is required to prepare AC by all activation methods, such as gas and chemical activations. The furnace manufactured in this study was comprised of two parts, an inner vessel and an outer shell. The outer shell was made of firebricks. Since the heat insulation was completely performed by the bricks, the inside temperature of the inner vessel easily reached over 1000$^{o}$C within 1 h after the ignition of wood charcoal as an energy source. In addition, the furnace was equipped with two inlets for water introduction into the inside of vessel. A nozzle of the first inlet was located at bottom of the vessel. As the inlet tube is wound into the chimney, hot water or a steamy mixture can be introduced into the vessel. A nozzle of the other inlet is located at upper side of the inner vessel. Thus, water or steam for steam activation can be supplied from both top and bottom of vessel.

**Table 1.** Steam activation conditions.

| Trial | Sample | Water introduction for steam activation | | | |
|---|---|---|---|---|---|
| | | Time (min) | Volume (ml) | Min. Temp. ($^{o}$C) | Max. Temp. ($^{o}$C) |
| 1st | Wood charcoal | 35 | Ca 230 | 950 | 1000 |
| 2nd | Wood charcoal | 50 | 250 | 895 | 970 |
| 3rd | Wood charcoal | 47 | 450 | 1032 | 1108 |
| 4th | Peat soil<br>Coconut husk | 20 | 230 | 980 | 1020 |

AC preparation from wood charcoal was attempted three times using the manufactured furnace to investigate relationship between steam activation conditions and the performance of resultant AC. The conditions for steam activation are shown in Table 1, and the relationship between iodine adsorption of resultant ACs and the position of specimens in the vessel are depicted in Fig. 3. In this study, AC adsorption performance was evaluated by iodine adsorption, because specific surface area could be deduced from the iodine adsorption (Moon et al. 2000; Uraki et al. 2008), and the iodine adsorption was one of measure for evaluation of water purification ability. The maximum temperature in

Table 1 indisputably indicates that the temperature of inner vessel reached over 1000 $^oC$, suggesting the firebricks were a very efficient insulator for heating of the inner vessel.

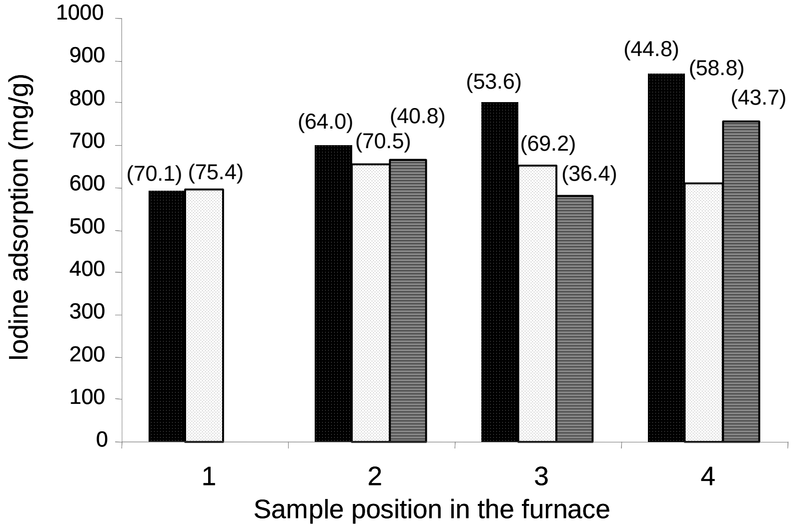



**Figure 3.** Iodine adsorption and yield of AC from wood charcoal. ■, first trial for AC production; □, second trial; ▤, third trial. The value in parenthesis is yield. The number of sample position means the basket position from the bottom of furnace.

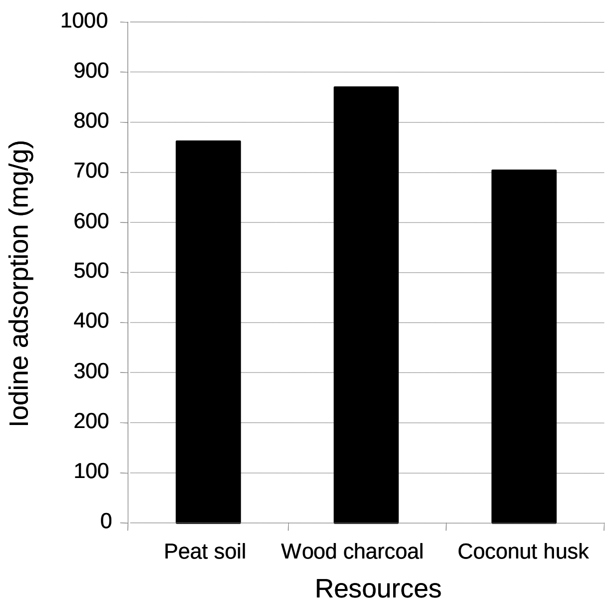


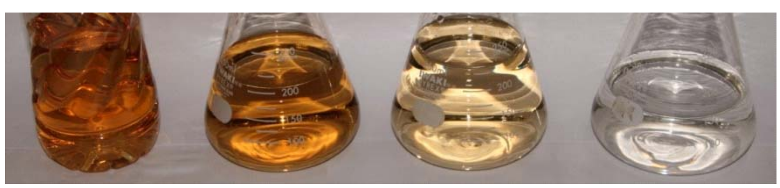

**Figure 4.** Iodine adsorption of AC from different raw materials.

The first trial for AC production from wood charcoal gave ACs with the best iodine adsorption performance, probably due to the most adequate conditions, such as temperature and period of water introduction. The iodine adsorption of the resultant AC was increased with increasing elevation of the position of the raw material container from the bottom, concomitantly with decreasing AC yield based on dry raw material. The AC prepared in the top container, thus, showed the highest value (870 mg/g). This result would imply that the upper position of the vessel reached higher temperature and was directly supplied with water through the inlet connected to the top of vessel, with the result that steam formation was more active than at lower parts.

To prepare AC with higher adsorption ability, AC production conditions were slightly modified. As a second trial, water introduction time was prolonged, and the ratio of upper inlet to lower inlet in water introduction was altered from about 5:5 to 3:7. As a third trial, water introduction volume and time increased as compared to those of first trial, but the introduction ratio was identical. As a result, poor improvement of iodine adsorption was found. In the second trial, the reason was a lower maximum temperature than that of the first trial during steam activation, resulting in a higher yield and lower adsorption ability. In the third trial, the yield was extremely low, probably due to excess activation. Although the first trial yielded AC with the best performance, a more excellent AC could potentially be produced by varying the water introduction conditions, such as volume, time, and the ratio of upper to lower volume introduced.

Based on the first trial conditions, we attempted to produce AC from Indonesian biomass, peat soil, and coconuts husk. The specimens were placed in the second and third baskets, respectively. Figure 4 shows iodine adsorption of resultant ACs in addition to the best result of wood charcoal AC. AC from peat exhibited a competitive performance to wood activated carbon and better than AC from coconut husk. As a result of measurement of specific BET surface area for peat AC and wood charcoal AC, peat AC showed a larger surface area (889 $m^2$/g) than that of wood AC (749 $m^2$/g). These results suggest that peat soil is a more suitable source for AC production, even though this electric-free furnace is not used.

**Table 2.** $COD_{OH}$, decoloration and bacterial colonization of creek water in University of Palangka Raya by purification with the produced AC with 884 mg/g of iodine adsorption.

| AC charge (g) | 0 | 1.0 | 2.0 | 5.0 |
|---|---|---|---|---|
| $COD_{OH}$ (mgO/mL) | 18.5 | 16.9 | 15.2 | 4.6 |
| Color of water |  | | | |
| Colonization of bacteria |  |  |  |  |

## Water Purification

Water samples in this study were collected on two different days, the 18th and 20th of February 2011. The $COD_{OH}$ of water samples from the small creek in University of Palangka Raya were 18.5 and 20.0 mgO/L, respectively. The $COD_{OH}$ of water from Kahayan River was slightly lower, 15.2 and 18.2 mgO/L, respectively. Thus the creek water was a more turbid than water of Kahayan. These $COD_{OH}$ values were much higher than those of corresponding water (8.75 for creek water and 3.76 mgO/L for Kahayan river water) measured in September, 2005 (Uraki.et al. 2008). This difference in $COD_{OH}$ values was attributed to the season of water collection. The water collection in 2011 was during the rainy season, while in 2005 samples were collected during the dry season. Thus water quality was dependent on the season around Palangka Raya. The residents around Palangka Raya are sometimes taking to drink untreated water directly from the Kahayan river, in spite of the fact that the water in this area is not suitable for daily drinking because of high $COD_{OH}$ and many bacterial colonies (Table 2 and Fig. 5). Therefore, the purification of river water around the city is an urgent subject from the view point of public sanitation.

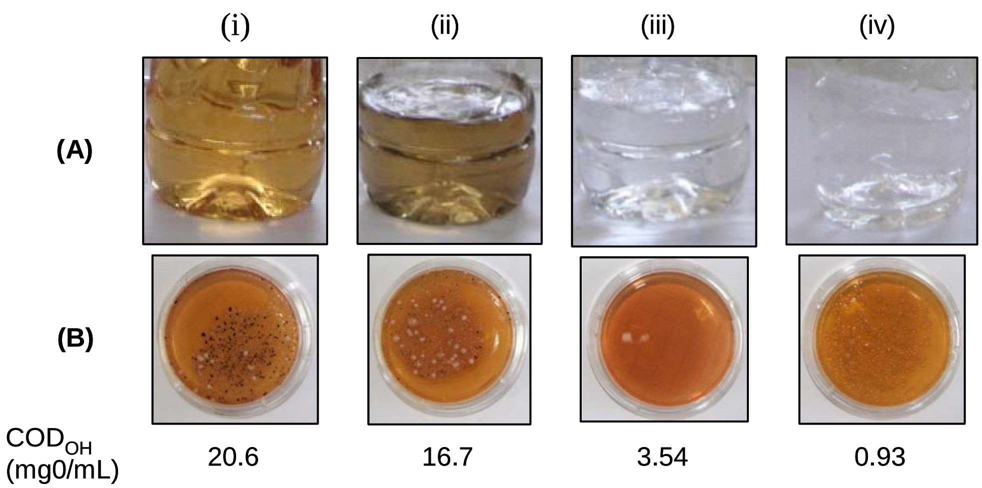



**Figure 5.** Decoloration (A) and bacterial colonization of the creek water in University of Palangka Raya purified by type B apparatus. See detail of this apparatus in Figure2. (i), after purification with keranggas; (ii), with keranggas followed by charcoal; (iii), with charcoal followed by AC with 870 mg/g of iodine adsorption; (iv), with AC followed by keranggas. The initial $COD_{OH}$ of this creek water was 20.0 mgO/mL.

At first, the purification of water with wood charcoal AC (iodine adsorption; 870 mg/g) was examined as a relationship between AC charge and $COD_{OH}$ reduction (Table 2). The $COD_{OH}$ reduction was gradual up to 2 g of AC charge to 200 mL of creek water, and then a remarkable decrease of $COD_{OH}$ was observed. The final $COD_{OH}$ at 5-g AC charge was 4.6 mgO/L. The $COD_{OH}$ was still higher than that for drinkable water (Ministry of the Environment 2009). According to the criteria, the river and lake water with less than 1 mgO/mL of COD value can be used as drinkable tap water after simple filtration. However, the decrease in the number of bacterial colony was confirmed depending on the charge of AC, as shown in the last line of Table 2. The black colony revealed *E. coli* species when using this medium, while the white colonies were other bacteria species. Therefore, a complete elimination of *E. coli* was performed by 5 g of AC charge. There are proposed two hypotheses for removal of bacteria with AC. One is strong alkaline condition around AC (Uraki et al. 2008), resulting in death of bacteria.

The other one is bacterial adsorption into and/or onto AC. However, we cannot clearly elucidate the mechanism.

As a second attempt, we fabricated a mobile water-purification apparatus (Type A apparatus in Fig. 2) using the material available in Palangka Raya. The apparatus was comprised of four layers; the first layer was made of keranggas (25 g) for removing insoluble contaminants, the second and third ones for water purification were wood charcoal (15 g) and wood charcoal-based AC (15 g), respectively, and the final layer was also keranggas (25 g) for removing small particles of charcoal and AC. Figure 5 shows $COD_{OH}$ values and images of bacterial culture medium after 48-h of treated water inoculation, which was passed through each layer.

The $COD_{OH}$ was slightly reduced by treatment with wood charcoal, and then was remarkably decreased by the AC treatment. The number of bacterial colonies was dramatically reduced by the AC treatment to almost zero or a very few. Thus, AC from wood charcoal has potential to reduce COD and to eliminate bacteria. Finally, $COD_{OH}$ of the creek water was purified from 20.0 mgO/L to 0.93 mgO/L in the initial water load (200 mL) to the apparatus. The value was lower than that with AC by 2.6 mgO/L, and fulfills the criteria of drinkable water in Japan (Ministry of the Environment 2009). It is, therefore, suggested that the keranggas layer acted as a removing agent for small carbonaceous particles from AC. Unfortunately, the bacterial colonization increased in the last purification process. The reason would be attributed to use without sterilization of keranggas.

Finally, the purification for Kahayan river water was attempted by using Type B apparatus in Fig. 2, where each layer was directly connected. Accordingly, in this process, $COD_{OH}$ at each purification process was not able to be measured. The $COD_{OH}$ of Kahayan river water was also reduced from 18.2 mgO/L to 0.74 mgO/L. After 2.3 L of water loading, the $COD_{OH}$ of final loaded water was 1.6mgO/L, suggesting that this apparatus still had a potential to purify the river. Therefore, these temporary devices for water purification were efficiently working for purification of polluted river water.

## CONCLUSIONS

An electricity-free system for activated carbon production by the steam activation was manufactured in collaboration with Hokkaido Univ. and LIPI, Serpong, Indonesia. In addition, we fabricated a mobile apparatus for river water purification from the materials available in Borneo in addition to the produced AC.

1. By using this furnace, Indonesian biomass, wood charcoal, peat soil, and coconut husk, could be converted to AC with significant adsorption performance.
2. Among the resources, peat soil yielded AC with the largest BET surface area. It is obviously suggested that peat soil is a promising source for AC in Borneo Island.
3. The dirty river waters from a creek and Kahayan river were decolorized and purified to drinkable water with less than one mgO/L of $COD_{OH}$.

Thus, we successfully fabricated a production system for drinkable water with an electricity-free furnace and purification apparatus.

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