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# TREATMENT EFFICIENCY AND COMPRESSIBILITY BEHAVIOR OF SOIL MODIFIED WITH POWDERED ACTIVATED CARBON

*Mohd Yuhyi Mohd Tadza[1], and Fauzi Baharudin[2]
[1]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, Malaysia [2]Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia

* Mohd Yuhyi, Received: 00June 2016, Revised: 00 June 2016, Accepted: 00 0000 2016

**ABSTRACT:** Riverbank filtration (RBF) systems are often used to treat surface water near rivers. The effectiveness of such systems depends heavily on the properties of the riverbank material that is used for filtering and treating the water. To improve the system's treatment efficiency, modifications may be conducted to the riverbank soil. Altering the properties of the soil might, however, affect the stability of the riverbank. In this study, soil and water samples near Lake Chini were collected and characterized. Filtration test was conducted to evaluate the efficiency of the soil in treating the water. The soil was modified by mixing it with powdered activated carbon (PAC) at varying percentage of 5 and 10%. In addition, compressibility test was carried out using a standard oedometer. Test results indicated that the soil alone was insufficient to treat the water to drinking water quality standards. Modification with activated carbon improved the water quality from Class II to Class I. However, compressibility test revealed that there were some changes to the pressure - void ratio relationship, indicating that the alteration of soil properties with the addition of activated carbon filters might affect the stability of the riverbank.

*Keywords: Riverbank Filtration, Water Treatment, Compressibility, Actived Carbon, Oedometer, Lake Chini*

## 1. INTRODUCTION

Lake Chini is the second largest natural riverine lake in Peninsular Malaysia [1]. The area with its diverse flora and fauna has been declared as Man and Biosphere Reserve by UNESCO in 2008 [2]. Despite being isolated, the lake is also home to the indigenous Jakun tribe [3]. For decades, the sustainability of the tribe is highly dependent on Chini's ecosystems for economic activities such as fishing, hunting and herb gathering. The Lake also provides fresh water for the tribe. In recent years however, Lake Chini has been developed for agricultural and tourism purposes, which have led to the deterioration of the lake [2][4]. High concentrations of contaminants from development activities resulted in the decrease in biodiversity as well as increased sedimentation in the lake [1]. Furthermore, chemical influx from the use of pesticides and fertilizers from nearby agricultural activities increased the chemical concentration in both water and sediment [5][6]. The construction of a small barrage downstream of Chini River to form a recreational lake has caused the water to become stagnant, resulting in higher pollution [1].

Studies have revealed that limited movement in a lake would severely affect its water quality [7]. Although the water quality of the lake has deteriorated over the years, communities of the Jakun tribe still rely on it as their sole source of fresh water. Due to the isolated nature of the lake, the construction of a water treatment plant would be challenging. Riverbank filtration (RBF) has been used successfully in treating surface water nearby rivers [8][9]. The system utilizes riverbanks as filtration media for the removal of contaminants and suspended solids in order to improve the quality of surface water [10][11]. Thus, RBF would be a viable alternative solution for supplying sustainable fresh water within the vicinity. However, the efficiency of the RBF system depends on the type, as well as the filtration and absorption capacity of the riverbank material [12]. In some cases, modification of the riverbank with other filtration material (i.e. sand, activated carbon, zeolite) or the construction of artificial barriers may be required to increase the riverbank's treatment efficiency to produce water of drinking water standards [13][14].

Both granular activated carbon (GAC) and powdered activated carbon (PAC) have been extensively and successfully used in water treatment applications [15][16][17]. They have been proven to be effective adsorbing agents for the removal of a wide range of organic and inorganic pollutants from water bodies. They are also capable of removing taste and odor from wastewater [18]. Modification of the riverbank with activated carbon filters however, may affect the stability of the riverbank. Malusis et al., [19] reported that soil modified with activated carbon up to 10% by weight would result in decreased permeability and increased compressibility. Thus, in constructing a RBF, the balance between water treatment efficiency and the compressibility should be taken into consideration.

To tackle the aforementioned issues, this study investigated the treatment efficiency of natural soil from Lake Chini as well as soil that has been modified with PAC in laboratory column tests. The compressibility behaviors (pressure-void ratio relationships) of both natural and modified soils were also evaluated using the double oedometer technique.

## 2. MATERIAL AND METHODS

### 2.1 Sampling

Soil sampling was carried out at selected sites at Kuala Brang around the Lake Chini area. Using a hand auger, undisturbed soil samples were collected to a depth of 1 meter below the ground surface. The samples were placed in sealed bags prior to being tested in the laboratory. Water samples were also collected from the lake. The samples were stored in plastic containers and chilled at 4 ± 1°C.

### 2.2 Determination of Soil Geotechnical Properties and Water Quality Parameters

The geotechnical properties namely, specific gravity, particle size distribution, liquid and plastic limits and organic content of both unmodified and PAC-modified soils were determined according to BS1377 standard laboratory procedures. The six main water quality parameters namely dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (AN), suspended solids (SS) and pH were determined in accordance with AHPA standard method procedures [20]. The water quality parameters were then used to calculate the Malaysian water quality index (WQI) as described by Norhayati *et al*. [21] using the following equation:

$$WQI = 0.22(SI\ DO) + 0.19(SI\ BOD) + 0.16(SI\ COD) + 015(SI\ AN) + 0.16(SI\ SS) + 0.12(SI\ pH) \quad (1)$$

where *SI* is the sub-index function of each given parameter. The water quality was later classified according to the Interim Water Quality Standards (INWQS). The apparent water quality, namely turbidity, was also measured. Each test was conducted in triplicates to ensure the reliability of the readings.

### 2.3 Adsorption and Filtration Tests

A simple adsorption test was conducted before the column filtration test was carried out. The adsorption tests were carried out at varying intervals of 5, 15, 30, 60 and 120 minutes on soil specimens which were slowly agitated (i.e. 100 rpm) in 500 ml conical flasks on an orbital shaker. Similar tests were carried out on soil specimens that have been mixed with PAC (Sigma-Aldrich) (at 5 and 10% by weight). The PAC used in this study has a particle distribution finer than 142 $\mu$m and a specific surface area of about 900 $m^2$/g. Turbidity improvement was the only parameter evaluated in this test. The above tests were conducted to determine (i) the optimum hydraulic retention time (HRT) and (ii) the optimum mixture of soil and activated carbon. Once the optimum conditions have been determined, column filtration was carried out using a standard falling head apparatus. The water samples were retained in the column in accordance with the optimum HRT that has been determined in the adsorption tests.

### 2.4 Compressibility Behavior

The volume change behaviors of both unmodified and PAC-modified soils were carried out simultaneously using the standard oedometer method [19]. It is anticipated that changes in the pore fluid ionic concentrations would affect the engineering behavior of soils [22][23][24]. Estabragh *et al*. [25] noted that the magnitude of soil deformation is affected by the water quality. In order to replicate the on-site interaction between water from the lake and the soil in terms of volume change behavior, the distilled water in the standard oedometer method was replaced with the water samples obtained from Lake Chini. Soil specimens were initially prepared by thoroughly mixing with water samples from the lake to slightly greater than liquid limit before being carefully placed inside the oedometer rings. A total of 8 specimens of each soil were tested at varying pressures of 0.125, 0.25, 0.50, 1.02, 2.03, 4.06, 8.13 and 16.26 MPa. Duplicate specimens were prepared at different applied vertical pressures.

## 3. RESULTS AND DISCUSSION

### 3.1 Soil Geotechnical Properties and Water Quality Parameters

The geotechnical properties and mean initial water quality parameters are presented in Table 1. It was found out that the soil contained a high amount of fine-grained fractions. The soil was also found to have low plasticity characteristics with a plasticity index of 12.46. Under the INWQS, the water was classified as Class II, which is suitable for recreational activities and direct contact with the human body. Based on this classification, the water in the lake is not suitable for direct consumption and hence, some treatment would be required to improve the water quality to Class I (i.e. drinkable level).

Table 1 Geotechnical properties and mean initial water quality parameters

| **Geotechnical properties** | |
|---|---|
| Specific gravity, G*s* | 2.67 |
| Liquid limit, *wl* (%) | 39.38 |
| Plastic limit, *wp* (%) | 26.92 |
| Particle size distribution % Passing (< 2 mm) | 63 |
| **Mean initial water quality parameters*** | |
| BOD (mg/l) | 8.04 |
| COD (mg/l) | 16.43 |
| DO (mg/l) | 5.20 |
| AN (mg/l) | 0.08 |
| SS (mg/l) | 12.74 |
| pH | 6.57 |
| Turbidity (NTU) | 181.1 |

*INWQS – Class I => 92.7 (no treatment required); Class II = 76.5-92.7 (conventional treatment required), Class III = 51.9-76.5 (extensive treatment required); Class IV = 31.0-51.9 (suitable for irrigation only); Class V =< 31.0 (heavily contaminated - not suitable for daily use).

### 3.2 Adsorption and Filtration Test Results

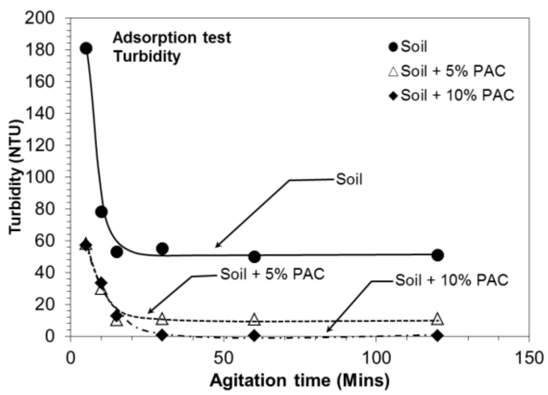


Fig. 1 Changes in turbidity with agitation time

Figure 1 shows the changes in turbidity with elapsed time for unmodified soil and soil mixed with PAC. Adsorption test results indicated that, the turbidity of the water decreased with increasing agitation time. A period of approximately 30 minutes was found to be sufficient for the turbidity readings to be equilibrated. Figure 1 also shows that, the turbidity decreased as the percentage of PAC increased. Interestingly, in the absence of PAC, the soil alone was found to be ineffective in reducing the turbidity to Class I (i.e. NTU <50). Thus, constructing RBF in the area would require some modifications to the existing riverbank.

Based on the adsorption test results (see Fig. 1), the filtration test was subsequently conducted only on the unmodified soil and soil mixed with 10% PAC. The filtration test results are presented in Table. 2. Some improvements on the water quality (i.e. water quality improved to Class I) were observed after the filtration test for both soils with and without the presence of PAC. However, no reduction in BOD, COD and DO concentrations were obtained following the filtration tests (i.e. water remained as Class II). In other words, no treatment is required for the water filtered using soil and 10% PAC mixture. Slight increase in the pH was observed due to the presence of PAC. Similar findings were also reported i.e. increased in pH with the presence of activated carbon [26][27].

Table 2 Improvement in water quality after filtration test

| **Water quality parameters*** | Soil | Soil + 10% PAC |
|---|---|---|
| BOD (mg/l) | 7.98 | 6.57 |
| COD (mg/l) | 16.45 | 16.1 |
| DO (mg/l) | 5.31 | 6.83 |
| AN (mg/l) | 0.03 | ND* |
| SS (mg/l) | 10.59 | 0.06 |
| pH | 6.57 | 7.14 |
| Turbidity (NTU) | 55 | 0.18 |

*ND – non detected

### 3.2 Compressibility behavior – pressure-void ratio relationships

Table 3 Effect of 10% PAC on the geotechnical properties of the soil studied

| **Geotechnical properties** | |
|---|---|
| Specific gravity, G*s* | 2.64 |
| Liquid limit, *wl* (%) | 42.13 |
| Plastic limit, *wp* (%) | 27.56 |

The effect of PAC on the geotechnical properties of the soil is shown in Table 3. Test results showed that the addition of PAC caused the specific gravity of the soil mixture to go down. However, the larger specific surface area resulted in increases in the liquid limit and plastic limit for the soil mixture.

The compression results from the oedometer tests are plotted in terms of void ratio, *e* and applied vertical pressures, *P* as shown in Fig. 2. A decrease in the void ratios was noted with an increase in the applied vertical pressures. Test results revealed that at the same applied pressures, there were differences in the void ratios between the unmodified soil and the soil with 10% PAC. Addition of PAC would result in some decrease in the void ratio, irrespective of the applied pressure.

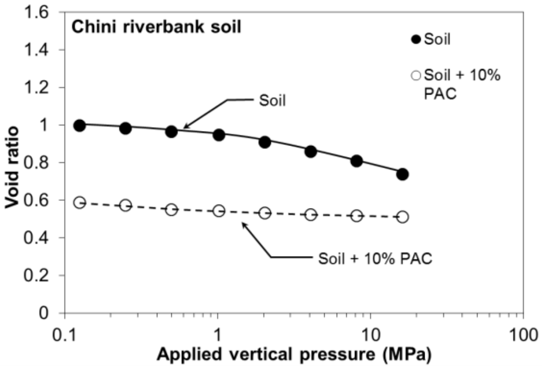


Fig. 2. Pressure – void ratio relationships

Similar observation on the behavior of soil modified with GAC and PAC was reported by Malusis et al. [19]. Calculation of the compression index was carried out using Eq. 1 following Herrero [28].

$$C_C = 0.185\left[G_S\left(\frac{\gamma_w}{\gamma_d}\right)^2\right] - 0.144 \qquad (1)$$

where $Cc$ is the compression index, $Gs$ is the specific gravity of soil solids, $\gamma_w$ is unit weight of water in kN/m$^3$ and $\gamma_d$ is dry unit weight of soil in kN/m$^3$. The $Cc$ values calculated were found to be 0.24 and 0.27 for unmodified soil and soil-PAC mixture, respectively. Addition of PAC is expected to cause slight reduction in the microstructural rigidity of the soil skeleton [19]. Furthermore, since the compressive strength of PAC is lower than soil, rearrangement in the microstructure is expected to occur.

These results also suggest that, the stability of a riverbank may be affected when modified with PAC, even though some improvements in the water quality were obtained (see Tables 1 and 2). The results also suggest that determination of appropriate percentage of PAC is crucial in maintaining the stability of the riverbank without jeopardizing the water quality. Construction of artificial barriers could therefore be considered as an alternative option to RBF in areas where instability and volume change issues could arise with riverbanks that are modified for RBF purposes.

## 4. CONCLUSION

The aboriginal Jakun community living around Lake Chini deserves a supply of clean water. The Lake has also grown to be a popular tourist destination. The need for water treatment to improve its water quality is becoming more imperative. The viability of modifying the Lake Chini riverbank material with PAC was investigated and evaluated in terms of treatment efficiency and compressibility behavior. Results of this study showed that the existing riverbank material was ineffective in improving the water from Class II to Class I. Modification of the riverbank material is therefore necessary. The addition of PAC improved several water quality parameters except BOD, COD and DO, from Class II to Class I. However, the addition of PAC up to 10% resulted in the reduction of the void ratios which might lead to instability of the banks. An alternative option to RBF would be the construction of artificial barriers on Lake Chini riverbanks to improve its water quality so as to be fit for drinking and other consumption purposes.

## 5. ACKNOWLEDGEMENTS

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