Effect of Activated Carbon Fibre in Decentralized Household Drinking Water Purification System

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Abstract

An intermittently operated slow sand filter combined with activated carbon fibre (ACF) was investigated for the development of a low cost household drinking water purification system for remote rural areas of developing countries. Two series of field-scale experiments were carried out to evaluate the efficiency of the water treatment system. The experimental unit was an acrylic rectangular tank, 60 cm in length, 20 cm in width and 70 cm in height with five internal compartments. These compartments were designed to maximize the water flowline through the unit. Experimental results showed that a higher degree of water purification was achieved with a combination of ACF and slow sand filtration than with slow sand filtration alone. Average removal efficiencies obtained from the unit with ACF for suspended solids, turbidity, iron and fecal coliform were 75%, 72%, 89% and 100 % respectively. ACF was found to play an important role in the removal of colour, chemical oxygen demand (COD), and manganese. The average removal efficiencies were found to be 82%, 92% and 95 % respectively. In addition, ACF had little effect on the development of head loss in the system.

Keywords: Activated carbon fibre, adsorption, slow sand filtration, drinking water

1. Introduction

It is estimated that about a fifth of the world's population, that is over one billion people, lack access to safe drinking water. The World Health Organization (WHO) suggests slow sand filtration as the most effective single process for improving the physical, chemical and bacteriological quality of normal surface water [1]. Raw water passing through the sand brings particulate organic matter into direct contact with individual sand grains, where it becomes attached to the sand. This process can be said to comprise three stages; collision, attachment, and biodegradation [2]. Activated carbon fibre (ACF) has been widely applied to water purification systems in recent years [3]. ACF effectively adsorbs and removes a broad spectrum of harmful substances [4, 5]. Activated carbon fibre can be obtained from appropriate fibrous precursors such as cellulose, resin, pitch or polyacrylonitrile (PAN) fibres, following adequate carbonization and activation; they are first pyrolysed and activated at a temperature of 700-1000°C in an atmosphere of steam or carbon dioxide [6, 7]. ACF has become popular for use in water purification because of its higher adsorption rate and capacities compared to other granular adsorbents, such as granular activated carbon (GAC) or powdered activated carbon (PAC) [7]. The adsorption kinetics and capacities for ACF are 10 to 100 times higher than these traditional adsorbents. It is thought that ACF's faster adsorption rate compared to GAC is due to its higher surface area. It arises from ACF's uniform micro-porous structure and graphite-like molecular characteristics [4, 5, 6].

A Drinking water purification system should give a final effluent water in line with the World Health Organization's (WHO) guidelines for drinking water quality. To date, few researchers have investigated the use of small-scale decentralized sand filtration units for household use. Slow sand filtration (SSF) is more commonly used on a much larger scale in centralized water purification systems for urban centers [7, 8]. In this study, two series of field-scale experiments were carried out to investigate the performance of the newly invented water purification system (combined activated carbon fibre and slow sand filtration) from Asian Institute of Technology, Thailand [3]. As this system has a potential to be a low-cost and low-maintenance for water purification it can be implemented in remote and rural areas of developing countries. The effect of applying ACF to the small-scale slow sand filter was investigated in this study. Water quality parameters such as colour, suspended solids and turbidity were monitored throughout the study to evaluate the performance of the SSF with and without ACF.

Table 1 Characteristics of raw water

Parameter	Unit	Concentration
Turbidity	NTU	4.5-18.0
Color	ADMI	4.0-14.0
TSS	mg/L	11.8-23.0
Iron	mg/L	0.1-0.3
Manganese	mg/L	0.2-0.3
Total hardness	mg/L	41.3-74.6
Chlorophyll- A	μg/L	3.2-23.6
COD	mg/L	27.1-32.1
Fecal coliform	CFU/100 mL	4.0-13.0

2. Materials and methods

2.1 Construction of water purification system

Fig. 1 shows a schematic diagram of the decentralised household water filter. The filter housing was constructed using 10mm acrylic plate (20 x 60 x 70 cm, width x length x height respectively). The unit was designed with five separate compartments to facilitate increased water flow in the system. The function of each compartment is as follows: **A**. Aerated zone with small gravel layer for regulating raw water flow rate, facilitating micro-organism growth and reducing odour. **B**. Transition to fine sand filtration. A sand bag packed with fine sand was installed between compartments A and B acting as an initial screen and filter. The sand bag can be easily removed and cleaned if water flow is impeded due to suspended solids build up. **C**. Down flow slow sand filtration zone. **D**. Upflow slow sand filtration zone. **E**. ACF and effluent zones. The raw water used for the experiment was taken from the surface water ponds adjacent to the Environmental Engineering laboratories at Asian Institute of Technology, Thailand. The characteristics of raw water used in the experiment are summarized in Table 1.

2.2 Preparation of activated carbon fibre and sand

The activated carbon fibre cartridge was manufactured from Kuractive 16 phenol-resin (Kuraray chemical Co., Japan). Average diameter of fibre was 14 μm while fibre length was kept less than 5 mm. The length and diameter of ACF cartridge were 10 cm and 5 cm respectively. The filtered effluents were collected inside of the ACF cartridge. Table 2 shows the physical properties of the ACF. Specific surface area of ACF (1500 m^2/g) was almost 10 to 100 times that compared to GAC (10-150 m^2/g). From the average pore radius and micro-pore volume, it was apparent that micro-pores dominate the surface of ACF. The micro-pore portion in this ACF was found to be 94% (1,500 m^2/g out of 1,600 m^2/g).

Table 2 Physical properties of ACF

Properties	Unit	Value
Surface area	m^2/g	1,600
Average pore radius		7.7
Micro-pore area	m^2/g	1,500
Total-pore volume	cc/g	0.63
Micro-pore volume	cc/g	0.52

Before starting the experiments, The ACF was immersed in distilled water for 24 hours to expel internal air. Physical properties of the fine sand used for slow sand filtration in the unit process are summarized in Table 3.Prior to filling the system with sand, sieving of sand was carried out in order to narrow the distribution of sand grain size. The uniformity coefficient (UC) of the fine sand (d_{60}/ d_{10}) was found to 2.4, which exceeds the recommended value of UC ≤2 [9]. Use of sand which has a UC value above the recommeneded UC≤2 would result in reduced filtration efficiency. To overcome this problem, sand of grain size d_{10}= 0.35 mm, UC =2.0 and diameter 0.50 to1.18 mm was selected for use in the water purification unit.

Table 3 Physical properties of sand medium

Parameter	Value
Coarse sand % <2.00 mm	25.7
Fine sand % 1.00 mm	71.0
Clay and silts	3.3
Porosity	0.49

2.3 Experimental operation

The filter was operated manually. A premeasured volume of diluted raw water was poured slowly into the influent tank and the effluent tap was opened in order to allow water flow freely through each compartment under the influence of gravity. During each subsequent operational phase, the unit was monitored in terms of flow and pressure by using a flow meter and a manometer. Headloss was monitored throughout the operation of the system. Average headloss development in SSF without ACF was 27.5 cm while it was 34.1 cm with ACF. Filtration rate in the water filter purification system was maintained to 1.5L/min throughout the operational period. Influent and effluent water quality was analysed at the regular time interval following APHA- AWWA – WPCF guidelines using Standard Methods for Examination of Water and Wastewater [10].

3. Results and discussion

3.1 Color removal

Colour removal from the SSF unit is shown in Fig. 2. The colour removal efficiency was 82.5%-90% with ACF and 40-60% without ACF in the unit. The corresponding concentrations at effluent range from 4 to 14 ADMI and less than 3 ADMI, respectively. The influent raw water concentration of what for the unit with ACF was higher than for the unit without ACF. The results show the higher removal efficiency from SSF with ACF indicating the effectiveness of ACF in removing color. ACF's catalytic properties and higher surface area act as an effective adsorbent on removing broad ranges of organic and inorganic substances including many pollutants such as pesticides [11, 12].

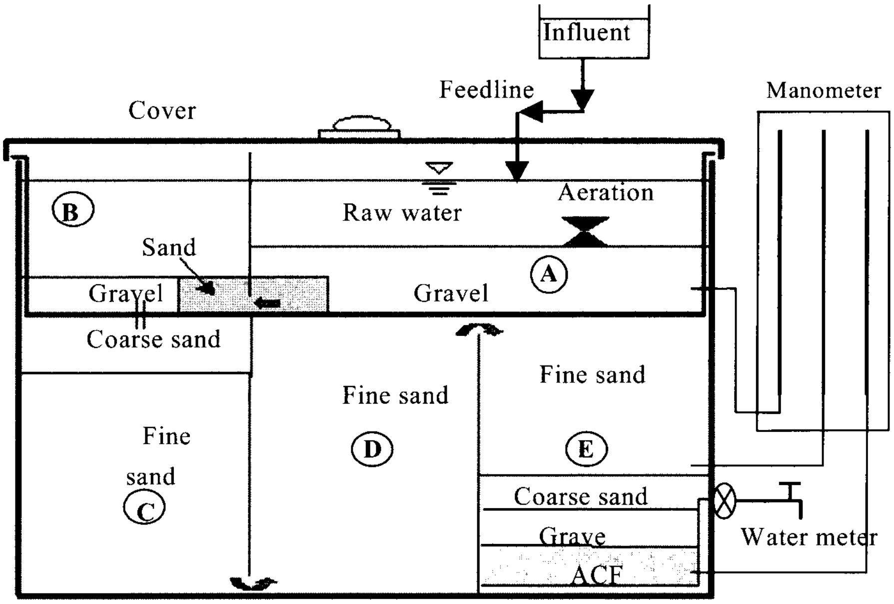
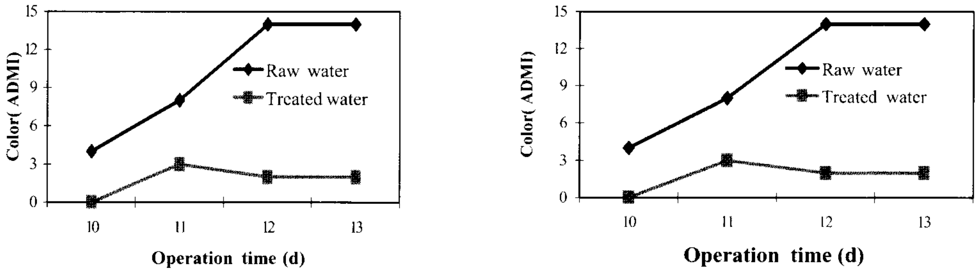


Figure 1 Schematic diagram of the household water filter



a. without ACF

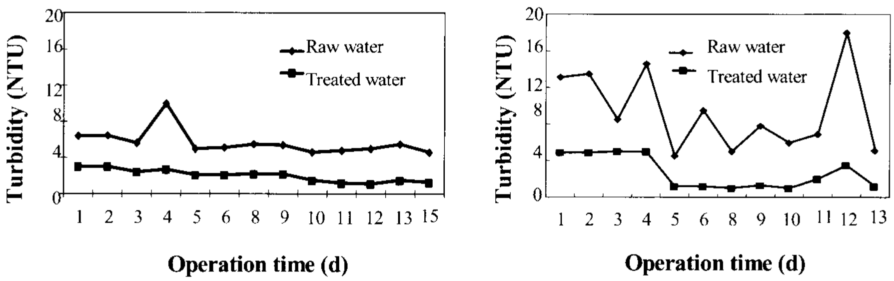
b.with ACF

Figure 2 Variation of color in effluent

3.2 Turbidity and Total Suspended Solids (TSS) removals

Turbidity level variation from SSF with and without ACF is shown in Fig. 3. Removal efficiency for turbidity with ACF was 71% - 83 %, which was slightly higher than turbidity removal efficiency without ACF (53.2 - 80.0%). This may be due to the effect of the consolidation of a fine sand layer in the filter or because ACF was absent from the system.

Suspended solids (SS) is one of the most important water quality parameters, which was monitored throughout the experiments at different time interval. Average removal efficiency with ACF was found to be 75% which was slightly higher than that without ACF (74%). These results show that ACF had little effect on the removal of suspended solids. This result reflects the degree to which the slow sand filter itself effectively removes suspended solids from the water



a. without ACF

b. with ACF

Figure 3 Variation of turbidity in effluent in SSF

3.3 Iron and manganese removal

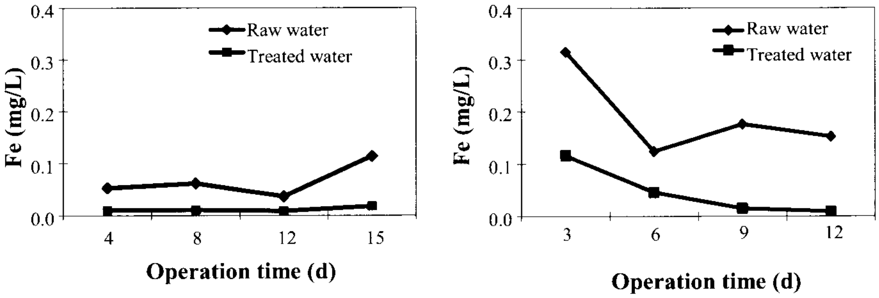
Fig. 4 shows the concentration of iron in raw water and treated water with ACF and without ACF in the unit. The removal efficiency was 82% with ACF and 89% in without ACF. The corresponding final effluent concentration was found to be 0.01 - 0.02 mg/L and 0.01 - 0.12 mg/L respectively. The removal efficiency for iron from the unit was almost similar in The presence and absence of the ACF. The unit was effective in removing iron while the ACF did not help.

It was reported that a few millimetres below the Schmutzdecke is an autotrophic zone where growing microflora metabolize organic matter [13]. In the process carbon dioxide is utilized and some oxygen released. The reaction pathway is shown below, which is the most probable path of iron removal from the water, represented by equation 1.

$$Fe^{2+} + O_2 + 10H_2O \longrightarrow 4\,Fe(OH)_3 + 8\,H^+ \quad \ldots(1)$$

Manganese removal from the SSF unit with and without ACF is shown in Fig. 5. The average manganese removal efficiency of the unit without ACF was 79% while it was 95% with ACF. High removal efficiency was achieved for both systems. The presence of the ACF in the unit further enhanced the removal of manganese.

Between 6 & 9 days, manganese was entirely removed from the water. WHO sets a maximum value for manganese in drinking water as 0.1 mg/L. Further study needs to be conducted before claiming this unit consistently provides effluent water containing manganese level of 0.1 mg/L or below, however, the unit shows good potential to be able to meet this standard.



a. without ACF b. with ACF

Figure 4 Variation of iron in effluent

a. without ACF b. with ACF

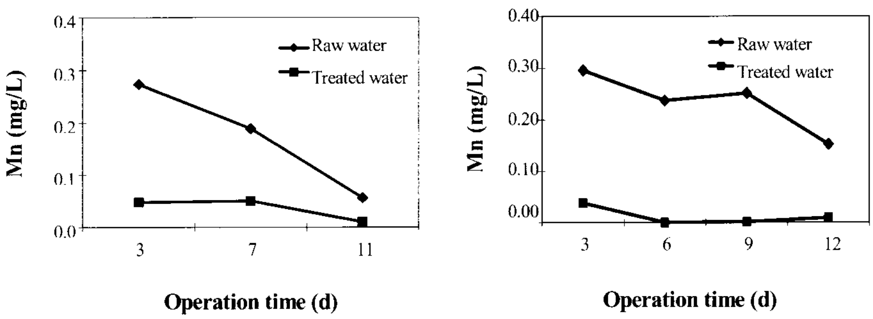


Figure 5 Variation of manganese in effluent

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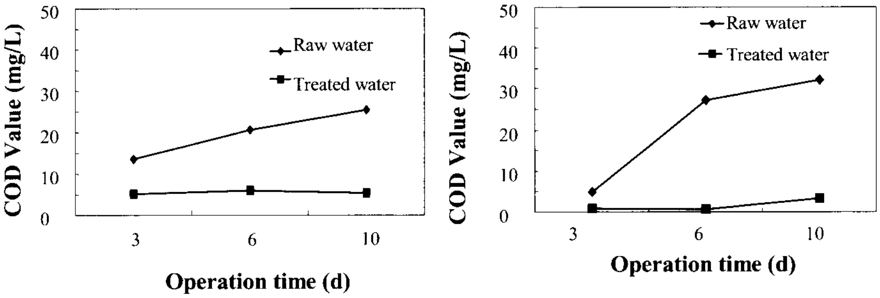

a. without ACF

b. with ACF

Figure 6 Variation of COD in effluent

3.4 COD removal

The standard chemical oxygen demand (COD) test can be applied to measure organic matter contained in wastewater as well as in natural water. The test is indicative of the potential biodegradability of different waters, depending on the degree of biodegradable matter present. The average COD removal efficiency with ACF was found to be 93.6% while it was only 72.4% without ACF. The details of removal of COD are shown in Fig.6. It is clear from these results that the use of ACF notably reduces the organic matter contained in the water giving a clarified effluent. A high proportion of the natural organic matter found in surface water consists of humic substances, proteins, carbohydrates and lipids [14]. Removal of such substances from the water passing through the experimental unit occurred in two ways, via the "Schmutzere" or biofilm and by the ACF itself, which acts as a repository for organic substances, adsorbing them into its microporous structure [15].

3.5 Other types of water quality parameters

Table 4 summarizes the average removal efficiency of the unit for different water quality parameters analysed during experiments. The unit was not effective in removing hardness of the water. Ca^{2+} and Mg^{2+} ions are dissolved in water and cannot be removed by both SSF and ACF. The unit was found to be efficient in removing bacteria and fecal coliform. Coliform count for both conditions was found as zero at the final effluent. Chlorophyll- A removal ranged from 90% to 100%. The result showed that most of the water quality parameters removal increased in the presence of the ACF in the unit. The increment in the removal efficiency was found to be more than 10% for colour, manganese, chlorophyll-A and fecal coliform.

Table 4 Average removal efficiencies of various types of water quality parameters

Parameter	Without ACF (%)	With ACF (%)	Increments (%)
Turbidity	64	72	+8
Color	67	82	+15
TSS	74	75	+1
Iron	82	89	+7
Manganese	79	95	+18
Total hardness	0	0	0
Chlorophyll- A	90	100	+10
COD	72	92	+20
Fecal coliform	100	100	0

4. Conclusion

SSF was found consistently superior in removing many water quality parameters the when ACF was added. ACF played an important role in removing color. Its content at the final effluent was reduced by 82.4% while it was reduced by only 67% in the absence of ACF. Similarly, COD removal was found to be 92%, which was about 20% higher removal than in the absence of ACF. Manganese removal was 95%, the higher removal of it could be due to the catalytic effect of ACF and chemical oxidation in the autotrophic zone of the SSF. SSF in the absence of ACF was enough in removing iron from influent water. Turbidity and TSS removal increased by small percentages when ACF was introduced in the SSF unit. Combining SSF with a ACF enhanced the water purification process of SSF. It shows that SSF with ACF unit has good potential to meet WHO guidelines for water purification.

5. Acknowledgement

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6. References

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