Membrane Water Treatment, *Vol. 6*, *No. 4* (*2015*) *339-349*
DOI: http://dx.doi.org/10.12989/mwt.2015.6.4.339

Performance of GACC and GACP to treat institutional wastewater: A sustainable technique

Mohammed R. Khaleel [1], Amimul Ahsan [*1,2], M. Imteaz [3], M.M. El-Sergany [4], N.N. Nik Daud [1], T.A. Mohamed [1] and Buthainah A. Ibrahim [5]

[1] *Department of Civil Engineering, and Institute of Advanced Technology, University Putra Malaysia, UPM 43400, Serdang, Selangor, Malaysia*
[2] *Department of Civil and Environmental Engineering, University of Sharjah, PO Box 27272, UAE*
[3] *Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Melbourne, Australia*
[4] *e-School of Health and Environmental Studies, Hamdan Bin Mohamed Smart University, Dubai, UAE*
[5] *Physics Department, Science Faculty, Diyala University, Baquba, Iraq*

(*Received November 19, 2014, Revised May 16, 2015, Accepted June 02, 2015*)

Abstract. Experiments were carried out using granular activated carbon (GAC) adsorption techniques to treat wastewater contaminated with organic compounds caused by diverse human activities. Two techniques were assessed: adsorbent GAC prepared from coconut shell (GACC) and adsorbent GAC from palm shell (GACP). A comparison of these two techniques was undertaken to identify ways to improve the efficiency of the treatment process. Analysis of the processed wastewater showed that with GACC the removal efficiency of biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, total suspended solids (TSS) and total dissolved solids (TDS) was 65, 60, 82, 82 and 8.7%, respectively, while in the case of GACP, the removal efficiency was 55, 60, 81, 91 and 22%, respectively. It can therefore be concluded that GACC is more effective than GACP for BOD removal, while GACP is better than GACC for TSS and TDS removal. It was also found that for COD and turbidity almost the same results were achieved by the two techniques. In addition, it was observed that both GACC and GACP reduced pH value to 7.9 after 24 hrs. Moreover, the optimal time period for removal of BOD and TDS was 1 hr and 3 hrs, respectively, for both techniques.

Keywords: institutional wastewater; activated carbon; pollutants; BOD; COD

1. Introduction

In recent years, effluent standards have become more stringent in an effort to minimize the impact of aqueous discharges into the environment. This has led to a growing need to improve the efficiency of wastewater treatment plants (Ulson de Souza *et al*. 2009) and increasing focus on the removal of those organic substances in wastewater that significantly amplify the risks to the aquatic environment. The features of municipal wastewater differ by location depending on a variety of factors such as the economic status and food habits of the community, the water supply site and the weather conditions of the area. Thus the features of wastewater in Malaysia might be

*Corresponding author, Ph.D., E-mail: ashikcivil@yahoo.com; aahsan@eng.upm.edu.my

http://www.techno-press.org/?journal=mwt&subpage=7 ISSN: 2005-8624 (Print), 2092-7037 (Online)

different from those in the USA. An analysis of the physical, chemical and biological features of wastewater has been conducted to find means of reducing the various pollutant absorptions (Ismaiel *et al*. 2013).

The conventional treatments of wastewater include chemical treatment, physicochemical treatment, biological treatment, and a combination thereof. However, because of the technological limitations and the differences in wastewater, many issues still need to be resolved to develop more efficient treatment processes, such as finding a way to reduce the low chemical oxygen demand (COD) degradation rate (Song *et al*. 2009). Also, because of the occurrence of water flowback into the water supply, it is essential to develop pollution avoidance methods that can reduce biochemical oxygen demand (BOD), pH, and COD. Also, better techniques are needed to reduce the proportion of total dissolved solids (TDS) and total suspended solids (TSS). In experiments, it has been observed that a considerable proportion of COD and BOD (71.1% and 75.6%, respectively) can be eliminated by the retting of wastewater by granular activated carbon (GAC) adsorption as compared to using jute processing waste (JPW) that results in a reduction of 13.8% and 33.3%, respectively (Sobhan and Sternberg 1999). To further improve these efficiencies in a more environment-friendly way, other solutions for wastewater treatment have been developed, one of which is the use of a natural substance, activated carbon (Karanfil and Kilduff 1999).

Activated carbon consists of microcrystallines that have blended hexagonal rings of carbon atoms, the formation of which is somewhat similar to graphite. There are spaces between the individual microcrystallines named micropores and these enable adsorption (Snoeyink *et al*. 1969). Activated carbon can be produced by using a simple technology (Rahman *et al*. 2013). Granular activated carbon (GAC) is a type of activated carbon usually found in the crushed granules of coal or in some shells such as coconut and palm (Meng *et al*. 2010). In fact, this type of carbon can be made from a range of carbon-based materials by using a high-temperature process to create a matrix of thousands of crevices and microscopic atoms. An amount of 1 lb of activated carbon has a surface area of 500–1500 m^2/g. The pores catch organic molecules and microscopic atoms at the same time as the activated surface area adsorbs or sticks to the organic molecules (Bhandari and Nayal 2008). Granular activated carbon adsorption has been used in the third-stage treatment of municipal and manufacturing wastewater (i.e., as a physicochemical treatment after second-stage treatment) or as a step in a physicochemical treatment series (coagulation, settling, filtration, GAC adsorption) in the place of biologic treatment. If it is used as a third treatment, GAC chiefly adsorbs the organic molecules that have not been removed by biologic treatment (Snoeyink *et al*. 1969, Weber *et al*. 1970).

Adsorption is considered one of the more efficient methods to treat wastewater and researchers have recognized that activated carbon can adsorb the compounds in wastewater effectively (Vyrides and Stuckey 2009). Rouabeh and Amrani (2012) reported the equilibrium modeling for adsorption of $NO3^{-}$ from aqueous solution on activated carbon. GAC adsorption is currently the most common method for treating wastewater; however, this type of treatment is costly (Hameed *et al***.** 2008). Carbon adsorption is one of the most commonly used and well-established techniques for home water treatment as it can eliminate unpleasant tastes and smells, including chlorine. Although activated carbon filters consist of a single piece of equipment, they are considered to be the best type of purification apparatus because they can remove many chemicals and gases. Moreover, sometimes they can also remove microorganisms. In addition, some activated carbon filter systems are considered the best way to remove lead, asbestos, volatile organic compounds (VOCs), cysts, and coliform (Çeçen and Aktaş 2011). For instance, the efficiency of a pilot plant in removing BOD was found to be 60.8%, where the BOD of the inlet sample ranged from 150 to 200 mg/l. Activated carbon reduced the BOD of the final tank to 50-90 mg/l (Gao *et al*. 2008). Moreover, the GAC technique has been found to remove a very high proportion of phenols (96%), turbidity (99%) and color (99%) from wastewater (Cyr *et al*. 2002).

Depending on the activation process and the raw material, a wide range of pore structures in activated carbon can remove multi-pollutants from surface water, groundwater, wastewater and industrial effluents including pesticides, nitrate and endocrine disrupting chemicals (EDC) such as nonylphenol, amitrol and bisphenol-A (Brennan *et al*. 2002, Choi *et al*. 2005, Ioannidou and Zabaniotou 2007). Besides wastewater, the landfill leachate can be treated by activated carbon and electrolysis (Rada *et al*. 2013, Fernandes *et al*. 2014, Ahsan *et al*. 2014, Rahman *et al*. 2014, Kabuk *et al*. 2013).

In light of the foregoing potential of GAC, in this paper, the results of experiments utilizing GAC prepared from coconut shell (GACC) and GAC from palm shell (GACP) were presented to reduce BOD, COD, turbidity, TDS, TSS and pH in wastewater. A comparison of these two techniques was undertaken to identify ways to improve the efficiency of the treatment process.

2. Materials and methods

2.1 Materials

The raw wastewater was sampled from a treatment plant (small-scale) in Putra University, Malaysia. This water is the used for various activities by several parts of the university such as administrative buildings, the restaurant, dormitories and laboratories, all of which produce different organic and inorganic pollutants. In addition, the water also contained a chemical contaminant discharged on occasion from the laboratories, which makes the water more difficult and complex to treat. The details of the raw wastewater quality are shown in Table 1.

The pilot plant is a laboratory experimental scale model for treating wastewater. As shown in Fig. 1, it consists of a storage tank, a sand filter, a GAC filter and final tank. The storage tank is 30 cm in depth, 60 cm in length and 30 cm in width. The waste matter is gathered from the existing plant and it can store about 10 L of wastewater. The sand filter container is made of fiber glass and measures 35cm deep and 40 cm in diameter and contains seven graded layers of gravel (14 mm, 8 mm, 4.75 mm, 2 mm, 850 μm, 600 μm) each having a thickness of 5 cm. A GACC filter and a GACP filter are used in the pilot plant. The size of the activated carbon tank is 20 cm long, 20 cm

Table 1 Concentration of the wastewater constituents

Parameters	Raw WW	Sand filter	GACP (CT = 0.1 hr)	GACC (CT = 0.1 hr)
BOD (mg/l)	300	275	240	195
pH	7.35	6.76	8.41	9.27
Total dissolved solids (ppm)	230	230	560	2290
Total suspended solids (ppm)	22	4.4	18	47
Turbidity (NTU)	35.78	7.83	6.76	25.67
Salinity (ppm)	150	160	400	1630
Electrical conductivity (μs/cm)	345	327.4	806	3290

*Note: WW = Wastewater; CT = Contact time

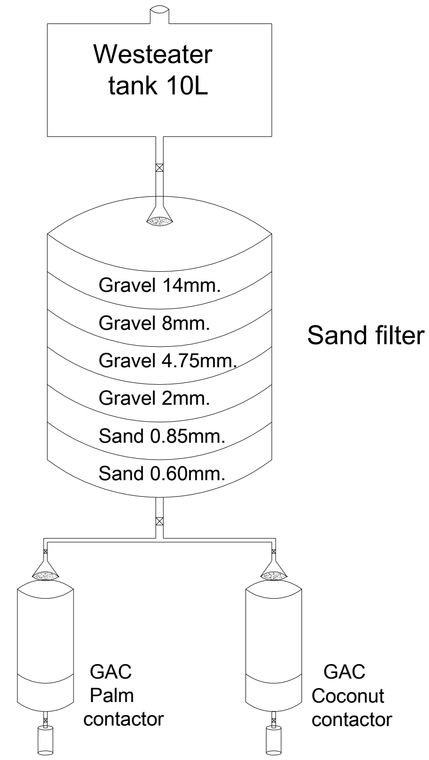

Fig. 1 Experimental setup of GAC contactor

in wide and 30 cm high. The final tank is 20 cm in depth and 15 cm in diameter. The treated water is gathered as the sample in the final tank.

2.2 Methods

An experiment was performed at room temperature using the setup shown in Fig. 1 and adsorption using the batch mode was carried out. First, wastewater was injected into the sand filter system to pass through the several gravel layers and was then split between the two activated carbon tanks; the first tank was used to test the GACC technique and the second was used to test the GACP technique. Detention periods of 0.1, 1, 2, 3 and 24 hrs were selected to allow the effluent sufficient processing by the two separate techniques. Analyses of the treated samples of wastewater gathered in the final tank after these periods were conducted to assess the removal efficiencies for BOD, COD, turbidity, TDS, TSS and pH.

The adsorption process consists of three stages. The main stage, macrotransport, involves the movement of the organic objects through the water to the liquid-solid interface by advection and diffusion. Microtransport engages the dispersal of the organic objects through the micropore system of GAC to the adsorption positions in the micropores and submicropores of the GAC. Adsorption happens at the surface of the granule and in the micropores as well as mesopores. Nonetheless, in comparison with the surface area of the micropores and submicropores, the surface area of these elements of GAC is very small.

One can define sorption as the addition of organic objects to GAC. As it is difficult to distinguish between chemical and physical adsorption, researchers use sorption. As soon as the rate of sorption equates to the rate of desorption, balance is achieved and the capacity of the carbon is reached. The results of studies on pilot plants using GAC indicate that it is possible to remove TDS by using activated carbon in filters. However, it should be noted that the size of the activated carbon is very important in decreasing TDS. Previous research has found that when the particle size of the activated carbon is reduced, its efficiency is augmented as the surface area is increased and therefore TDS can be decreased substantially. However, using a very fine powder of activated carbon is not efficient enough while the porosity is augmented to a large extent (Kim 2002).

3. Results and discussion

3.1 pH

The initial pH was 7.35. In experiment, the pH value increased to 9.27 and 8.41 by GACC and GACP, respectively. Then, after 24 hrs, a reduction of the pH value to 7.9 for both GACC and GACP was observed, as shown in Fig. 2. Laboratory studies suggest that this rise in pH occurs when wastewater is treated by activated carbon because there is as an interaction between the naturally-occurring protons and anions in the wastewater and the carbon surface. This interaction can be described as an ion-exchange type of phenomenon in which the carbon surface sorbs the corresponding hydronium ions and anions from the water. Researchers have emphasized that the increment of the pH value is due to anion sorption. However, an increase of pH value is independent of the raw material that is used for the activated carbon whether it is sub-bituminous or produced, e.g., bituminous, coconut, wood or peat (Banerjee and Dastidar 2005).

3.2 BOD removal

The value of BOD in the inlet sample was 300 mg/l. At 0.1 hr, the BOD value was 195 mg/l by GACC and 240 mg/l by GACP as shown in Fig. 3. However, after 1 hr, BOD was 258 mg/l and 162 mg/l by GACC and GACP, respectively. A wide variation is observed between them due to the use of different properties of the carbon materials. This indicates that the GAC adsorption of

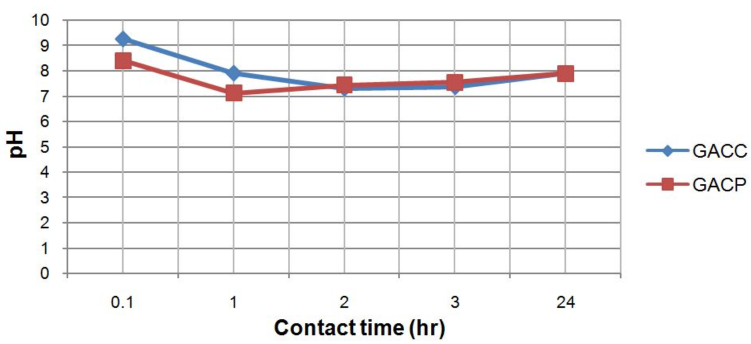

Fig. 2 Commercial GACC and GACP effect on pH

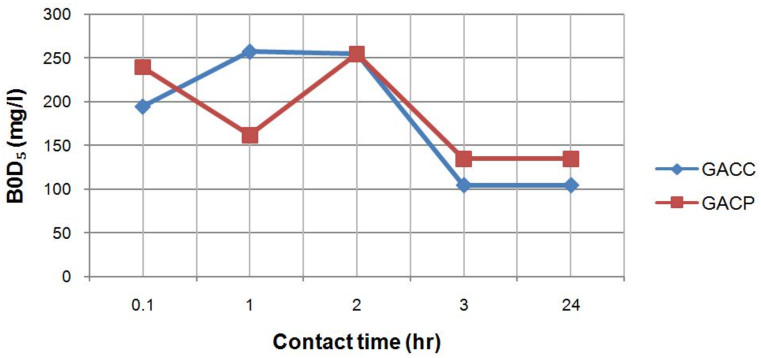

Fig. 3 Commercial GACC and GACP effect on BOD

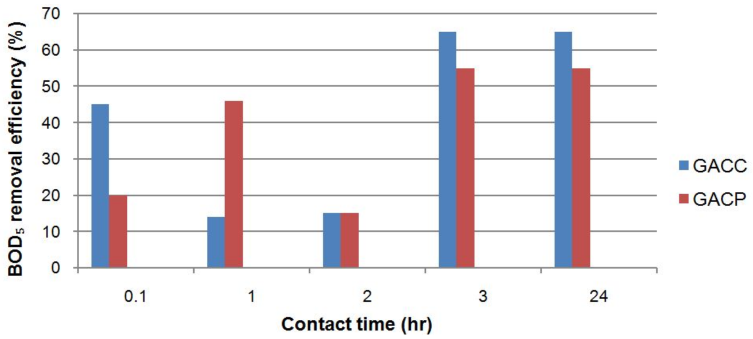

Fig. 4 Percentage removal of BOD_5 by using commercial GACC and GACP with different contact times

wastewater can be classified into three stages: first, a rapid adsorption process, then a gradual slowing down of adsorption and, finally, a balanced adsorption. These stages could be attributed to adsorbent surface adsorption, internal diffusion adsorption and adsorption equilibrium in turn. The time at which equilibrium was reached was almost 1 hr.

After 2 hrs, the value of BOD for both GACC and GACP was similar. At the end of 24hr experimental period, substantial removal of BOD (65%) was achieved by GACC, while 55% was removed by GACP, as shown in Fig. 4. Furthermore, it can be seen that no change occurred during the 3-24hr period. Therefore, it can be concluded that GAC reached saturation point at 3 hrs and was unable to reduce the BOD value further. In other words, the adsorption equilibrium of BOD approximately approached the same value during the 3-24hr period. Hence, the optimum time was 3 hrs for BOD removal.

3.3 COD removal

Fig. 5 illustrate that the COD for the inlet sample was 80 mg/l and this was reduced to 56 mg/l and 70.4 mg/l by GACC and at GACP techniques at 0.1 hr, respectively. However, the lowest value recorded for COD was 16 mg/l and 42 mg/l by GACC and GACP, respectively at 1 hr. The initial COD value was 64 mg/l in both GACC and GACP. This can be attributed to the dynamic equilibrium between desorption and adsorption. It is part of the organics (during the second and the third hour), which was adsorbed and then after saturation was desorbed, to lead to a slight reduction after the removal rate reached the maximum. The organics in wastewater diffused from activated carbon surface to inner pores as time went by and gradually became stable. This process could due to the stages of adsorbent surface adsorption, internal diffusion adsorption and adsorption equilibrium in turn. The time to reach equilibrium was between 2-3 hrs for GACC, whereas for GACP it was at the third hour. Bian *et al*. (2011) found the similar results. Thus, the kinetics of adsorption is affected quickly (up to 1 hr). After 24 hrs, the COD removal efficiency was 60% for both GACC and GACP (Fig. 6).

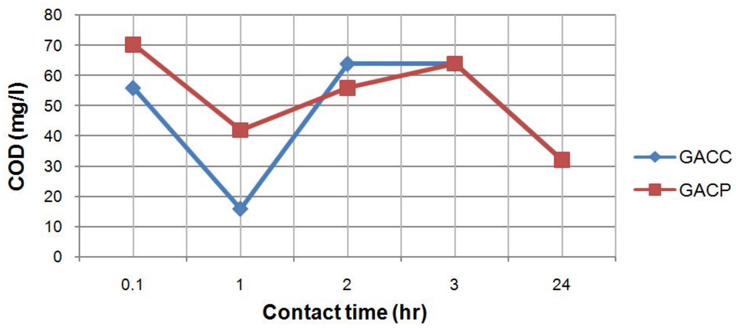

Fig. 5 Commercial GACC and GACP effect on COD

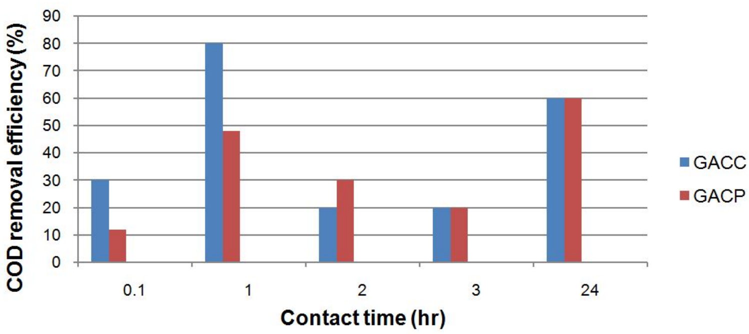

Fig. 6 Percentage removal of COD by using commercial GACC and GACP with different contact times

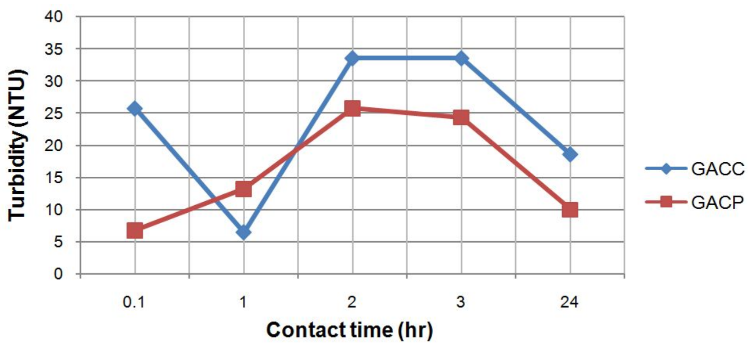

Fig. 7 Commercial GACC and GACP effect on turbidity

3.4 Turbidity removal

The turbidity of the inlet sample was 35.78 NTU. Figs. 7 and 8 show the measured turbidity of the effluent samples and the turbidity removal efficiency, respectively. The turbidity values were 25.76 NTU and 6.76 NTU by GACC and GACP techniques, respectively at 0.1 hr, respectively. However, the lowest value of turbidity was 6.44 NTU by GACC at 1 hr. At 24 hrs, the removal efficiency for turbidity was 72% and 48% by GACP and GACC, respectively.

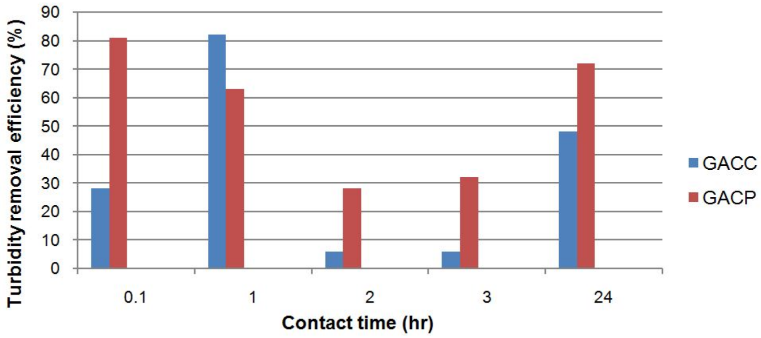

Fig. 8 Percentage removal of turbidity by using commercial GACC and GACP with different contact times

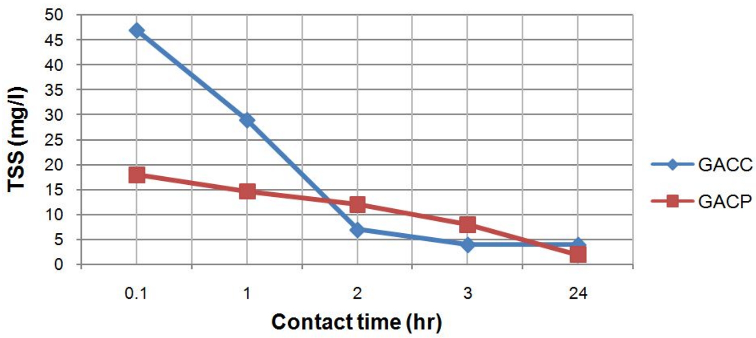

Fig. 9 Commercial GACC and GACP effect on TSS

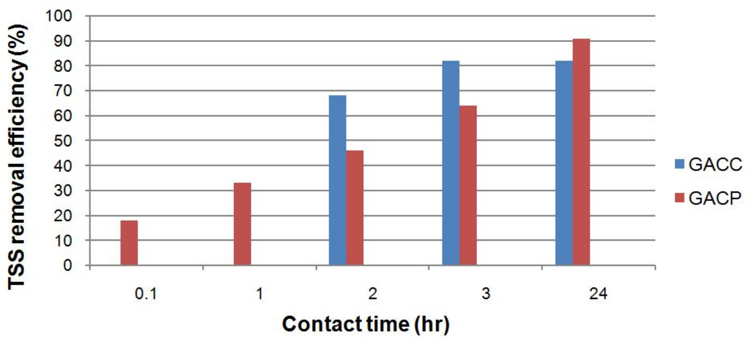

Fig. 10 Percentage removal of TSS by using commercial GACC and GACP with different contact times

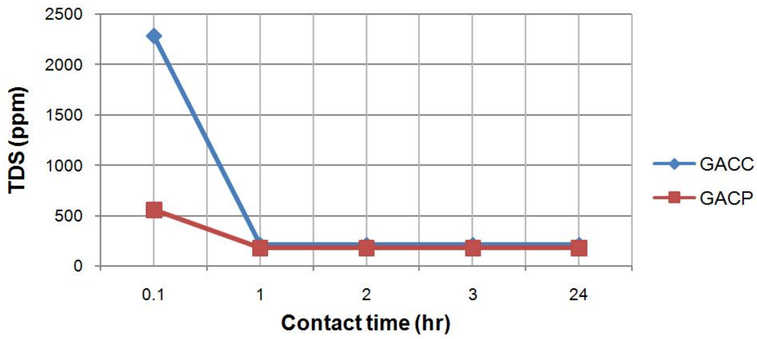

Fig. 11 Commercial GACC and GACP effect on TDS

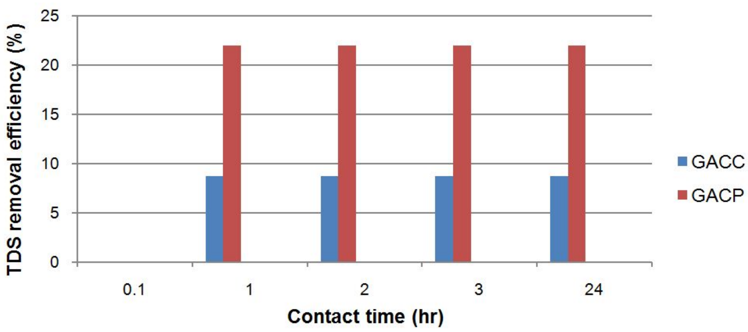

Fig. 12 Percentage removal of TDS by using commercial GACC and GACP with different contact times

3.5 TSS removal

The initial value of TSS was 22 ppm. The TSS increased to 47 ppm by GACC because of the impurities in the sample and limited treatment time. However, the value of TSS decreased to 18 ppm at 0.1 hr by GACP (Fig. 9). After 24 hrs, it was observed that the value of TSS decreased to 4 ppm and 2 ppm by GACC and GACP, respectively. The highest removal efficiency for TSS was 82% by GACC and 91% by GACP, respectively as illustrated in Fig. 10.

3.6 TDS removal

The initial value of TDS was about 230 ppm. The TDS reached to 2290 ppm and 560 ppm by GACC and GACP, respectively as shown in Fig. 11. This result is due to the impurities and salts in GAC. However, after 1 hr, the value of TDS reduced to 210 ppm and 180 ppm by GACC and GACP, respectively. The highest removal efficiency for TDS was 8.7% and 22% by GACC and GACP, respectively (Fig. 12).

4. Conclusions

The results of this part of the study show that the GACC technique is better than the GACP technique in removing high ratios of BOD, turbidity and TDS from wastewater. However, both of these techniques have the same efficiency in removing a high proportion of COD. On the other hand, GACP is more efficient than GACC in removing a high proportion of TSS. Our experiments showed that high removal efficiency for BOD and TDS occurred at 1 hr and 3 hrs for both techniques. The pH range was 7.9-9.27 using the GACC technique, whereas it was 7.9-8.41 using the GACP technique. A simple pretreatment (e.g., electrolysis) can be applied for wastewater and landfill leachate prior to activated carbon filtration to get high removal efficiency for various pollutants.

Acknowledgments

The partial financial support provided by UPM under RUGS, 05-02-12-1874RU, 9344400 is acknowledged. Authors gratefully acknowledge those students who supported this study.

References

Ahsan, A., Kamaludin, M., Rahman, M.M., Anwar, A.H.M.F., Bek, M.A. and Idrus, S. (2014), "Removal of various pollutants from leachate using a low cost technique: integration of electrolysis with activated carbon contactor", *Water Air Soil Poll*., **225**(12), 1-9.

Banerjee, S. and Dastidar, M.G. (2005), "Use of jute processing wastes for treatment of wastewater contaminated with dye and other organics", *Biores*. *Tech*., **96**(17), 1919-1928.

Bhandari, N.S. and Nayal, K. (2008), "Correlation Study on Physico-chemical parameters and quality assessment of Kosi river water, Uttarakhand", *J. Chem*., **5**(2), 342-346.

Bian, D., Ren, Q., Ai, S., Zuo, Y. and Liu, J. (2011), "Study on treatment of wastewater from the production of PolyTHF with adsorption method", *Proceedings of the International Conference on IEEE*; *Electric Information and Control Engineering* (*ICEICE*), Wuhan, China, April, pp. 6188-6190.

Brennan, J.K., Thomson, K.T. and Gubbins, K.E. (2002), "Adsorption of water in activated carbons: Effects of pore blocking and connectivity", *Langmuir*, **18**(14), 5438-5447.

Çeçen, F. and Aktaş, Ö. (2011), "Water and Wastewater Treatment: Historical Perspective of Activated Carbon Adsorption and its Integration with Biological Processes", In: *Activated Carbon for Water and Wastewater Treatment*: *Integration of Adsorption and Biological Treatment*, John Wiley & Sons, New York, NY, USA, pp. 1-11.

Choi, K.J., Kim, S.G., Kim, C.W. and Kim, S.H. (2005), "Effects of activated carbon types and service life on removal of endocrine disrupting chemicals: Amitrol, nonylphenol, and bisphenol-A", *Chemosphere*, **58**(11), 1535-1545.

Cyr, P.J., Suri, R.P. and Helmig, E.D. (2002), "A pilot scale evaluation of removal of mercury from pharmaceutical wastewater using granular activated carbon", *Water Res*., **36**(19), 4725-4734.

Fernandes, A., Spranger, P., Fonseca, A.D., Pacheco, M.J., Ciríaco, L. and Lopes, A. (2014), "Effect of electrochemical treatments on the biodegradability of sanitary landfill leachates", *Appl*. *Catal*. *B*: *Environ*., **144**, 514-520.

Gao, H., Chu, S., Li, S. and Ma, W. (2008), "Study on treating dyeing and finishing wastewater with combined process of anaerobic-PAC-SMBR", *Proceedings of the 2nd International Conference IEEE*: *Bioinformatics and Biomedical Engineering* (*ICBBE*), Shanghai, China, May, pp. 2861-2864.

Hameed, B.H., Mahmoud, D.K. and Ahmad, A.L. (2008), "Equilibrium modeling and kinetic studies on the adsorption of basic dye by a low-cost adsorbent: Coconut (Cocos nucifera) bunch waste", *J. Haz*. *Mat*., **158**(1), 65-72.

Ioannidou, O. and Zabaniotou, A. (2007), "Agricultural residues as precursors for activated carbon production – A review", *Renew*. *Sustain*. *Eng*. *Rev*., **11**(9), 1966-2005.

Ismaiel, A.A., Aroua, M.K. and Yusoff, R. (2013), "Palm shell activated carbon impregnated with task-specific ionic-liquids as a novel adsorbent for the removal of mercury from contaminated water", *Chem. Eng. J.*, **225**, 306-314.

Kabuk, H.A., İlhan, F., Avsar, Y., Kurt, U., Apaydin, O. and Gonullu, M.T. (2013), "Investigation of leachate treatment with electrocoagulation and optimization by response surface methodology", *CLEAN – Soil, Air, Water*, **41**(5), 1-7.

Karanfil, T. and Kilduff, J.E. (1999), "Role of granular activated carbon surface chemistry on the adsorption of organic compounds. 1. Priority pollutants", *Environ. Sci. Tech.*, **33**(18), 3217-3224.

Kim, S.H., Ngo, H.H., Chaudhary, D., Kim, J.C., Vigneswaran, S. and Moon, H. (2002), "Characterization procedure for adsorption of DOC (Dissolved Organic Carbon) from synthetic wastewater", *Korean J. Chem. Eng.*, **19**(5), 888-894.

Meng, Z., Lianqing, Y., Ruozheng, L. and Jilin, T. (2010) "Treatment of phenol-containing wastewater with specially-made activated carbon", *Proceedings of the 4th International Conference IEEE: Bioinformatics and Biomedical Engineering (iCBBE)*, Chengdu, China, June, pp. 1-4.

Rada, E.C., Istrate, I.A., Ragazzi, M., Andreottola, G. and Torretta, V. (2013), "Analysis of electro-oxidation suitability for landfill leachate treatment through an experimental study", *Sustainability*, **5**(9), 3960-3975.

Rahman, M.M., Bari, Q.H., Mohammad, N., Ahsan, A., Sobuz, H.R. and Uddin, M.A. (2013), "Characterization of rice husk carbon produced through simple technology", *Adv. Mater. Sci. Appl.*, **2**(1) 25-30.

Rahman, M.M., Salleh, M.A.M., Rashid, U., Ahsan, A., Hossain, M.M. and Ra, C.S. (2014), "Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review", *Arab. J. Chem.*, **7**(1), 139-155.

Rouabeh, I. and Amrani, M. (2012), "Equilibrium modeling for adsorption of $NO3^{-}$ from aqueous solution on activated carbon produced from pomegranate peel", *Adv. Environ. Res., Int. J.*, **1**(2), 143.151. DOI: 10.12989/aer.2012.1.2.143

Snoeyink, V.L., Weber Jr, W.J. and Mark, Jr. H.B. (1969), "Sorption of phenol and nitrophenol by active carbon", *Environ. Sci. Technol.*, **3**(10), 918-926.

Sobhan, R. and Sternberg, S.P. (1999), "Cadmium removal using Cladophora", *J. Environ. Sci. Health Part A*, **34**(1), 53-72.

Song, X.-S., Wang, S.-F., Zhang, G.-Z. and Wu, F.-P. (2009), "Use of combined fenton process for ammunition disposal wastewater: A pilot plant study", *Proceedings of the 3rd International Conference IEEE: Bioinformatics and Biomedical Engineering (ICBBE)*, Beijing, China, June, pp. 1-4.

Ulson de Souza, A.A., Forgiarini, E., Brandão, H.L., Xavier, M.F., Pessoa, F.L.P. and Guelli U Souza, S.M.A. (2009), "Application of Water Source Diagram (WSD) method for the reduction of water consumption in petroleum refineries", *Resour. Conser. Recyc.*, **53**(3), 149-154.

Vyrides, I. and Stuckey, D.C. (2009), "Saline sewage treatment using a submerged anaerobic membrane reactor (SAMBR): Effects of activated carbon addition and biogas-sparging time", *Water Res.*, **43**(4), 933-942.

Weber, Jr. W.J., Hopkins, C.B. and Bloom, Jr. R. (1970), "Physicochemical treatment of wastewater", *J. Water Pollut. Con. Fed.*, **42**(1), 83-99.