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ORIGINAL ARTICLE

# Low-cost activated carbon production from organic waste and its utilization for wastewater treatment

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**Abstract**

In the present study, organic waste materials, like coconut shell, orange peels, and banana peels were used to produce activated carbon. Chemical activation was carried out using phosphoric acid ($H_3PO_4$). The activation temperatures were selected at the range of 200–300 °C. Surface morphology of the different activated carbon derived from the different waste materials was investigated using scanning electron microscope. Pollution removal efficiency of different activated carbons was carried out by Jar test. The jar test was carried out at 120 rpm, at 20 °C temperature for 1 h. Three different sizes; 75 µm, 150 µm and 425 µm, and three concentration; 100 mg/l, 200 mg/l and 500 mg/l of the activated carbon were selected for the pollution removal experiments. Water quality parameters like pH, TSS, and COD were analyzed using standard AWWA/APHA methods to know the pollution removal efficiency. COD removal varies from 48 to 99% in different activated carbon at different size and concentration. TSS removal varies from 43 to 100% by different activated carbon. The highest adsorption was observed by 75 µm activated carbon. Among all the experimented materials activated carbon made from orange peels performed better than others possibly due to the formation of more C–O and C=O functional groups due to the presence of more carbon and oxygen elements than others. This study opens a new way of wastewater treatment in Oman by using low-cost activated carbon made from locally available organic waste and at the same time, it shall help in managing organic waste.

**Keywords** Activated carbon · Adsorbent materials · Coconut shell · Banana peels · Orange peels · Wastewater treatment

**Abbreviations**

| | |
|---|---|
| COD | Chemical oxygen demand |
| TSS | Total suspended solid |
| AC | Activated carbon |
| CAARU | Central analytical and applied research unit |
| AWWA/APHA | American Water Works Association/American Public Health Association |
| SEM | Scanning electron microscopy |
| CSAC | Coconut shells activated carbon |
| BPAC | Banana peels activated carbon |
| OPAC | Orange peels activated carbon |

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## Introduction

The world is facing a drinking water crisis (Gupta et al. 2012) and Sultanate of Oman is not an exception. Limited viability of fresh water makes the sultanate more sensitive to the water crisis. Wastewater treatment and recycle could reduce some pressure on freshwater sources. This has forced the researchers to cost-effective and efficient wastewater treatment technology (Gupta and Ali 2013a). There are various techniques, like adsorption, membrane filtration and reverse osmosis are being used to make wastewater suitable for further use (Gupta and Ali 2013b). Adsorption using activated carbon is considered one of the most efficient and cost-effective techniques (Ali and Gupta 2007; Ali et al. 2012). In a review paper, (Ali 2012) discussed various aspects of water treatment by adsorption using nanoadsorbents. High cost of coal-based activated carbon has stimulated the search for the cheapest alternatives (Abdurrahman et al. 2013; Ali 2010). Low-cost activated carbon has been the focus of research in recent years. Agricultural waste such as coconut shell (Arena et al. 2016), orange and banana peels (De Gisi et al. 2016) are getting much attention these days. The basic components of the agricultural waste materials include hemicelluloses, lignin, lipids, proteins, simple sugars, water, hydrocarbons, and starch, containing a variety of functional groups with a potential sorption capacity for various pollutants (Bhatnagar and Sillanpää 2010; Bhatnagar et al. 2015). Use of the waste as a low-cost adsorbent will provide two advantages, firstly, recycling of waste material and secondly economical (Grassi et al. 2012). It has already been established that the activated carbon from agriculture act as a good adsorbent for the various pollutants (Foo and Hameed 2012). After comparing chemical oxygen demand (COD) reduction efficiency of acid-activated pecan shell-based granular activated carbon with the adsorption efficiency of the commercial carbon (Bansode et al. 2004) concludes that acid-activated pecan shell-based carbons had higher adsorption for organic matter measured as COD. Specific properties of activated carbon depend not only on the raw material but also on the activation process employed, which may be conducted by physical processes (De Gisi et al. 2016). Activated carbon with a lower temperature of carbonization was exhibiting better characteristics compared with activated carbon prepared at a higher temperature of carbonization (Ashtaputrey and Ashtaputrey 2016). Phosphoric acid increases the porous structure resulting high surface and high total pore volume of carbons (Yakout and El-deen 2016). Therefore, chemical activation affects the adsorption of activated carbon and ability based on differences properties such as surface area, density, pH, and conductivity. Though there are plenty of studies reported about activated carbon around the world, however, there is a dearth of studies in Oman. Moreover, according to the literature available, low-cost adsorbents represent a promising green technology. Potentially, they can be applied at full-scale wastewater treatment. However, there are only a few studies reported using real wastewater. Also, there is a lack of data concerning the characteristics of the adsorbents such as their average particle size or specific surface area (De Gisi et al. 2016). To fill the gap, this study is aimed to ascertain the pollution removal capacity of various activated carbons derived from waste materials generated in Oman; effects of different particle size and concentration were also studied.

## Materials and methods

### Preparation of activated carbon

Raw materials (coconut shell, banana peels, and orange peels) were collected from the home kitchen; 250 g for each material was taken, chopped into small pieces, washed with tap water and then dried under the sunlight for 24 h. Each material was burned at different temperatures depending on their characteristic and amount. Each material was put in a metal container, and then, the containers were placed into a muffle furnace, containing material separately at the pre-decided temperature and time; coconut shell was burned at 300 °C for 1 h, banana and orange peels were burnt separately at 200 °C temperature for 1 h. As the lower temperature in the carbonization process gives a better result than high temperature (Ashtaputrey and Ashtaputrey 2016), the temperature was increased to the set level by increasing at the rate of 20 °C/min increment. After taking out the samples from the furnace, the samples were cooled for 30 min at room temperature, washed with distilled water; to remove dust and impurities, and dried in the oven at 105 °C for 1 h. Then, the samples were crushed into powder using mortar and then sieved using a sieve to remove big particles. For acid activation, three beakers of 500 ml were taken for the three materials. The milled coconut shells, orange peels, and banana peels were separately added to the 100 ml of concentrated phosphoric acid ($H_3PO_4$) in a 500 ml beaker, for 24 h. This will help in increasing porosity of activated carbon at the same time increases surface area for adsorption process (Yakout and El-deen 2016). The soaked shells and peels were burned at the same temperature and time which was taken initially before for the carbonization process. Then, the samples were soaked again in 100 ml of distilled water with 1 gm of sodium bicarbonate for 24 h; excess phosphoric acid was removed from the sample. Samples were then washed separately with distilled water for 4–5 times until pH becomes neutral. The washed samples were dried at 110 $^{O}$C. The activated carbon of each material was milled and sieved to a 75 µm, 150 µm and 425 µm mesh size to get a different size activated carbon. Dried and sieved samples were stored in the clean and dry container.

### Physical properties of AC

Physical properties of CSAC, BPAC, and OPAC of 75 microns activated carbon, which achieved the best adsorption of all pollutant, were analyzed by scanning electron microscopy (SEM) at Central Analytical and Applied Research Unit (CAARU), Sultan Qaboos University, Oman.

## Pollution removal efficiency

Nine conical flasks were taken for each material and different concentration of activated carbon, i.e., 10 mg, 20 mg, 50 mg was added into each conical flask with different size (75, 150 and 425 microns), each conical flask filled with 100 ml of wastewater sample prior to adding activated carbon. The samples were shaken at 120 rpm, at 20 °C for 1 h using Orbital Shaker. Samples were taken from the orbital shaker and left for 30 min for settling down the activated carbon. Then, samples were filtered using 40 grade Whatman filter paper. After filtration samples were analyzed for different water quality parameters. Water quality parameters like pH, COD and TSS were analyzed using AWWA/APHA standard methods (Association et al. 1915).

## Results and discussion

### Physical properties of activated carbon using SEM

#### Physical properties of CSAC

As shown in (Fig. 1), CSAC has a lot of pores with different size and shapes. From the micrographs, the shape of the external surface of the activated carbons looks like a wall has cracks and some grains in various sizes in some holes. And the activated carbon morphology looks like a bone. The analysis of CSAC, shown in (Fig. 2), showed the presence of various elements along with a high amount (77.4%) of carbon. Good activated carbon formation evident by the presence of high amount of carbon and formation of holes and rough surface which attribute to better adsorption of pollutants.

#### Physical properties of BPAC

Figure 3 illustrates the SEM images of banana peels activated carbons. As shown (Fig. 3), the surface looks smooth and there is a channel-like wall on the surface of raw material and pores of different size, shapes, and small grains. It can be seen from (Fig. 4) the presence of various elements with 60.8% of carbon. That is considered a good amount of carbon present in the sample.

#### Physical properties of OPAC

Figure 5 shows the SEM images of orange peels activated carbon. As shown (Fig. 5), the surface is smooth and there was a channel-like wall on the surface of the raw material and pores of different size and shapes also have different size of grains in the surface area. Figure 6 shows the presence of various elements with a high amount (72.9%) of carbon. The external surface has a crack and a lot of grains particles with irregular and heterogeneous surface morphology with a well-developed porous structure. That attributes to better adsorption of pollutants.

Among activated carbon made different studied materials, activated carbon made from coconut shells have a high percentage of carbon 77.4%, then activated carbon made from orange peels with 72.9% carbon, while activated carbon made from banana peels have least amount (60.8%) of carbon. With more holes and roughness on the surface, the formation of active surface is more in the activated carbon made from coconut shells and orange peels than the activated carbon made from banana peels.

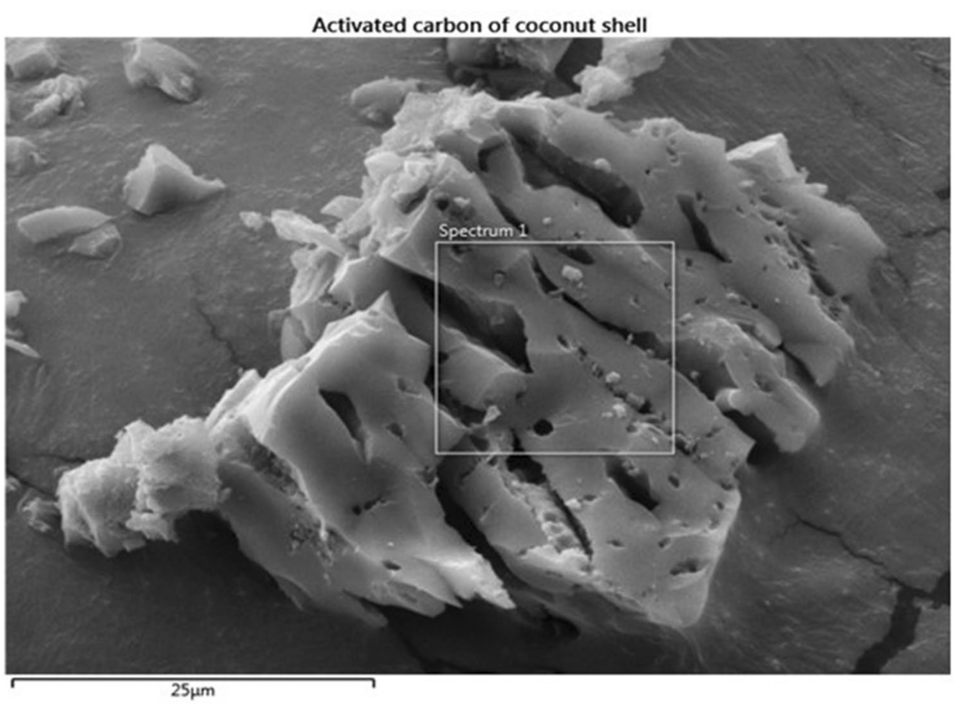



**Fig. 1** Scanning electron microscopic analysis of activated carbon made from coconut shell

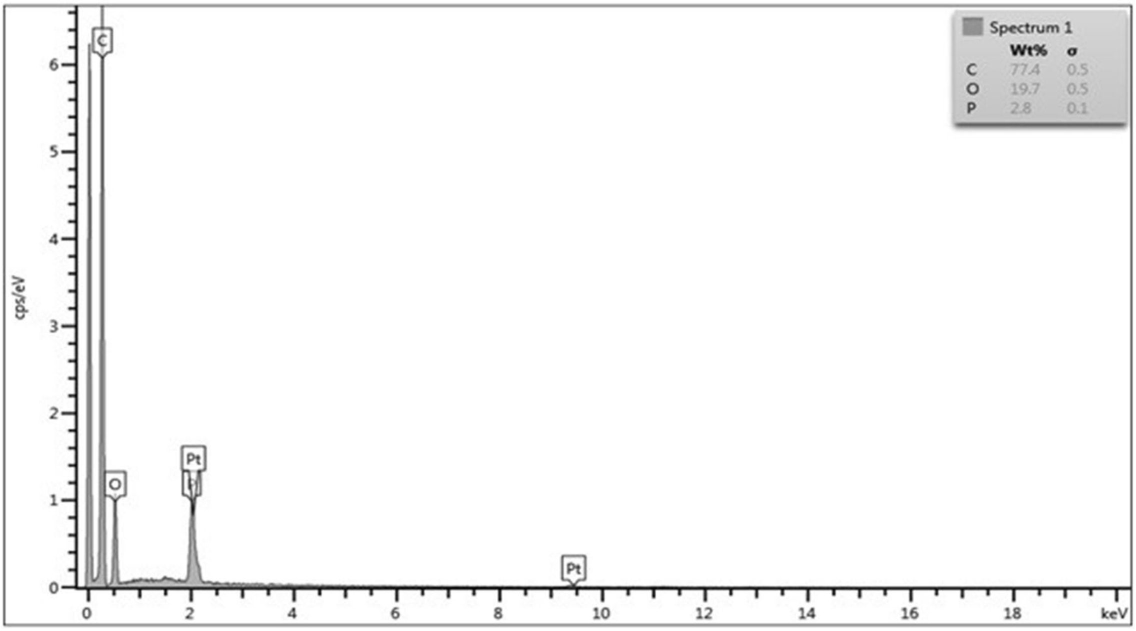
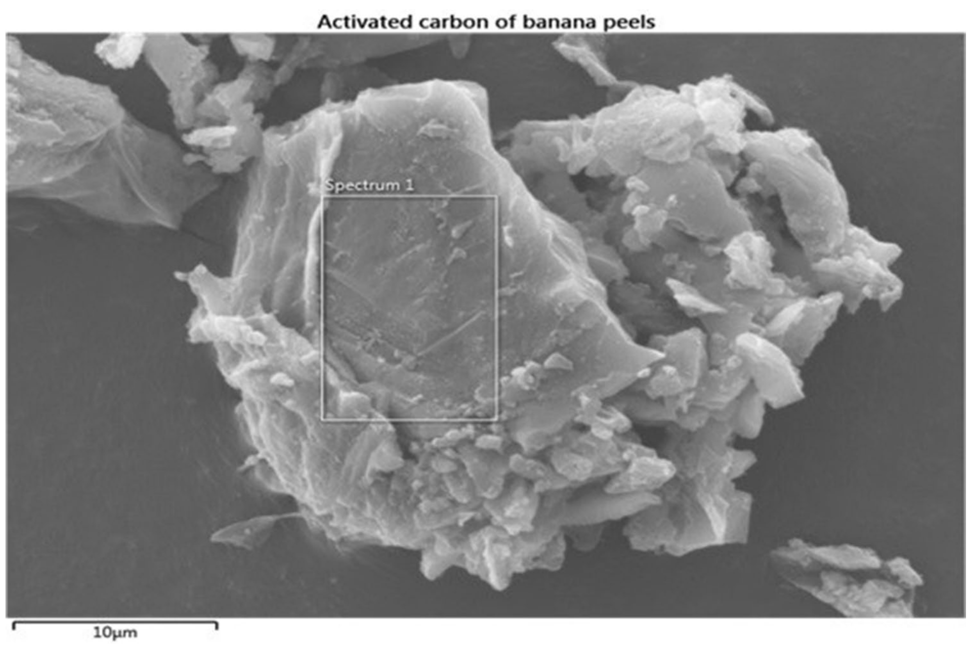



**Fig. 2** Different elements observed during scanning electron microscopic analysis of activated carbon made from coconut shell

**Fig. 3** Scanning electron microscopic analysis of activated carbon made from banana peels




## Pollution removal efficiency

Figure 7 shows results of COD and TSS removal by activated carbon made from coconut shell. COD and TSS removal by 75 µm at 200 mg/l concentration was observed to be 89.15% and 92.85%, respectively, while TSS removal at 500 mg/l was similar to 200 mg/l; however, COD removal increased to 96.93%. At 100 mg/l, 85.71% of TSS removal and 87.26% COD removal was observed. By 150 µm size and at 500 mg/l, 85.72% TSS removal and 97.64% COD removal was observed. TSS removal by 150 µm at 200 mg/l concentration was to be 78.57% and COD removal was 90.8%. While at 100 mg/l concentration by 150 µm TSS removal decreased drastically, which is 50% while COD removal was to be 80.66%, which can be considered as good removal. TSS and COD removal by 425 µm size activated carbon at 500 mg/l concentration was 85.71% and 86.56%, respectively. Similar

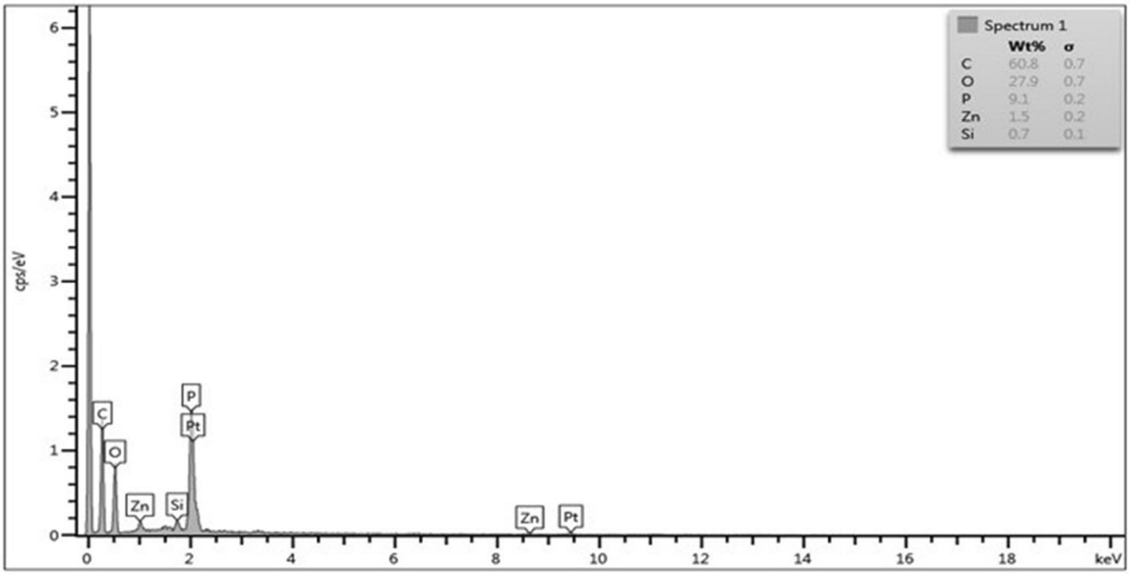



**Fig. 4** Different elements observed scanning electron microscopic analysis of activated carbon made from banana peels

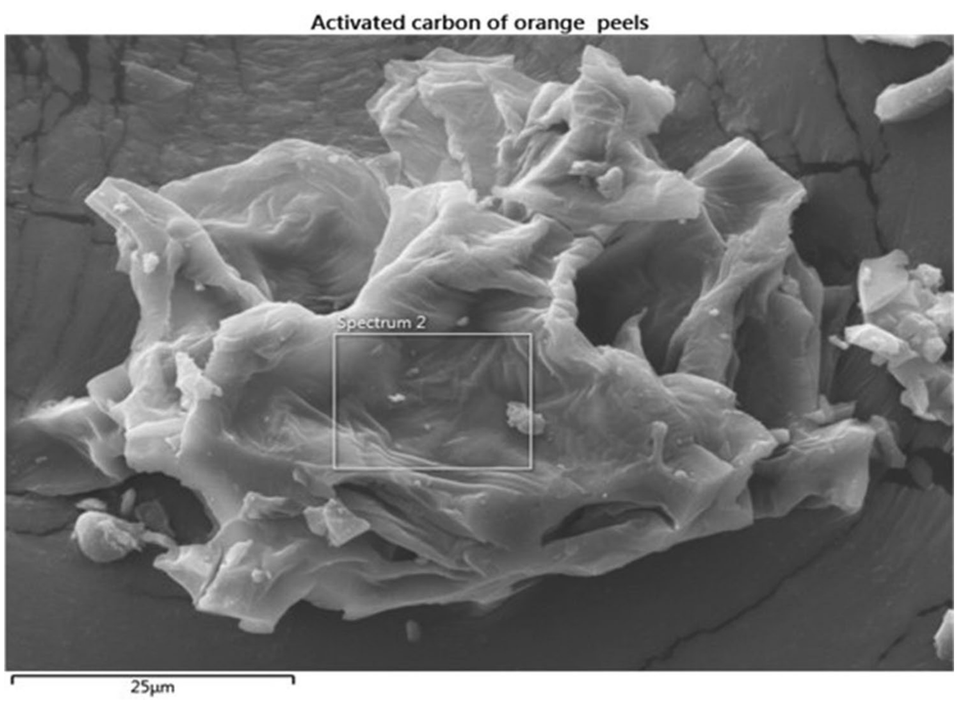



**Fig. 5** Scanning electron microscopic analysis of activated carbon made from orange peels

size activated carbon at 200 mg/l concentration removed 71.43% TSS and 81.36% COD, and at 100 mg/l TSS removal was 57.14% and COD removal was 76.41%. Pollutants removal increased with the increase in activated carbon concentration and decrease in the size of activated carbon which is quite obvious. Overall, the adsorbents achieved the best result in pH 7.2–7.3 at 500 mg/l concentration. The results obtained in this study are similar to the results of (Amuda and Ibrahim 2006) for coconut activated carbon.

Figure 8 shows the pollutants removal results of activated carbon made from banana peels (BPAC) at different concentration and size. As shown in Fig. 8, TSS and COD removal by 75 μm at 500 mg/l concentration was observed

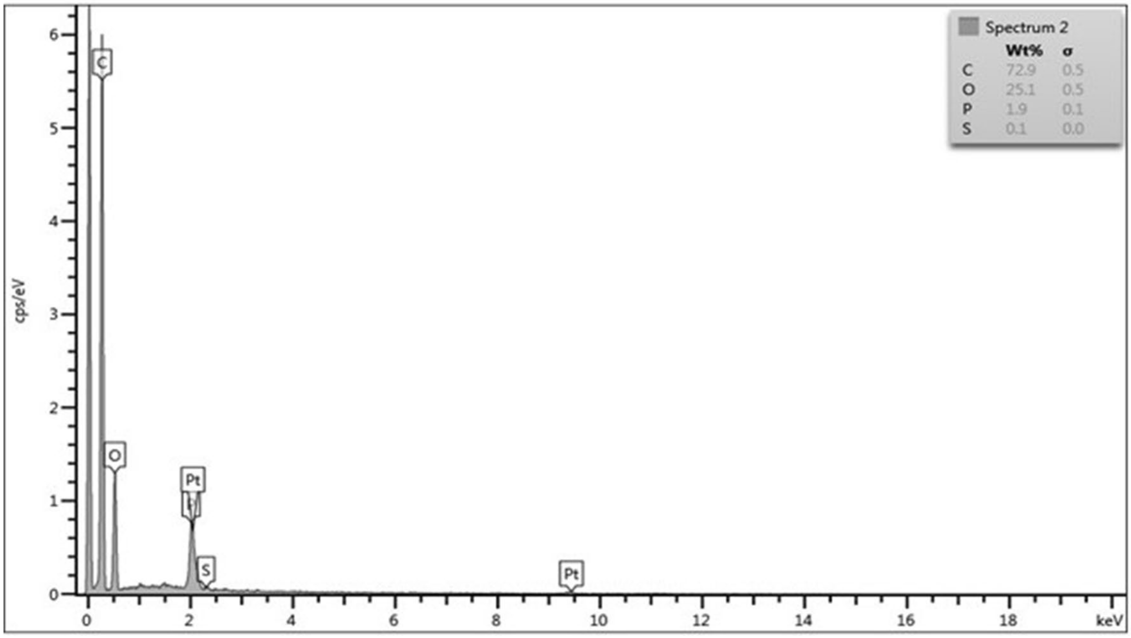



**Fig. 6** Different elements observed scanning electron microscopic analysis of activated carbon made from orange peels

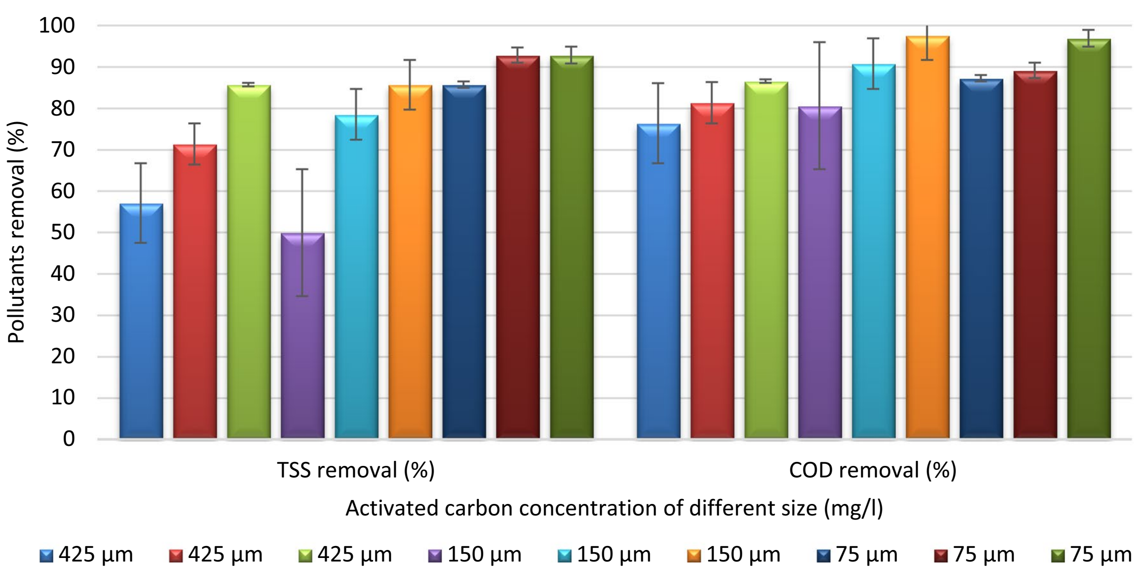



**Fig. 7** Effect of coconut shell activated carbon concentration and size on removal efficiency of different pollutant

to be 100% and 96.46%, respectively, while TSS removal at 200 mg/l was to be 92.85% and COD removal was to 96.22% observed. At 100 mg/l, 71.43% of TSS removal and 92.21% COD removal was observed. By 150 µm size and at 500 mg/l, 100% TSS removal and 87.5% COD removal was observed. TSS removal by 150 µm at 200 mg/l concentration was to be 85.71% and COD removal was 79%. While at 100 mg/l concentration by 150 µm TSS removal decreased drastically, which is 57.14% while COD removal was to be 57%. TSS and COD removal by 425 µm size activated carbon at 500 mg/l concentration was 100% and 68.39%, respectively. Similar size activated carbon at 200 mg/l concentration removed 85.71% TSS and 71.69% COD, and at 100 mg/l TSS removal was 42.85% and COD removal was 48.11%. Our results are almost similar to Ali et al. (2016), for activated carbon made from banana peels. The pH was in range 7–7.5, and the removal was high in pH 7.

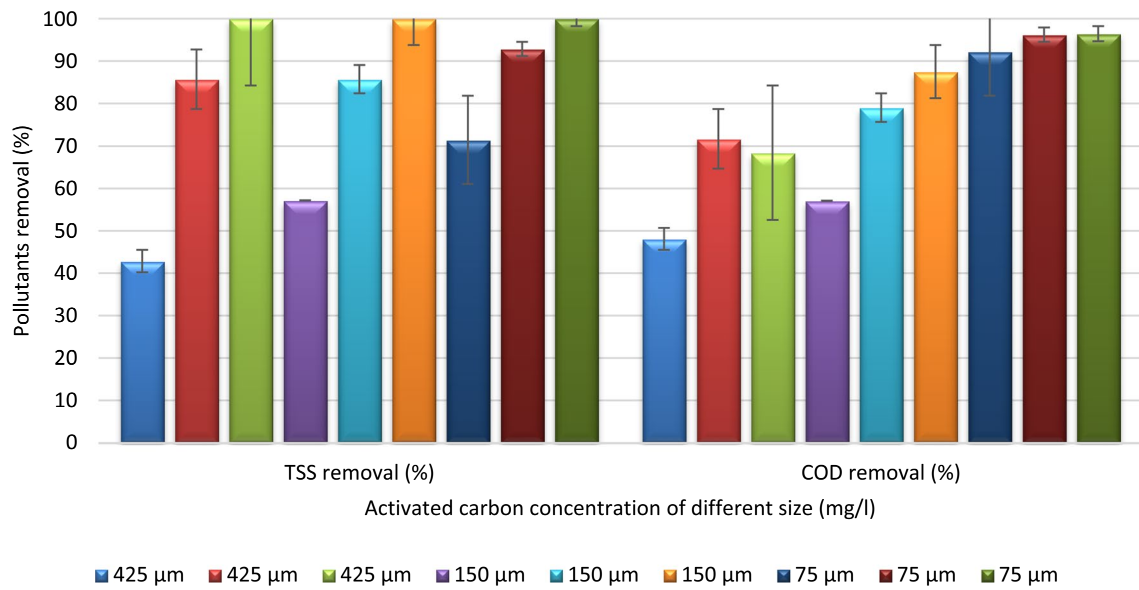



**Fig. 8** Effect of banana peels activated carbon concentration and size on removal efficiency of different pollutant

Results of TSS and COD removal by activated carbon made from orange peels (OPAC) at different size and concentration are shown in Fig. 9. TSS and COD removal by 75 µm at 500 mg/l concentration was observed to be 100% and 99.29%, respectively, TSS removal at 200 mg/l was to be 100% and COD removal was to 97.41% observed. At 100 mg/l, 92.85% of TSS removal and 91.27% COD removal was observed. By 150 µm size and at 500 mg/l, 100% TSS removal and 92.22.5% COD removal was observed. TSS removal by 150 µm at 200 mg/l concentration was to be 85.71% and COD removal was 91%. While at 100 mg/l concentration by 150 µm TSS removal decreased drastically, which is 78.57% while COD removal was to be 89.86%. TSS and COD removal by 425 µm size activated carbon at 500 mg/l concentration was 64.28% and 86.55%, respectively. Similar size activated carbon at 200 mg/l

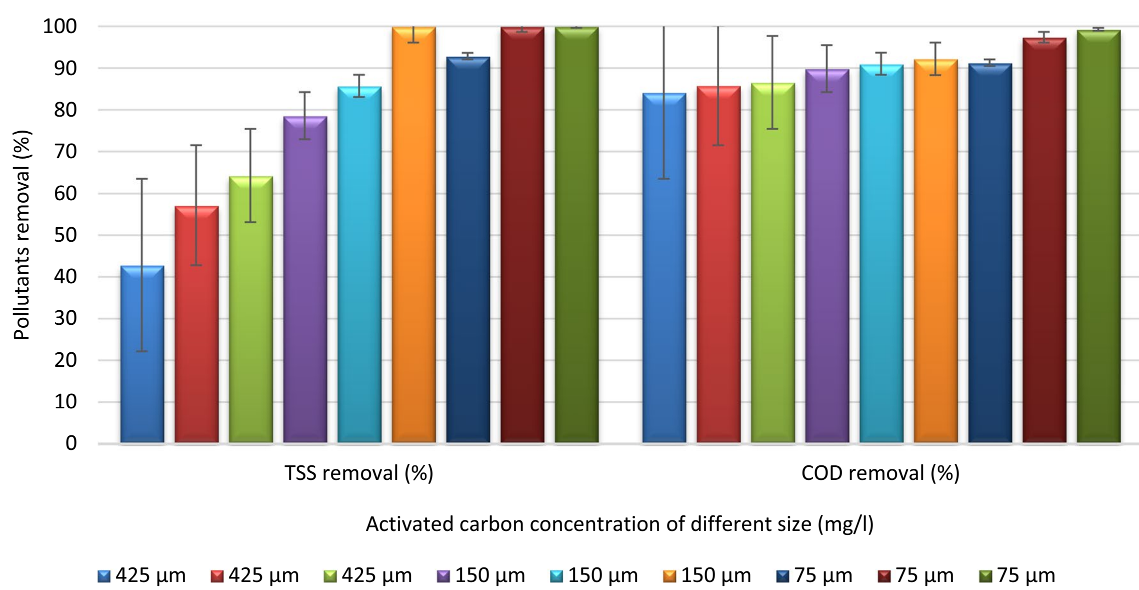



**Fig. 9** Effect of orange peels activated carbon concentration and size on removal efficiency of different pollutant

concentration removed 57.14% TSS and 85.84% COD, and at 100 mg/l TSS removal was 42.85% and COD removal was 84.2%. Results show that the best absorption was achieved in all concentrations and size at pH 7–7.5. Furthermore, the removal percentage of TSS and COD increase with increasing the mass of activated carbon in all size of each material.

As shown in Figs. 10 and 11, overall pollutants removal in terms of COD and TSS is better in case of the activated carbon made from orange peels and the activated carbon made from coconut shells is also performing better in terms of COD removal, however, activated carbon made from banana peels at more size shows better removal of TSS than the activated carbon made from coconut shells. The reason behind the better performance of activated carbon made from orange peels could be possibly because of formation more C=O and C–O functional groups (Mopoung et al. 2015) due to the presence of more carbon and oxygen in orange peels activated carbon (Fig. 6). Activated carbon made from banana peels has the least carbon (Fig. 4) leads to less formation of C=O or C–O functional groups, which might be the reason for low COD removal.

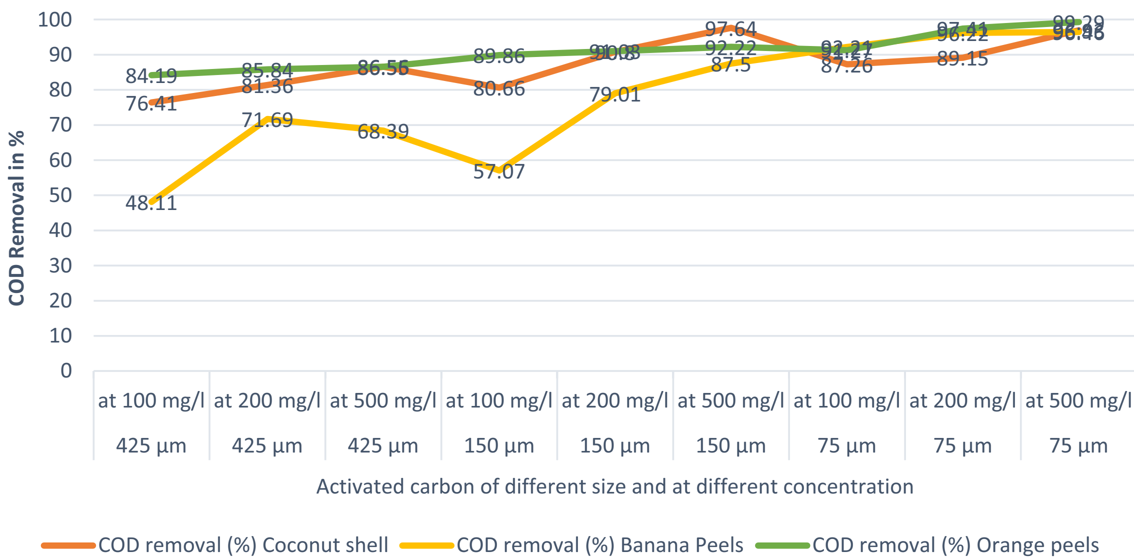



Fig. 10 Comparison of COD removal efficiency of activated carbon made from various organic materials

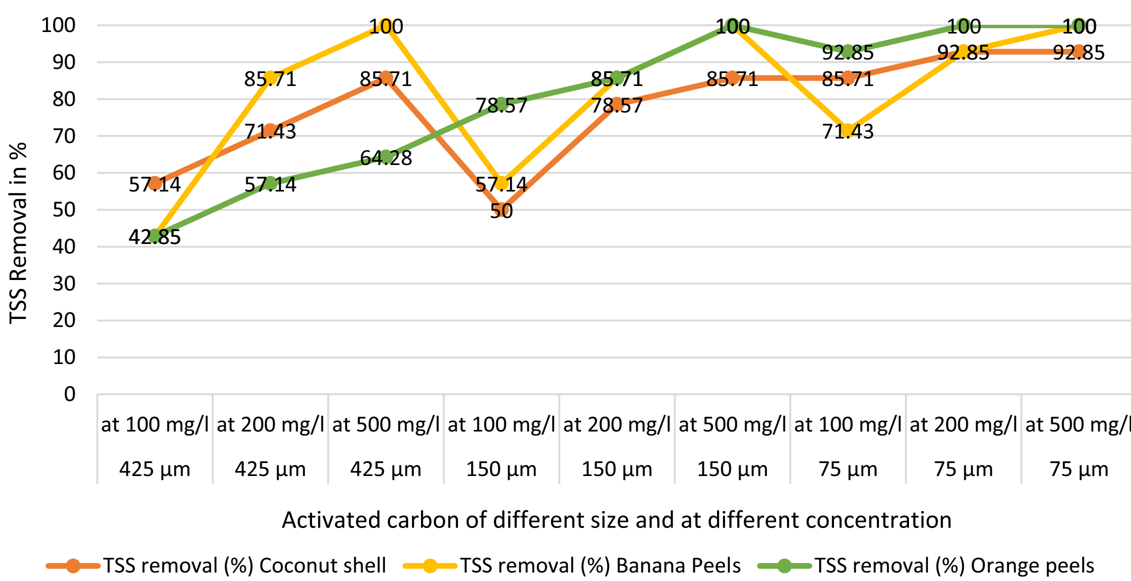



Fig. 11 Comparison of TSS removal efficiency of activated carbon made from various organic materials

## Conclusions

Activated carbon derived from coconut shell, orange peels and banana peels by chemical activation act as a good adsorbent for the removal of pollutants from the water. COD removal varies from 48 to 99% in different activated carbon at different size and concentration. TSS removal varies from 43 to 100% by different activated carbon. Small size and a higher concentration of activated carbon lead to more removal of pollutants. The highest adsorption was observed by 75 µm AC, when the size of AC decreased the ratio of surface area/unit mass increases. Among all the experimented materials activated carbon made from orange peels performed better than other possibly due to the formation of more C–O and C=O functional groups (Mopoung et al. 2015). The use of low-cost organic materials to produce activated carbon for wastewater treatment will be an alternative to the expensive method, and by using organic waste to make low-cost activated carbon could reduce a load of organic waste in the landfill.



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