ACTIVATED CARBON FROM WASTE BRANCHES OF ACACIA ASAK TREE: SINGLE, TWO AND THREE STEPS ACTIVATION PROCESSES

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ABSTRACT

This paper depicts the work done for the production and characterization of activated carbon (AC) from locally available waste Acacia asak (Fabaceae) tree branches. Three types of AC; AAB-AC1, AAB-AC2 and AAB-AC3 produced utilizing; single, two and three step processes using K_2CO_3 as an activating agent. Characterization of Acacia asak tree branches activated carbon (AAB-AC) carried out by proximate and detailed analysis including ash and moisture content, elemental analysis, bulk density, volatile matter, hardness value, pH value, Iodine number, BET surface area and pore volume. Results show that AAB-AC having quality well comparable to the available commercial activated carbon (CAC). Highest BET surface area was found to be 814.3 m^2/g. Higher hardness and low ash content of produced ACs making it suitable for liquid phase continues flow and batch type separation processes. A simple cost analysis shows that the cost of produced ACs ranges from $0.35 to $0.42/ kg, which is quite cheaper than the commercially available AC in the market. Produced AC applied to treat synthetic wastewater containing methylene blue (MB) dye. At first the removal efficiency of AAB-AC less than the CAC however, after one hour the removal efficiency of AAB-AC became comparable (98.5% for CAC and 96.5% for AAB-AC3). Methylene blue (MB) dye uptake capacity also evaluated and found to be 237.5 mg MB/g AC and 240.7 mg MB/g AC for CAC and AAB-AC3 respectively. Therefore, increasing requirement of AC in the country can be handled by utilizing locally available waste branches of Acacia asak tree as precursor material and in turn improving the solid waste management strategy. The three steps carbonization and activation process will produce AC of well comparable qualities.

KEY WORDS: *Activated Carbon, Production, Characterization, Three step process, Acacia asak, S_{BET} Surface area*

1.0 INTRODUCTION

Activated carbon (AC) is a microcrystalline form of carbon with large surface area due to the presence of very high porosity existing in the form of macrospores, microspores and mesopores. Its large surface area and physicochemical properties allows it to preferentially adsorb organic materials and other polar and non polar compounds from gas or liquid streams (Chen et al., 2007). AC is a well-known absorber used globally for the removal of several organic contaminants (even in trace amounts) from industrial, domestic and other wastewater effluents. However, high cost of commercial AC limits the use of this excellent adsorbent (Rao et al., 2006). Present day environmental legislations and environmental control strategies requires large quantities of AC with suitable characteristics for each particular application. In general, an AC which is used in any of the most

common applications must have adequate adsorptive capacity, purity, mechanical strength and regeneration capabilities. In addition to that, all these specifications should coexist with a low production cost. Virtually, AC can be produce with any carbonaceous material containing cellulosic carbon and researchers used wide range of material to get AC having high surface area utilizing low cost precursor material (Ramirez et al., 2017). However, production of AC required some physical and chemical activation along with some thermal treatment. AC production techniques are proprietary and commercial in nature.

Activated carbon is obtained from a carefully controlled process of dehydration, carbonization and oxidation of organic substances (Özsin et al., 2019). However, in order to manage the huge demand of AC, it should be produced by utilizing locally available low cost raw materials and production techniques. The use

of waste materials as low-cost adsorbents is a feasible option due to their contribution in reduction of waste disposal cost and pollution load on the environment (Ramirez et al., 2017; Zhou et al., 2018; Sartova et al., 2019).

Researchers utilized variety of materials for AC production including Moringa oleifera seeds (Warhurst et al., 1997), apricot (Erdogan et al., 2005), corn cobs (Cao et al., 2006), date stones (Haimour and Emeish, 2006), cherry stones (Olivares-Marín et al., 2006), waste tea (Amarasinghe and Williams, 2007), cotton stalk (El-Hendawy et al., 2008), olive stoves (Kula et al., 2008), olive cake (Baccar et al., 2009), bamboo (Liu et al., 2010), almond shells (Plaza et al., 2010), giant reeds (Yue et al., 2010), coconut shell (Cazetta et al., 2011), Acacia mangium (Danish et al., 2013), date palm fronds (Ahmad et al., 2015), Acacia etbaica (Gerbrekidan et al., 2015), olive stones (Yakout and El Deen, 2016), wood waste (Ramirez et al., 2017), waste tea (Zhou et al., 2018), winemaking wastes (Alcaraz et al., 2018), chickpea waste (Özsin et al., 2019), cotton processing wastes (Sartova et al., 2019), etc.

Although extensive research in the past addressing the production and characterization of AC from various carbonaceous materials however, there is limited information available about the use of Acacia asak tree branches (AAB) as a raw material. Production of activated carbon from AAB provides two fold benefits, acquiring a low cost AC from waste material generated during pruning of trees and reduction in the environmental pollution due to decay and disposal of this material (Shivayogimath et al., 2014).

1.1 Production of Activated Carbon

Production of AC could be done utilizing physical or chemical means. Conveniently, AC can be produced in one or two steps, in two step process first carbonization of precursor material performed in an inert atmosphere (Chowdhary et al., 2013). This step facilitates the formation of narrow or macropores. Carbonization process reduce the volatile components, produce char and increase the carbon content per unit mass of material. Generally, carbonization temperature used are 400°C to 800°C (Üner and Bayrak, 2018). In the second step activation of carbon done either by physical or chemical activation processes. This process enhances the pores significantly in the material. In the physical activation process the precursor material activated with steam, carbon dioxide or nitrogen to develop micro, meso and even nanopores (Lua and Yang, 2005; Alayan et al., 2018). Classically, activation temperature utilized is ranging from 800 to 1000 °C (Guo and Lua, 2000; Herawan et al., 2013).

However, activation can be done at low temperature if some activation agent is present (Alslaibi et al., 2013).

In the chemical activation process, a carbonaceous material is imbued with activating agents such as an acid) or a base. The porosity in the material developed due to degradation and dehydration (Nor et al., 2013). Chemical activation generally done at low temperatures and shorter activation time than physical activation. (Guo and Lua, 2000; Nor et al., 2013). Therefore, process provides cost effective method for AC production by utilizing less energy (Guo and Lua, 2000; Herawan et al., 2013). Generally, chemical activation provides higher surface area and better yield of carbon than a physical activation process (Danish and Ahmad, 2018). Researchers utilized variety of dehydrating agents, such as H_3PO_4 (Kalderis et al., 2008), $ZnCl_2$ (Moreno-Pirajan and Giraldo, 2010), KOH (Romanso et al., 2011), H_2SO_4 (Jawad et al., 2016) and Phytic acid, $C_6H_{18}O_{24}P_6$ (Cheng et al., 2016). However, it is reported that high surface area obtained while utilizing K_2CO_3 as an activating agent (Hayashi et al., 2005; Sun et al., 2010). In a single step process carbonization and activation done simultaneously in a single step heating with an activation agent (Kalderis et al., 2008).

In the recent past a three step process was utilized to prepare AC from Cassra fistula (Golden shower) in which hydrothermal carbonization process followed by pyrolysis process to form biochar. In the third step, obtained biochar was activated chemically utilizing potassium carbonate, K_2CO_3 to produce AC having better adsorption performance for cationic dye than AC produced by single or two step processes (Tran et al., 2017). Both carbonization and activation steps are critical in defining the final physical and chemical properties of AC (Katesa et al., 2013). Studies shows that three step synthesis is more effective approach for AC production (Wong et al., 2018). Therefore, in the present study a three step process along with single and two step process utilized to compare the AC produced by three methods. K_2CO_3 is utilized as an activating agent due to its favorable properties as a solvent, low degradation rates, low corrosivity and reported to be an effective agent giving high SBET surface area (Hayashi et al., 2000; Sun et al., 2010; Okman et al., 2014).

Saudi Arabia possess a huge industrial setup spread in Jubail, Yanbu, Dammam and some other regions. These industries ranging from refining petroleum products to manufacturing industrial to domestic products along with large number of support industrial sectors (JC, 2016). Until the end of the first quarter of 2018, industrial units exceed to 7630 units involve the total investment beyond SR1.1 trillion and

country enjoy the revenue of about SR 116,609 million in 2017 by exporting the products (SIDF, 2019). The variety of industries utilizing huge quantities of AC to meet their demand which is imported from outside the country. As reported by Essa and colleagues that more than 6.5 metric tonnes of AC was imported during 1995 to 2002 (Essa et al., 2004). The annual expenditure exceeds \$3.2 million for importing AC to meet the growing demand (Saleem et al., 2017).

The most appropriate raw material to produce AC is having least economical value and provide AC of comparable quality as the commercially available AC. Saudi Arabia is situated in a region possessing arid and dry climate. However, it has more than 97 types of trees among them more than 80% are available in eastern, western and southwestern regions (Aref et al., 2003). Acacia tree has highest population and having more than 10 species including Acacia seyal, Acacia mellifera, Acacia etbaica, Acacia origeua, Acacia asak etc. (Aref et al., 2003). Most of the Acacia trees are available in eastern region of Saudi Arabia and large number of Acacia asak trees present in Dammam, Jubail and surrounding areas grown naturally or planted for greenery enhancement. AC produced from Acacia tree found to be economically more feasible due to its availability as a low cost precursor material, AC obtained will have harder structure providing better resistant to attrition (Gratuito et al., 2008; Danish et al., 2013; Saleem et al., 2017). However, the Acacia asak tree has not been used in the past as per the knowledge of authors. Therefore, in the present work Acacia asak tree branches (AAB) are utilized to produce AC due to its abundant availability as a waste material during tree pruning, trimming and cutting services and possibility to have AC with good properties comparable to available commercial AC in the market.

2.0 MATERIAL AND METHODS

The main objective of present study is to produce AC utilizing abundantly available waste AAB. Other objectives are 1) producing AAB-AC utilizing potassium carbonate K_2CO_3 as activating agent while using three processes a) single step process b) two step process and c) three step process, 2) characterize the AAB-AC and 3) compare the adsorptive capacity of all three ACs with the commercially available AC (Filtrasorb ®-400 and QAC-400) available with Calgon Carbon Corporation and Quantum Active Carbon Pvt. Limited respectively.

2.1 Preparation of AAB-AC

Branches of Acacia asak tree were collected from Jubal Industrial city. Branches excluding leaves were washed and cleaned thoroughly with hot distilled water. Later branches were cut into small pieces and dried in Blast Air Drying Oven (DHG-9030A, China) at 110 ±5 °C for 48 hours. Finally, dried pieces were cut into 0.4 to 0.5 mm size particles utilizing variable speed Universal Cutting Mill (PULVERISETTE 19). Prepared granular material divided into three test samples and these samples undergone single, two and three steps processes to obtain three types of AC named; AAB-AC1, AAB-AC2 and AAB-AC3.

Single step process for AAB-AC1 production: In this part of study single step chemical activation process, utilizing K_2CO_3 as activated agent was used. Prepared granular material first impregnated with 40% V/V K_2CO_3 (purity 99.99%, Sigma-Aldrich) and obtained slurry was placed in Muffle Furness (BEXCO, 251) for 12 hours at 600 ±5 °C (Saleem et al., 2017). After cooling the product at room temperature washed with 0.2% HCl solution than with distilled water to obtain AC having pH near neutral value.

Two step process for AAB-AC2 production: In this part the precursor material is placed in the Muffle Furness for 12 hours at 600 ±5 °C for carbonization. Later the biochar formed was mixed with 40% V/V K_2CO_3 and salary was left idle for 24 hours which hydrolyzed the glycosidic linkage present in polysaccharides of cellulose and hemicellulose material. Following that, produced AC is placed in the Muffle Furness for 12 hours at 600 ±5 °C. The final product was neutralized as mentioned before.

Three step process for AAB-AC3 production: In this part of study the prepared granular material mixed with 50% V/V distilled water and material undergone hydrothermal carbonization for 24 hours at 200±5 °C in a sealed container which exerted an extra steam pressure, providing additional driving force for hydrochar production. Later produced hydrochar was mixed with 40% V/V K_2CO_3 and slurry was left idle for 12 hours. In the last step product was placed in Muffle Furness for 12 hours at 600 ±5 °C to produce AC followed by neutralization of the produced AC.

Once the AC is produced, characterization is required. Characterization is the measure of different properties or parameters on the basis of which, a comparison can be made to find the suitability of product. Therefore, a number of parameters have been developed to characterize activated carbon such as the iodine number, hardness number, surface area, moisture content, ash content, volatile matter content, pH value, iodine number etc. Following section discussed the characterization phase of the present study.

2.2 Characterization of Precursor Material and Produced ACs

Characterization of all produced ACs was done by performing the proximate and detailed analysis following the standard procedures (Schaeffer, 2002). The type of test and utilized ASTM standard and/or methods are summarized in table 1.

In order to determine the elemental composition of precursor material AAB, analysis done utilizing The PerkinElmer® 2400 Series II CHNS/O Elemental Analyzer. The proximate analysis was performed by utilizing TGA 4000 System, with a compact ceramic furnace following the standard ASTM procedures. Hardness determined by utilizing Gilson SS-30 Ro-Tap Sieve Shaker. The fixed carbon calculated as residue of 100% after subtracting moisture content, volatile matter and ash content (Goswami, 2004).

Fixed carbon (%) = 100 – [moisture (%) + ash (%) + volatile matter (%)]   …..(1)

Table 1. Summary of the analysis and utilized standard ASTM procedures and methods.

Type of analysis	Method/ASTM standard procedure
Bulk density	ASTM D2395
Moisture content	ASTM D4933-99, 201
Fixed carbon	ASTM D3172; ISO 1350
Volatile matter	ASTM D5832-98
Hardness	ASTM D3802
Ash content	ASTM D2866-94, 2004
S_{BET}-Surface area	Brunauer–Emmett–Teller, BET surface area
Pore volume	ASTM D4641-17
Pore mean radius	Empirical calculations
Iodine number	ASTM D4607-94

The BET surface area (S_{BST}) and pore volume were determined by utilizing the amount of N_2 held at a relative pressure P/Po = 0.98 reaching equilibrium. The S_{BET} surface area determined by Quantachrome Nova-2200e series instrument. During determination and handling the equipment all safety precautions were adopted including use of protective clothing, mask, safety goggles and heat resistant gloves (Brunauer and Teller, 1938). The sample was degassed for 2 hours under vacuum at 330˚C prior to analysis. The sample was then transferred to the analysis system where it was cooled in liquid nitrogen. The specific surface area (SBET) was calculated by the Brunauer–Emmett–Teller (BET) equation. Pore mean radius (R) is calculated from values of pore volume (Vp) and BET surface area (S_{BET}) utilizing the empirical relationship (Haul,1982)

$$R = 2Vp/S_{BET}$$ ……………………….. (2)

2.3 Removal Efficiency of AAB-AC

Among other color dyes textile industries utilizing Methylene Blue (MB) dye in various dying processes. Therefore, to comply with the environmental control and meet the effluent discharge limits removal of MB dye is a major issue in textile industry. In the present study synthetic wastewater containing MB dye used to test the produced ACs and determine their removal efficiency (Shah et al., 2015; Saleem et al., 2017).

A stock solution of 50 mg/l MB dye was prepared. Three sets of 100 ml borosilicate bottles containing 10 gm of ACs (produced three types of ACs) were filled with 100 ml of MB solution.

Prepared bottles were placed in a mechanical shaker and allowed to equilibrate for 48 hours (Saleem et al., 2010). Following the equilibration period, 20 ml samples were used from each bottle, filtered through 0.45 µm filter (Millipore), and analyzed for residual concentrations of MB dye using the UV-spectrophotometer Shimadzu UV-1301PC at 644 nm wavelength. A calibration curve between absorbance and MB concentration was prepared by using MB standard solutions having concentrations from 10 mg/l to 50 mg/l. Parallel experimental runs were performed while using commercial AC Filtrasorb ®-400 for comparison purpose.

3. RESULTS AND DISCUSSION

In the present detailed experimental investigation preparation, characterization along with comparative analysis performed. Results obtained in the present study are discussed in the following sections

3.1 Production and characterization of activated carbon

Generally, a precursor material containing high carbon content and low Sulphur and ash content results

in good quality AC (Macías-Pérez et al., 2007). Results of elemental analysis of AAB along with the elemental composition of other species of Acacia tree branches are presented in table 2. Results reveal that AAB having higher carbon content along with lower ash content which is making AAB a candidate precursor material to yield AC having qualities comparable to commercially available AC in market. Composition of other elements including potassium, nitrogen, hydrogen, phosphorus and oxygen are comparable with the reported values in the literature (Shivayogimath et al., 2014; Saleem et al., 2017). In addition to that, lower Sulphur content (0.02%) ranking it as an environment friendly material to produce AC (Shahid et al., 2011). Therefore, AAB seems to be a suitable precursor material for good quality AC production.

Table 2. Results of elemental analysis and comparison with the other Acacia species reported in the literature.

Constituent (%)	*Acacia asak*	[1]*Acacia seyal*	[2]*Acacia nilotica*
C	52.7	51.3	48
K	0.93	1.82	--
Al	ND	0.17	--
N	0.42	0.33	0.4
H	5.3	5.8	6
Zn	0.01	0.01	--
S	0.02	0.03	--
P	0.1	0.09	--
O	41.5	32.9	44
Ash	4.7	5.9	5.8

ND: Not Detected
[1] Saleem et al., (2017)
[2] Shivayogimath et al., (2014)

Gravimetric analysis of raw AAB was performed by TGA at temperature range from 0°C to 1000°C in an inert atmosphere. Results of weight loss versus temperature are presented in figure 1. It can be seen from figure 1 that curve represents three major stages of weight loss; first stage from 60°C to about 180°C which is mainly due to loss of moisture and volatile material. Weight loss of about 3.96% observed in this temperature range. In the second stage which ranges from 180°C to 355°C maximum weight loss of about 57.62% observed which is mainly due to breakdown and conversion of lignocellulose material into gases form and tar which generally occurs in this temperature range (Kumar et al., 2008). In the third stage carbonization of AAB occurred which ranges from 355°C to 1000°C showing minimum weight loss of about 2.79%.
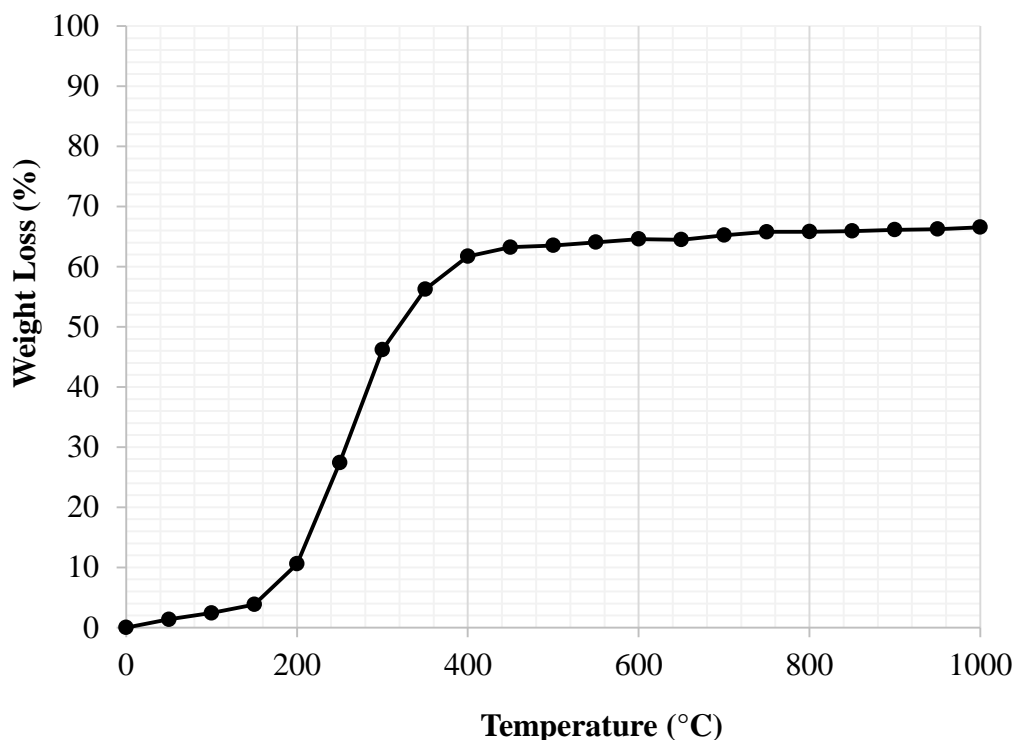
Figure 1. TGA analysis, weight loss versus temperature

Table 3 presents a comparison of results obtained after performing proximate and detailed analysis for all three types of produced ACs along with two commercially available ACs (Filtrasorb ®-400 and QAC-400). Comparison also made between produced ACs and AC produced from other species of Acacia trees (Acacia seyal and Acacia nilotica) reported in the literature.

Results reveal that all ACs prepared in the present study by single, two and three step processes possess high BET surface area and quite comparable to the commercially available ACs. Among three produced ACs, obtained area is in the order of AAB-AC3> AAB-AC2>AAB-AC1. Therefore, AAB-AC3 achieved highest surface area (814.3 m2/g) while utilizing three step process which provides better carbonization and

activation with activating agent K_2CO_3. Similar results were reported elsewhere when comparing the AC produced by single, two and three steps chemical activation method (Tran et al., 2017). Lowest surface area obtained by AAB-AC1 (753.3 m2/g) which may be attributed to the fact that less time was available for carbonization which reduce the carbon content per unit mass and ultimately the available surface area. The three step process contributing in getting higher surface area which may be due to fact that hydrothermal treatment of precursor material produced hydrochar during carbonization in which better penetration of activating agent K_2CO_3 occurred in the pore space, which results in relatively higher surface area during activation.

Table 3. Comparison of characteristics of AAB-AC1, AAB-AC2 and AAB-AC3 with Commercial ACs and AC produced from other species of Acacia tree

Property	AAB-AC1	AAB-AC2	AAB-AC3	[1]Acacia seyal	[2]Acacia nilotica	*Filtrasorb® 400	#QAC-400
Ball-Pan Hardness	95	94	90	91	Low	High	95
Ash (%)	5.7	6.2	5.73	5.9	5.8	5-6	6
Bulk Density (g/cc)	0.41	0.39	0.35	0.3	--	0.44	0.55
Moisture Content (%)	4.7	4.2	4.6	4.2	4.1	--	5
Volatile matter	6.14	5.52	2.73	--	5.12	--	--
Fixed Carbon	83.46	84.08	86.94	--	--	--	--
pH	7.9	8.1	7.6	6.5	7.0	6.2	9-10
S_{BET} (m^2/g)	753.2	772.7	814.3	762	590	944	400
Pore Volume (m^3/g)	4.38	4.79	5.1	4.92	4.4	0.6	--
Pore mean radius (mm)	11.63	12.39	12.52	12.91	14.91	1.27	--
Iodine Number (mg/g)	749	846	892	827	480	1000	400

* Calgon Carbon Corporation, Pennsylvania, 15205 USA.
# Quantum Active Carbon Pvt Limited (2016)
[1] Saleem et al., (2017)
[2] Shivayogimath et al., (2014)

Results reported in table 3 also showing that the obtained BET surface area of produced ACs are well comparable to the area obtained by researchers utilizing other species of Acacia tree branches; Acacia seyal and Acacia nilotica. Once comparing with the BET surface are of Filtrasorb ®-400 (i.e 944 m^2/g) the surface areas of AAB-AC1, AAB-AC2 and AAB-AC3 are 79.77%, 81.78% and 99.87% respectively. Results of Iodine number demonstrated similar behavior.

Results of pore volume and iodine number showing that the properties of AC strongly depends on the type of preparation method and adsorbent pore volume increase with the number of steps during activation. Thus, three step process seems to be more favorable method in the preparation of better AC. A similar conclusion has been drawn by other researchers (Tran et al., 2017; Wong et al., 2018). The Ball-Pan Hardness Test which reflects the resistance of an AC against degradation, measured and results show that all the produced ACs possess very good hardness and well suitable for liquid phase batch and continues flow separation processes.

Furthermore, a simple cost analysis performed by considering the cost of raw material, chemical used, energy consumption and cost related to manpower and laboratory analysis. It was found that the final cost of produced ACs ranging from $0.35 to $0.42 per Kg. Therefore, the AC produced by Acacia asak branches, which are available in abundance, obtained during tree pruning and considered, as solid waste will result in an economical means of producing AC and contribute in solid waste reduction and management.

3.2 Removal efficiency of AAB-ACs

Removal efficiency of AAB-ACs along with commercial AC Filtrasorb ®-400 was evaluated in laboratory batch experiments in which produced and commercial ACs were suspended in 50mg/l MB solution as mentioned before.

The temporal removal efficiency of AAB-ACs and Filtrasorb ®-400 is depicted in figure 2. It is evident from figure 2 that initially commercial AC removal is highest up to 20 minutes as compared to all AAB-ACs however, after that the removal efficiency of AAB-AC3 becomes comparable to it. After about 40 minutes

of experimental run the improvement in the removal efficiency became insignificant for all the ACs. The final removal efficiencies of ACs achieved were 98.5%, 96.3%, 91.1% and 85.6% for Filtrasorb ®-400, AAB-AC3, AAB-AC2 and AAB-AC1 respectively. The high removal efficiency of AAB-AC3 for MB dye may be attributed to the utilization of K_2CO_3 as an activating agent and three step process which aids in the yield of high BET surface area and well developed porosity.
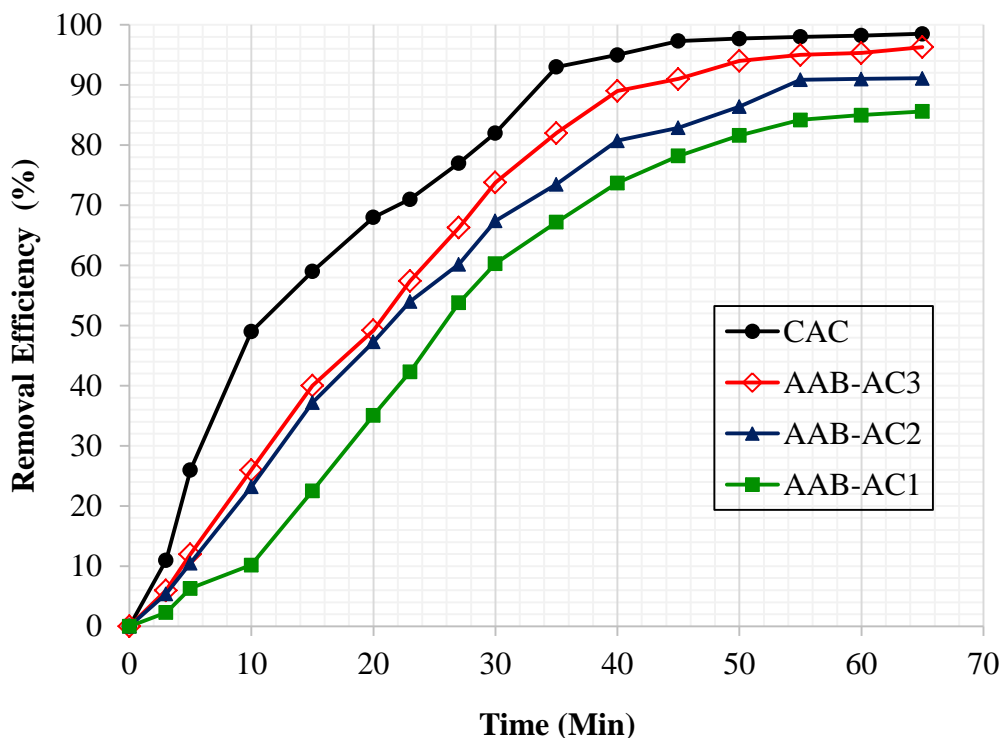

Figure 2. Comparison of MB Removal efficiency of ACs

3.3 MB dye uptake capacity of AAB-AC3

In this part of study the experimental runs were performed to compare the MB dye uptake capacity of AAB-AC3 and commercial AC Filtrasorb ®-400. The uptake capacity of Filtrasorb ®-400 and AAB-AC3 found to be 240.7 mg MB/g of AC and 237.5 mg MB/g of AC respectively. which shows that the adsorption capacity of AAB-AC3 is about 98.7% of commercial AC. It is noted that the MB uptake capacity of AAB-AC3 is comparable to the S_{BET} value found before (99.87% of Filtrasorb ®-400). It means that the produced AC has good relationship between BET-Surface area and the MB uptake capacity of produced AC. In addition to that, the pore volume of AAB-AC3

is 5.1 m³/g as compared to the pore volume of Filtrasorb ®-400 which is 0.6 m³/g. It shows that the MB uptake capacity may not only depends on the pore volume and the controlling parameter could be the BET-Surface area. Current findings are not consistent with the finding of study conducted by Hussein et al., which showing the dependency of AC uptake capacity solely on the pore structure and volume (Hussein et al., 2015). Variance in the studies could be attributed to the use of different raw material (date palm tree biomass) which may produce pore volume due to different pore structure. However, further study is warranted to investigate effect of various precursor material on pore volume, SBET surface area and the uptake capacity.

4. CONCLUSIONS AND RECOMMENDATIONS

Results of the study revealed that the Acacia asak tree branches is a potential precursor material for AC production. Elemental analysis of precursor material shows high carbon content (52.7%) and very low ash content (4.7%) ranking it as an excellent material for AC preparation. Three types of AC production methods were utilized and found that three steps AC production method provides better carbonization and activation while using K_2CO_3 as activating agent and yield with an AC having S_{BET} surface area close to commercially available AC (99.87% of Filtrasorb ®-400). Hydrothermal treatment of precursor material produced hydrochar in which better penetration of precursor material occurred. TGA analysis shows that carbonization occurred about 360C and showing minimum weight loss of about 2.79% which reflect the low volatile component in the produced AC.

Temporal removal efficiency shows that MB removal of AAB-AC3 is high as compared to AAB-AC2 and AAB-AC1 during initial 20 minutes (but less than Filtrasorb ®-400). However, after 40 minutes of run both ACs achieved similar removal efficiency (96.3% and 98.5% for AAB-AC3 and Filtrasorb ®-400 respectively). MB uptake capacity of AAB-AC3 find to be about 98.7% of commercial AC (237.5 mg/g of AC). Higher hardness and low ash content of produced ACs making it suitable for liquid phase continues flow and batch type separation processes. A simple cost analysis shows that the cost of produced ACs ranges from $0.35 to $0.42/ kg which is quite cheaper than the commercially available AC in the market.

Therefore, the results of the present study show that that AC produced by three steps carbonization and activation method is producing economical and well comparable AC (with commercially available ACs) if the availability of low cost raw material and low energy consumption are considered. However, more investigations are required to verify other parameters such as hydrolysis time and temperature, impregnation ratio of activating agent, types of activating agents, time of activation and utilization of other steps such as microwave heating etc.

Acknowledgments

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