



SYNTHESIS OF ACTIVATED CARBONS FROM PUTRESCIBLE SOLID WASTE FOR TREATING TEXTILE DYE EFFLUENT

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ABSTRACT

In the present study an attempt has been made to compare the adsorption efficiency of activated carbons (PVW and PFW) prepared from putrescible solid waste. Methylene blue dye (MB) was selected as the model compound. Activated carbons were characterized to find their adsorption capacity. Batch mode adsorption studies were conducted to evaluate the effect of various parameters. BET surface area was found to be 603.7 and 227.3 m²g⁻¹ for PVW and PFW respectively. The adsorption followed pseudo second order kinetics for both the adsorbents. The isotherm data concluded that the adsorption of MB onto both the adsorbents is monolayer and chemisorption in nature. The adsorbents showed a maximum desorption of 40.2% for PVW and 70.1 % for PFW. Batch mode adsorption was carried out with textile dye effluent and the results confirmed that the activated carbons can be employed as effective adsorbents for improving their quality.

Indexing terms/Keywords

Putrescible solid waste, Methylene Blue, Langmuir isotherm, Freundlich isotherm, Desorption, Textile dye effluent

Academic Discipline And Sub-Disciplines

Environmental chemistry

SUBJECT CLASSIFICATION

Chemistry

TYPE (METHOD/APPROACH)

Experimental work

1. INTRODUCTION

Solid waste can be defined as the waste that is not transported by water but that has been rejected for further usage. Glynn Henry & Gary Heinke (2005) stated that solid waste generated from houses increased significantly in quantity and complexity with the advent of the throwaway society and the growth of the packaged and processed food industry. In spite of incurring huge expenditure, the services that are provided towards solid waste management are not fulfilling the requirements thereby causing public health hazard and nuisance. Hence there is a strong need to develop appropriate technology for the proper management of urban as well as rural solid wastes.

Abundance and low cost agricultural by-products and municipal waste materials known as putrescible solid waste is a good selection as a precursor for the preparation of activated carbon. From market places, juice shops, hostels, hotels and marriage halls putrescible solid wastes have been generated and mostly thrown out into open spaces. Vegetable and fruit peel-off can be separated and converted into activated carbon. Much research has been carried out for the proper disposal of vegetable wastes into value added products (G€unther Laufenberg et al., 2003). Certain processes like vermicomposting (Arancon Norman et al., 2008), incineration (Bai and Mardina, 2002) and anaerobic digestion (Mata-Alvarez et al., 2005) were carried out for the conversion of vegetable wastes into useful products. Also conversion of vegetable residues into bio-adsorbents for waste water treatment was also suggested.

Basic dyes are generally used for the dyeing of wool, silk, leather, cotton, jute, etc. (Mall et al., 2006). They may enter into the food chain and could possibly cause carcinogenic, mutagenic and teratogenic effects on humans (Mall et al., 2005). Physico-chemical processes like flocculation, precipitation, coagulation, ion-exchange, and ozonation can be employed for the treatment of dye laden wastewater (McKay et al., 1999). If adsorbent is inexpensive and readily available then, among all methods adsorption process provides an attractive alternative treatment.

Activated carbon is a micro porous inert carbon with a large internal surface area (up to 1500 m²/g). It is capable of adsorbing a wide range of organic substances, oxidizing materials (such as chlorine and ozone) and certain heavy metals from liquids and water. Many agricultural by-products such as orange peel (Arami et al., 2005), oil palm fruit bunch fibre (Sajab et al., 2013), coconut husk (Foo and Hameed, 2012), Jack fruit peel (Stephen Inbaraj and Sulochana (2006), cotton stalk (Deng et al., 2010) and bagasse pith (Nevine Kamal Amin, 2008) have been discovered to be suitable precursors for the preparation of highly efficient activated carbons.

In the present work the adsorption behavior of activated carbon is determined by their physico-chemical properties and their porous structures. A thorough analysis of activated carbon surface chemistry enables preparation of



adsorbent with appropriate characteristic for specific application. Thus the present study is intended to segregate and to convert putrescible solid waste into activated carbons (PVW and PFW) which would increase its economic value and provide a potentially inexpensive raw material for commercial activated carbon. Effect of various treatment methods on the properties of activated carbons were also analyzed and characterized. From the work an efficient, low cost, strong carbonaceous material could be identified which find its application for improving the quality of textile dye effluent.

2. MATERIALS AND METHODS

2.1 Collection and conversion of raw material into activated carbons

Activated carbons were prepared using putrescible solid waste (PSW) which was collected from market places, kitchens of college hostels and marriage halls in and around Coimbatore city, Tamilnadu, India throughout the year. During the one year period all types of vegetable and fruit wastes used in the region and their peel off were collected. PSW was segregated into vegetable and fruit peel-off and were dried in sunlight. They were separately impregnated with a boiling solution of 30 % H_3PO_4 for 2 hours and soaked in the same solution for 24 hours (Meena Sundari and Meenambal, 2015). At the end of 24 hours, the excess solution decanted off and air dried and was carbonized in muffle furnace at 400°C. The dried material were powdered and activated in a muffle furnace at 800°C for a period of 10 minutes. Finally the activated carbons from vegetable and fruit peels (PVW and PFW) were washed with plenty of water to remove residual acid, air dried and powdered.

2.2 Collection of textile dye effluent

Five different water samples were collected from the common effluent treatment plant at Tiruppur, Tamil Nadu at different time periods. They were stored and analyzed for their initial water quality parameters.

2.3 Adsorbate

The molecular formula and molecular weight of malachite green dye is $C_{23}H_{25}N_2Cl$ and 319.85 gmol^{-1} respectively. Stock solutions of the dyes were prepared by dissolving 1g of the dye in 1000ml of double distilled water. Different initial concentrations were prepared by diluting the stock solution. Double distilled water was employed throughout the study as solvent. The pH measurements were made using pH meter. The pH adjustments of the solution were made by 0.1M HCl or 0.1M NaOH. The chemicals were of analar grade and all the adsorption experiments were carried out at room temperature ($27 \pm 2^\circ\text{C}$).

2.4 Equilibrium studies

The adsorption of MG was performed by batch experiments. The batch technique was selected because of its simplicity. The experiments were carried out in a mechanical shaker at 150rpm using 250ml shaking flasks containing 50ml of the dye solutions of desired concentrations and initial pH values. The effect of each parameter like adsorbent dose, adsorbent particle size, different dye concentrations, agitation time, were studied by fixing the values of other parameters. To correct any adsorption of dye on containers, control experiments were carried out in duplicate. It was noted that there was no adsorption by the container walls. The percentage of dye adsorbed by the adsorbents was calculated (Santhi et al., 2010).

3. RESULTS AND DISCUSSION

3.1 Surface and pore characteristics

Physico-chemical parameters of PVW and PFW are given in Table 1. Parameters like moisture content, ash content and water soluble content are higher for PVW than PFW. Iodine number is the most fundamental parameter used to characterize the performance of activated carbon. Higher iodine number indicates higher degree of activation and its typical range is 500–1200 mg/g (Malik et al., 2006).

Table 1. Physico-Chemical characteristics of PVW and PFW

Parameters	Values	
	PVW	PFW
Moisture content (%)	4.5	5.1
Ash content (%)	8.37	8.92
Water soluble content (%)	19.26	20.27
Acid soluble content (%)	1.63	1.52
Volatile matter (%)	20.5	23.5
Iodine number (mg/g)	1101.9	821.2
Methylene blue number	525	512



Bulk density (g/mL)	0.388	0.352
Specific gravity	0.98	0.98
Porosity	60.4	62.5
pH	6.65	6.5
pH _{ZPC}	6.87	6.55
Electrical Conductivity	0.151	0.145
Yield (%)	66.48	72.6

It is a measure of the micropore and mesopore content of the activated carbon by adsorption of iodine from solution. Methylene blue number indicates the adsorption power of carbon to adsorb high molecular weight substances (Meena Sundari and Meenambal, 2013). If it is greater than 400 then it indicates that the carbon is good for dye adsorption. From Table 1, it was clear that PVW has higher iodine number and methylene blue number than PFW, indicating that PVW is best suited for dye removal.

FTIR spectra for both the adsorbents are given in Fig.1. In both the adsorbents broad bands are seen between 3400 – 3600 cm^{-1} which is due to the presence of –OH stretching (Salman et al., 2011) and also an intense band is observed at 1597 cm^{-1} due to C=O groups on the carbon surface. In PVW, a broad band at 1166 cm^{-1} can be ascribed to C-O group and also significant bands below 887 cm^{-1} are C–H out of-plane bending absorption in aromatic ring and C–C stretching (Moreno-Castilla et al., 2000). An intense band at 694 cm^{-1} is due to C-P bonds. In PFW, a broad band at 1603 cm^{-1} is due to carbonyl groups and at 1175 cm^{-1} can be ascribed to –C-O groups. A sharp band at 692 cm^{-1} is contributed by C-P bond which is due to impregnated phosphoric acid (Sivakumar, 2009). Based on the collective FT-IR data, both the carbons prepared by impregnation of H_3PO_4 have high heterogeneity which is useful for more adsorption of dye molecules.

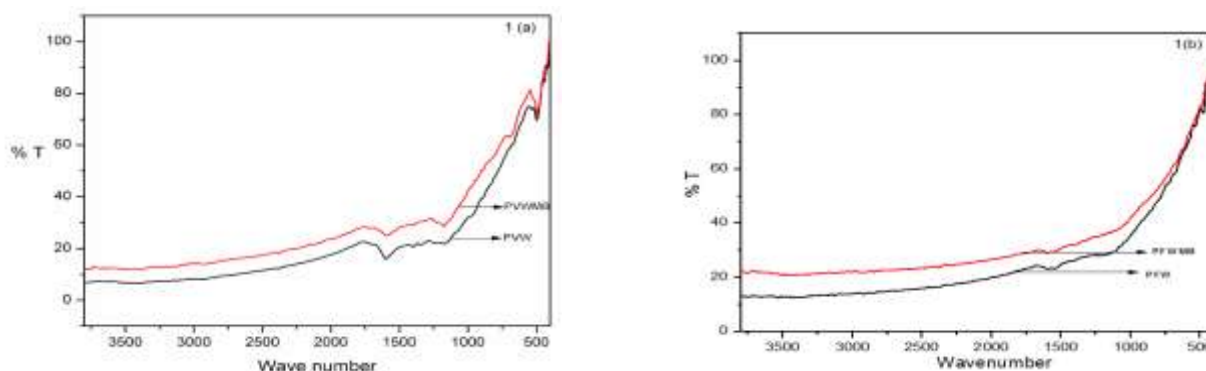


Figure 1: : IR spectra for (a) PVW and PVWMB (b) PFW and PFWMB

XRD spectra for PVW and PFW are shown in Fig. 2 (a) and (b). It is understood from the figure that both the adsorbents are amorphous in nature with few crystallite formations. In PVW intense peaks at 2θ 15.09, 23, 24.3 and 26.6 are characteristics of silicon dioxide and silicates which are present in minimum percentage in the carbons (Djilani et al., 2012). Peaks at 31.6 and 37.7 were due to calcium ions present in PVW (Selvakumar et al., 2008). XRD pattern of PFW (Fig. 2(b)) shows it to be amorphous with an intense peak at 2θ 44.2 is due to silicon dioxide present in the carbon.

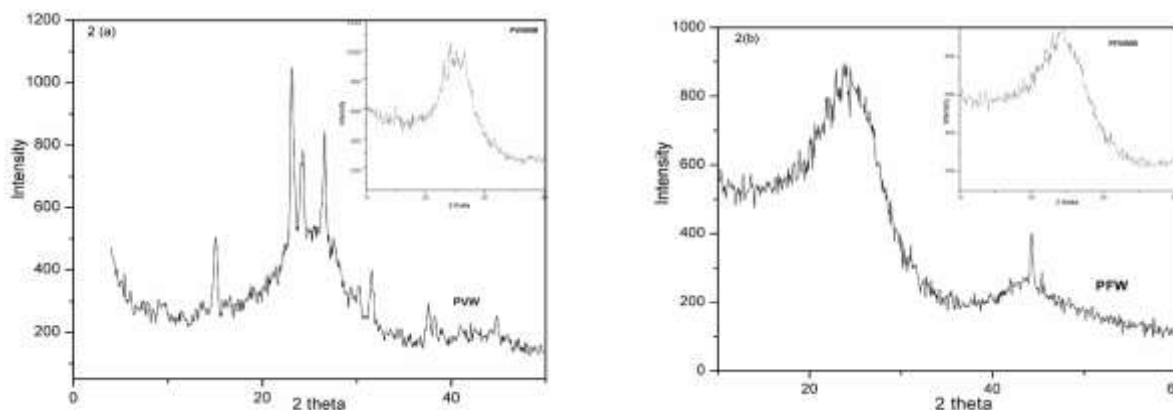


Figure 2: XRD spectra for (a) PVW and PVWMB (b) PFW and PFWMB

On comparing the BET surface area and total pore volume for the adsorbents using various methods (Table 2), it is observed that surface area and pore volume are higher for PVW than PFW (Tay et al., 2009). Total pore diameter is higher for PFW than PVW. Even though the surface area is higher for PVW pore diameter is found to be higher in PFW. Presence of pores was further confirmed by SEM images (Fig. 3(a) and 3(b)). From the characterization studies, it can be concluded that the activated carbons synthesized from putrescible vegetable as well as fruit waste are having surface heterogeneity and better adsorption capacity suitable for adsorbing dye molecules from effluent water.

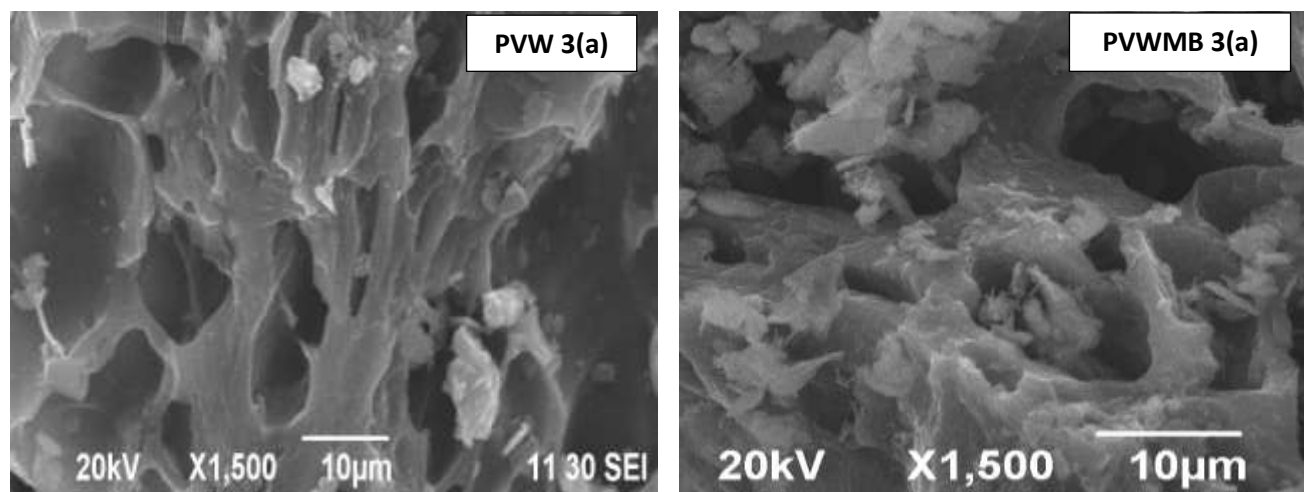


Figure 3 (a): SEM images for PVW and PVWMB

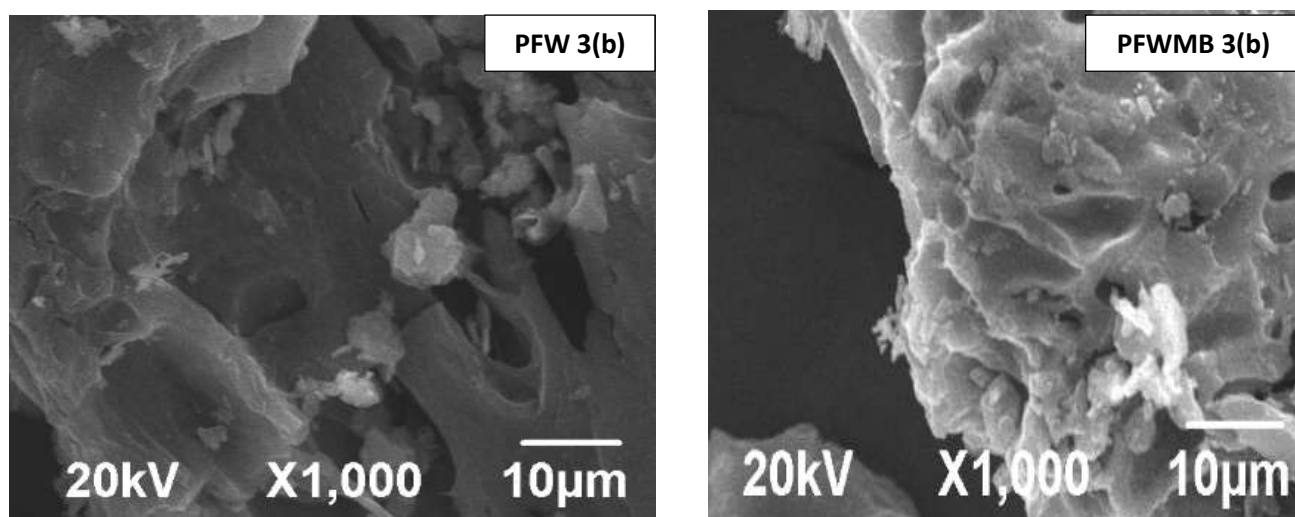


Figure 3 (b): SEM images for PFW and PFWMB

3.2 Effect of adsorbent dosage

PVW and PFW were ground well and sieved to different particle sizes. A particle size with higher yield was selected. For both the adsorbents a particle size of 105 – 75 μ was selected for the entire study. It was observed in both the adsorbents that as the amount of adsorbent increased the removal percentage also increased. This is due to the greater availability of the adsorbent sites at higher concentrations of the adsorbent (Santhi et al., 2010).

3.3 Effect of pH

By varying the pH at various initial dye concentrations the study was carried out. It was found that at pH 7, PVW removed 92% MB and PFW removed 75%. This is due to the reason that MB produces cations and reduced ions. As the pH increases the negative charge density on the adsorbents increases leading to more electrostatic attraction of positively charged dye molecules (Meena Sundari and Meenambal, 2013). Similar studies were reported in the adsorption of methylene blue by fly ash (Sivakumar, 2009), tuncbilek lignite (Parimalam et al., 2011).



Table 2: Pore characteristics of PVW and PFW

Parameters	Values	
	PVW	PFW
Surface area parameters (m²/g)		
BET Surface area	603.7	351.5
BJH method cumulative adsorption surface area	505.7	184.6
DH method cumulative adsorption surface area	535.2	187.8
Pore volume data (cm³/g)		
Total pore volume	0.7053	0.6319
BJH method cumulative adsorption pore volume	0.6416	0.5026
DH method cumulative adsorption pore volume	0.6411	0.4938
Pore Size data (A⁰)		
Average pore diameter	46.74	55.61
BJH method cumulative adsorption pore diameter	18.19	31.07
DH method cumulative adsorption pore diameter	18.19	31.07

3.4 Effect of contact time and initial dye concentration

On comparing the dye removal of both the adsorbents with respect to effect of time it was found that as the time of contact increases the removal percentage also increases. After a particular time, the process attains equilibrium and further uptake of dye is stopped. This is due to the reason that the limited capacity of the adsorbent checks any further adsorption of dye. Hence the overall removal percentage decreased (Kirk, 1998; Rahman et al., 2012). The equilibrium time and maximum MB (25 ppm) removal for PVW and PFW was at 110 minutes with 83.5% and 150 minutes with 79% respectively. Thus for PVW 110 minutes and for PFW 150 minutes was fixed as equilibrium time for the entire study (Fig. 4). As observed from the above studies PVW has better adsorption capacity than PFW because of its higher surface and higher adsorption capacity.

3.5 Comparison of Kinetic properties

3.5.1 Pseudo first order kinetic model

The pseudo first-order model of Lagergren (2005) is based on the assumption that the rate of change of adsorbed solute with time is proportional to the difference in equilibrium adsorption capacity and the adsorbed amount. The pseudo first-order equation is expressed as in Eq.1

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (1)$$

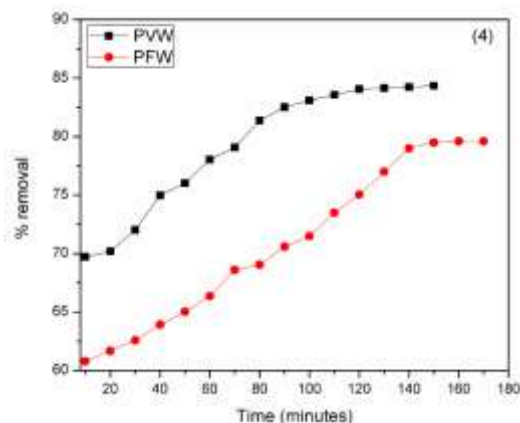


Figure 4: Effect of contact time for PVW and PFW

When the boundary conditions $q_t = 0$ at $t = 0$, Eq. (2) can be integrated into the following equation:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \quad (2)$$

where q_e (mgg^{-1}), and q_t (mgg^{-1}), are the adsorption capacity per unit weight of adsorbent at equilibrium and at time t (min) respectively. The pseudo first-order rate constant is k_1 (min^{-1}). Linear plot of $\log(q_e - q_t)$ versus t gives the value for rate constant k_1 (Fig. 5). Fig. 5 clearly shows that all the data points for PVW and PFW do not fall on the straight line. Table 3 also supports that there is a vast deviation between $q_{e(\text{exp})}$ and $q_{e(\text{cal})}$ and the correlation coefficient values is not nearing to 1. It is thus proved that the adsorption of MB onto PVW and PFW do not follow first order kinetics (Nagashanmugam and Srinivasan, 2010).

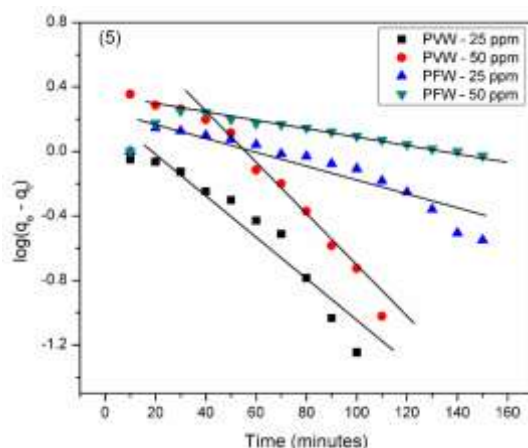


Fig 5: Pseudo First order kinetics for the adsorption of MB onto PVW and PFW

3.5.2 Pseudo second order kinetic model

The pseudo second-order model (Gupta et al., 2007) is based on the assumption that the rate-limiting step involves chemisorption. The equation is represented as in Eq. (3)

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (3)$$

When the initial conditions $q_t = 0$ at $t = 0$, after integration, the linear form of the pseudo second-order equation is given in Eq. (4)

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} (t) \quad (4)$$

where k_2 is the pseudo second-order rate constant ($\text{gmg}^{-1}\text{min}^{-1}$). The initial adsorption rate h ($\text{mgg}^{-1}\text{min}^{-1}$) at $t = 0$ is defined as follows:

$$h = k_2 q_e^2 \quad (5)$$

The straight line plot of t/q_t versus t , for the adsorption of MB by both the adsorbents is shown in Fig.6. From the linear plot the values of h , q_e and k_2 are calculated (Table 3). The correlation coefficients are greater than 0.99 (Table 3). From the

Fig.6 where all the points falling on the straight line confirms that the adsorption of MB onto PVW and PFW follows pseudo second order kinetic model (Hameed et al., 2007).

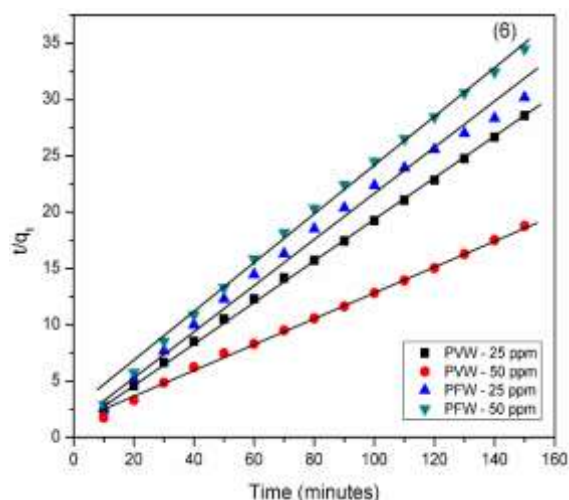


Figure 6: Pseudo Second order kinetics for the adsorption of MB onto PVW and PFW

gently with double distilled water to remove any un-adsorbed dye, if present. By varying the pH of the solution desorption study was carried out. It was found that for PVW maximum desorption occurred in the pH range 2 -3 and about 40.2% of MB could be desorbed. For PFW maximum desorption was in the pH 3 and 70.1% MB could be desorbed. This result indicates that nature of adsorption of MB onto PVW is chemisorption and PFW is physisorption. Fig. 9 clearly depicts the desorption nature of both the adsorbents.

3.6 Comparison of Isotherm properties

When the adsorption reaction reaches equilibrium state, the adsorption isotherm can indicate the distribution of dye molecules between the solid phase and the liquid phase. In order to understand the significance of the adsorption behavior various adsorption isotherm models can be utilized. In this paper Langmuir and Freundlich isotherms were employed to investigate the adsorption behavior.

3.6.1 Langmuir isotherm model

The Langmuir isotherm theory is based on the assumption that adsorption takes place at specific homogeneous sites within the adsorbent. The interaction among the adsorbate molecules can be negligible, and the adsorbent surface is saturated after monolayer adsorption. It also assumes that uniform energies of adsorption onto the surface without transmigration of adsorbate in the plane of the surface (Langmuir, 1917). It plays an important role in the determination of the maximum capacity of adsorbent.

Table 3: Comparison of the Kinetic parameters for the adsorption of MB onto PVW and PFW

Kinetic model	PVW		PFW	
	25 ppm	50 ppm	25 ppm	50 ppm
$q_{e(\text{exp})}$ (mg/g)	5.250	7.987	2.468	4.937
First order kinetic model				
$q_{e(\text{cal})}$ (mg/g)	0.6725	0.4128	1.040	1.002
$K_1 \times 10^{-2}$ (min^{-1})	3.245	5.578	1.206	0.534
R^2	0.8585	0.8744	0.9013	0.9098
Second order kinetic model				
$q_{e(\text{cal})}$ (mg/g)	5.456	8.555	2.131	4.493
$K_2 \times 10^{-3}$ (g/mg/min)	3.257	1.154	1.837	2.601
h	0.9696	0.8428	0.4821	0.5309
R^2	0.9996	0.9988	0.9961	0.9993



The form of Langmuir isotherm equation is expressed as follows:

$$q_e = \frac{Q_m K_a C_e}{1 + K_a C_e} \quad (6)$$

where Q_m is the theoretical maximum adsorption capacity per unit weight adsorbent (mgg^{-1}), K_a is Langmuir adsorption constant (Lmg^{-1}), C_e and q_e are concentration and amount of dye adsorbed at equilibrium respectively. The Langmuir isotherm Eq. (6) can be linearized into the following form

$$\frac{C_e}{q_e} = \frac{1}{K_a Q_m} + \frac{1}{Q_m} \times C_e \quad (7)$$

A plot of C_e/q_e versus C_e should indicate a straight line of slope $1/Q_m$ and an intercept of $1/(K_a Q_m)$ (Fig. 7). The results obtained from the Langmuir model for the removal of MB onto PVW and PFW are shown in Table 4.

Data from Langmuir isotherm reveals that both the adsorbents are suitable for the removal of MB from aqueous solution. Maximum monolayer adsorption capacity was observed for the adsorption of MB onto PVW at 30°C . It can be implied that the activated carbon prepared from vegetable waste is better than fruit waste. Strong positive evidence for the good adsorption capacity is also obtained from the correlation coefficients R^2 as shown in Table 4.

Freundlich isotherm is a model based on the distribution of solute between the solid phase and liquid phase at equilibrium (Freundlich, 1906). The Freundlich equation is expressed as follows:

$$q_e = K_F C_e^{1/n} \quad (8)$$

where K_F is a constant for the system, related to the bonding energy. K_F can be defined as the adsorption or distribution coefficient and represents the quantity of dye adsorbed onto adsorbent for unit equilibrium concentration. $1/n$ is indicating

Table 4: Comparison of the coefficients isotherm parameters for the adsorption of MB onto PVW and PFW at 30°C

Adsorbents	Langmuir isotherm parameters			Freundlich isotherm parameters		
	Q_m (mg/g)	b (L/mg)	R^2	$1/n$	K_F (mg/g)	R^2
PVW	21.54	0.1491	0.9977	0.2221	2.437	0.9572
PFW	8.247	0.1781	0.9702	0.1213	7.3198	0.9708

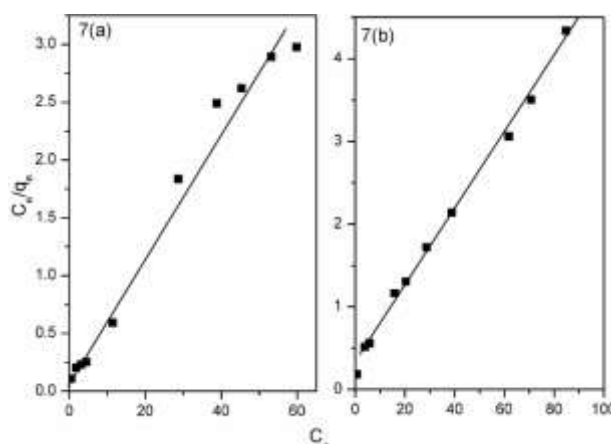


Figure 7: Langmuir isotherm model for the adsorption of MB onto (a) PVW and (b) PFW

Freundlich isotherm model

the adsorption intensity of dye onto the adsorbent or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero. A value for $1/n$ below 1 indicates a normal Freundlich isotherm while $1/n$ above 1 is indicative of

cooperative adsorption. Eq. 8 can be linearized in the logarithmic form [Eq. 9] and the Freundlich constants can be determined:

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \quad (9)$$

The applicability of the Freundlich adsorption isotherm was also analyzed, using the same set of experimental data, by plotting $\log q_e$ versus $\log C_e$. The data obtained from linear Freundlich isotherm plot for the adsorption of the MB onto PVW and PFW is presented in Table 4 and Fig. 8. The correlation coefficient shows that the Freundlich model is comparable to the Langmuir model. The value for $1/n$ is lower than 1.0 (Table 4), indicating that adsorption of MB by both the adsorbents is favorable.

3.7 Nature of adsorbents after adsorption

The samples were collected after carrying out effect of dye concentration. Samples were adsorbed with 100 ppm dye concentration for an equilibrium time of 110 minutes for PVW and 150 minutes for PFW at 30°C. They were washed well with double distilled water and dried in hot air oven at 110°C for one hour for complete drying. They were cooled to room temperature and used for the study.

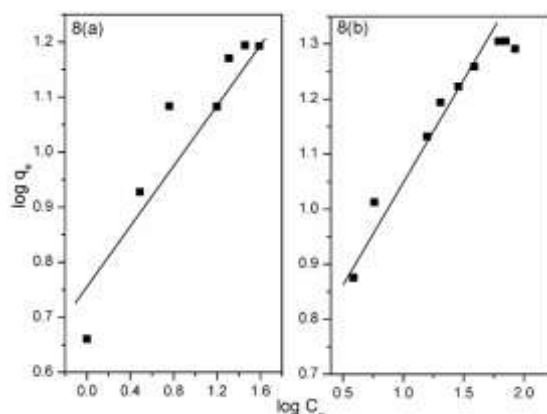


Figure 8: Freundlich isotherm model for the adsorption of MB onto (a) PVW and (b) PFW

3.7.1 IR, XRD and SEM analysis of PVW and PFW after adsorption with methylene blue dye

The IR spectral studies were carried out for PVW and PFW after the batch mode adsorption studies. On considering the IR spectra for PVW before and after adsorption (Fig. 1(a)), it was observed that the percentage absorption of the dye laden carbon (PVWMB) is increased and there is no shift in the band at 1597 cm^{-1} due to C=O groups. Bands representing C-H and C-C stretching 1166 cm^{-1} and 900 cm^{-1} a sharpening has occurred after adsorption. In PFWMB, a band shift has occurred from 1597 cm^{-1} to 1603 cm^{-1} due to MB adsorption. Band sharpening was seen in PFWMB at 1175 cm^{-1} . It can thus be confirmed that due to MB adsorption some changes are being observed in the IR spectra of both the adsorbents.

XRD spectra of PVWMB shows decreased intensity in the peaks at 2θ 15.09, 23, 24.3 and 26.6 due to MB adsorption onto PVW. Peaks at 2θ 31.6 and 37.7 due to calcium ions disappeared. In PFWMB, peak at 2θ 44 due to silica disappeared. There is no variation in the amorphous nature of both the activated carbons after adsorption. SEM images also show variation in the nature of the pores of PVW and PFW after adsorption.

3.8 Desorption

Desorption studies as a function of pH were conducted to analyze the possibility of reuse the adsorbent for further adsorption and to make the process more economical. After adsorption experiments the dye loaded carbons were washed (fig. 8).

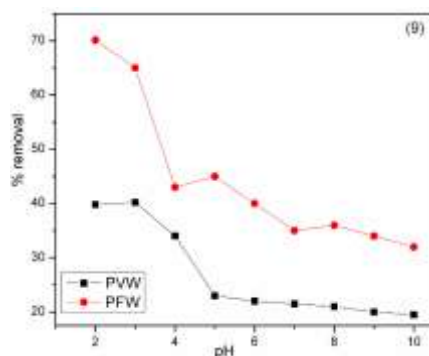


Figure 9: Desorption studies for PVW and PFW



3.9 Characterization of effluent samples before and after treatment

The main purpose of effluent analysis is to evaluate better – performing, advanced treatment methods with the aim of reuse, recovery of valuable products or safe disposal. Characterization of effluent samples before and after treatment with PVW and PFW are given in the Tables 5 and 6. The data in tables clearly pictures that PVW and PFW could improve the quality of the utilized textile dye effluent. Among the two adsorbents PVW could improve the effluent's water quality than PFW.

Table 5: Characterization of effluent samples before and after treatment with PVW

Parameters	MAL*	Sample 1		Sample 2		Sample 3		Sample 4	
		BT	AT	BT	AT	BT	AT	BT	AT
Colour	Colorless	Blackish green	Clear	Dark blue	Pale grey	Reddish black	Pale red	Black	Clear
pH (at 25 ^o C)	6.5-8.5	10.3	8.5	9.6	3.94	11.1	6.78	10.8	7.6
Turbidity (NTU)	5-10	34	7	45	4	38	4	51	3
BOD (20 ^o C, 3 days, mg/L)	max 30	28	ND	45	ND	52	12	32	ND
COD (mg/L)	max 250	860	72	580	55	430	45	400	50
TDS (mg/L)	500-2000	4110	2466	5274	3567	5040	3356	2727	1024
Total hardness (mg/L)	300-600	1200	156	799	76	656	80	645	42
Total alkalinity (mg/L)	200-600	950	242	1124	180	786	211	815	174
Chloride (mg/L)	200-600	622	181	220	60	408	60	392	80
Sulphate (mg/L)	200-400	1080	534	612	15	400	10	128	5

*Maximum Acceptable Limit as per BIS standard

ND – Not detectable

3.10 Economical evaluation of PVW and PFW

Putrescible solid waste material is available in abundance as a solid waste from market places, kitchens of marriage halls, hostels and hotels at no cost. Cost involved was for handling, segregation, collection, transportation of the waste and phosphoric acid used for the conversion of PVW into PAC. Consumption charges for drying in hot air oven and activation in muffle furnace were also taken into account. Table 6 clearly show the cost involved for production of both the adsorbents. Considering the entire expenditure, individual production cost for 1 kg of PVW and PFW would be approximately Rs.679.2.

4. CONCLUSION

Two different activated carbons were prepared from putrescible solid waste and were employed for the removal of a basic dye, methylene blue from its aqueous solution. They were characterized to find their adsorption capacity. BET surface area was found to be 603.7 and 227.3 m²g⁻¹ for PVW and PFW respectively. Iodine number, MB number and porosity were higher for PVW than PFW. Batch mode adsorption studies concluded that maximum adsorption took place in pH 7 at 30^oC. The adsorption followed pseudo second order kinetics for both the adsorbents. Langmuir isotherm model showed a best fit than Freundlich isotherm model. The isotherm data concluded that the adsorption of MB onto both the adsorbents is monolayer and chemisorption in nature. Spectral studies were done after adsorption and it is proved that adsorption of MB onto activated carbons has occurred. The adsorbents showed a maximum desorption of 40.2% for PVW and 70.1 % for PFW. Cost analysis of the adsorbents was Rs.679.2 per kg per adsorbent. Also the characterization of the effluent samples before and after adsorption confirmed that PVW can be effectively for effluent treatment than PFW. The results confirmed that activated carbons from vegetable and fruit peels can be effectively employed for the removal of basic dyes from their aqueous solution.



Table 6: Characterization of effluent samples before and after treatment with PFW

Parameters	MAL*	Sample 1		Sample 2		Sample 3		Sample 4	
		BT	AT	BT	AT	BT	AT	BT	AT
Colour	Colorless	Blackish green	Pale green	Dark blue	Clear	Reddish black	Pale grey	Black	Clear
pH (at 25°C)	6.5-8.5	10.3	9.3	9.6	5	11.1	7.8	10.8	8.1
Turbidity (NTU)	5-10	34	11	45	22	38	9	51	17
BOD (20°C, 3 days, mg/L)	max 30	28	13	45	ND	52	27	32	ND
COD (mg/L)	max 250	860	156	580	123	430	211	400	45
TDS (mg/L)	500-2000	4110	3548	5274	3221	5040	3887	2727	998
Total hardness (mg/L)	300-600	1200	150	799	101	656	77	645	342
Total alkalinity (mg/L)	200-600	950	444	1124	197	786	359	815	221
Chloride (mg/L)	200-600	622	198	220	85	408	200	392	86
Sulphate (mg/L)	200-400	1080	454	612	246	400	119	128	50

*Maximum Acceptable Limit as per BIS standard

ND – Not detectable

REFERENCES

1. Arami, M.; Limaee, N. Y.; Mahmoodi, N. M.; Tabrizi, N. S. (2005) Removal of dyes from colored textile wastewater by orange peel adsorbent: Equilibrium and kinetic studies. *J. Colloid and Interf. Sci.*, 288, 371 - 376.
2. Arancon Norman, Q.; Clive, A.; Andrei Babenko,; John Cannon,; Paola Galvis; James Metzger, D. (2008) *App. Soil ecology.*, 39, 91.
3. Bai, R.; Mardina, S. (2002) The practice and challenges of solid waste management in Singapore. *Waste managt.*, 22(5), 557 - 567.
4. Deng, H.; Guoxue Li, Y.; Hongbing, T.; Jiping,; Jianguyun, T. (2010) Preparation of activated carbon from cotton stalk by microwave assisted KOH and K₂CO₃ activation. *Chem. Engg. Jl.*, 163, 373 – 381.
5. Djilani, C.; Zaghdoudi, R.; Modarressi, A.; Rogalski, M.; Fay, Djazia.; Abdelaziz Lallam. (2012) Chemical Engineering Journal Elimination of organic micropollutants by adsorption on activated carbon prepared from agricultural waste. *Chem. Engg. Jl.*, 189, 203 - 212.
6. Freundlich, H. (1906) Über die adsorption in Losungen, *Zeitschrift für Physikalische Chemie*, 57, 387.
7. Foo, K. Y.; Hameed, B. H. (2012) Coconut husk derived activated carbon via microwave induced activation: Effects of activation agents, preparation parameters and adsorption performance. *Chem. Engg. Jl.*, 184, 57 - 65.
8. Glynn Henry, J.; Gary Heinke, W. (2005) Environmental science and Engineering, Prentice Hall of India Private Limited, New Delhi.
9. G€unther Laufenberg.; Benno Kunz.; Marianne Nystroem.; (2003) Review paper on Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations. *Biores. Tech.*, 87, 167 - 198.
10. Gupta, V. K.; Ali, I.; Saini, V. K. (2007) Defluoridation of wastewaters using waste carbon slurry. *Water Resh.*, 41, 3307 – 3316.
11. Hameed, B. H.; Ahmad, A. L.; Latiff, K. N. (2007) Adsorption of basic dye (methylene blue) onto activated carbon prepared from rattan sawdust. *Dyes and Pigments.*, 75, 143 - 149.
12. Kirk, P. B. (1998) Ph.D. Dissertation, Purdue University, West Lafayette, IN.
13. Langmuir, I. (1916) The constitution and fundamental properties of solids and liquids. *Jl. of American Chem. Soc.*, 38, 2221.
14. Lagergren, S. (1898) Zur Theorie Der Sogenannten Adsorption Geloester Stoffe. *Royal Swedish Academy of Sciences.*, 24, 1-39.



15. Mall, I. D.; Srivastava, V. C.; Kumar, G. V.; Mishra, I. M. (2006) Characterization and utilization of mesoporous fertilizer plant waste carbon for adsorptive removal of dyes from aqueous solution. *Colloids Surface A: Physicochem. Engg. Aspects.*, 278, 17 - 28.
16. Mall, I. D.; Srivastava, V. C.; Nitin Kumar, A.; Mishra, I. M. (2005) Adsorptive removal of malachite green dye from aqueous solution by bagasse fly ash and activated carbon-kinetic study and equilibrium isotherm analyses. *Colloids Surface A: Physicochem. Engg. Aspects.*, 264, 1-3, 17 (2005).
17. McKay, G.; Porter, J. F.; Prasad, G. R. (1999) The removal of dye colors from aqueous solutions by adsorption on low-cost materials. *Water Air Soil Pollution.*, 114, 423 – 438.
18. Malik, R.; Ramkete, D. S.; Wate, S. R. (2006) Physico-chemical and surface characterization of adsorbent prepared from groundnut shell by ZnCl₂ activation and its ability to absorb colour. *Indian Jl. of Chem. Tech.*, 13, 319 - 328.
19. Mata-Alvarez, J.; Mace, S.; Llabres, P. (2000) Anaerobic digestion of organic solid wastes: An overview of research achievements and perspectives. *Biores. Tech.*, 74, 3 – 16.
20. Meena Sundari, P.; Meenambal, T. (2015) A comparative study on the adsorptive efficiency of low-cost adsorbents for the removal of methylene blue from its aqueous solution. *Desalination and water treatment.*, 1 – 10.
21. Meena Sundari, P.; Meenambal, T. (2013) Comparative study of raw and microwave irradiated industrial solid waste as adsorbent for the removal of methylene blue from its aqueous solution. *Indian Jl. of Chem. Tech.*, 20, 165 – 172.
22. Moreno-Castilla, C.; Lopez-Ramon, M. V.; Carrasco-Marina, F. (2001) Dehydration of methanol to dimethyl ether catalyzed by oxidized activated carbons with varying surface acidic character. *Carbon*, 39, 869 – 875.
23. Nagashanmugam, K. B.; Srinivasan, K. (2010) Evaluation of Lead (II) removal by carbon derived from gingelly oil cake. *Asian Jl. of Chem.*, 22, 5447 – 5462.
24. Nevine Kamal Amin. (2008) Removal of reactive dye from aqueous solutions by adsorption onto activated carbons prepared from sugarcane bagasse pith *Desalination*, 223, 152 – 161.
25. Parimalam, R.; Raj, V.; Sivakumar, P. (2011) Adsorption isotherms, kinetics, thermodynamics and desorption studies of reactive orange 16 on activated carbon derived from Ananas comosus Carbon. *ARPJ. Engg. and App. Sci.*, 6 (11), 15 – 26.
26. Rahman, M. A.; Ruhul Amin, S. M.; Shafiqul Alam, A. M. (2012) Removal of Methylene Blue from Waste Water Using Activated Carbon Prepared from Rice Husk. *Dhaka Univ. J. Sci.* 60, 185 – 192.
27. Sajab, M. S.; Chin Hua, C.; Sarani, Z.; Poi Sim Khiew. (2013) Cationic and anionic modifications of oil palm empty fruit bunch fibers for the removal of dyes from aqueous solutions. *Biores. Tech.*, 128, 571 - 577.
28. Salman, M.; Njoku, V.O.; Hameed, B. H. (2011) Bentazon and carbofuran adsorption on date seed activated carbon: Kinetics and equilibrium. *Chem. Engg. Jl.*, 173, 361 – 368.
29. Santhi, T.; Manonmani, S.; Smitha, T. (2010) Removal of malachite green from aqueous solution by activated carbon prepared from the epicarp of Ricinus communis by adsorption. *Jl. of Hazard. Mater.*, 179, 178 - 186.
30. Selvakumar, R.; Kavitha, S.; Sathishkumar, M.; Swaminathan, K. (2008) Arsenic adsorption by polyvinyl pyrrolidone K25 coated cassava peel carbon from aqueous solution. *Jl. of Hazard. Mater.*, 153, 67 - 74.
31. Sivakumar, P. (2009) Adsorptive removal of textile dyes from aqueous solution using a non-conventional low cost adsorbent. Ph.D. thesis, Anna University, Chennai.
32. Stephen Inbaraj, B.; Sulochana, N. (2006) Use of jackfruit peel carbon for adsorption of Rhodamine-B, a basic dye from aqueous solution. *Ind. Jl. of Chem. Tech.*, 13, 17-23.
33. Tay, T.; Ucar, S.; Karagoz, S. (2009) Preparation and characterization of activated carbon from waste biomass. *Jl. of Hazard. Mater.*, 165, 481- 485.