CHAPTER 2

LITERATURE REVIEW

2. Literature Review

In this chapter, we have reviewed the adsorption capacity of different activated carbon prepared by different raw material with chemical activation for the removal of hexavalent chromium metal and methylene blue dye from aqueous phase. The activation condition and result of adsorption is also discussed in this chapter.

2.1 Hexavalent chromium Cr (VI)

Yang et al. (2015) reported the adsorption of hexavalent chromium from aqueous solution by activated carbon prepared from longan seed. The activated carbon was prepared from longan seed by chemical activation with sodium hydroxide (NaOH). It was observed that the surface area of the prepared activated carbon was 1511.8 m^2/g which was favourable for the adsorption of any metal from aqueous solution. The maximum adsorption of Cr (VI) was observed at pH 3.0 and at 170 rpm. The percentage removal of Cr (VI) was found to be maximum with increasing dosage of activated carbon. The kinetics was best explained by the pseudo second-order kinetic model with the activation energy 84.4 kJ/mol. The adsorption isotherms data of Cr (VI) on LSAC was calculated at different temperatures for Langmuir and Freundlich models and it was observed that the data was better represented by the Langmuir isotherm model.

Gottipati and Mishra (2016) prepared microporous activated carbon from Aegle Marmelos fruit shell with $ZnCl_2$ activation for the removal of chromium (VI). The characterization revealed the micropore surface area as 1339 m^2/g and micropore volume as 0.48cm^3/g. The effect of solution pH was studied and it was seen that the pH played important role in Cr (VI) adsorption. It was found that the maximum removal (82.3%) was observed at pH 2.0 with adsorption capacity (q_e) of 43.54 mg/g. The

kinetics was studied at different initial concentrations of Cr (VI) and it was observed that the kinetic data is better explained by the pseudo-second order model. The adsorption data was fitted to Freundlish and Langmuir isotherms and it was seen that the Freundlich isotherm was appropriate for this system.

Maneechakr et al. (2017) studied the removal of Fe (II) and Cr (VI) on activated carbon prepared from Combretum quadrangulare Kurz with chemical activation by 45%w/w phosphoric acid (H_3PO_4). For preparation of activated carbon the raw material was pyrolysied under 400-500 ^{0}C for 1–5 h. It was found that the activated carbon prepared at the temperature of 500 ^{0}C for 1 h had the high adsorption ability. It was found that the equilibrium data for Fe^{2+} and $Cr_2O_7^{2-}$ adsorption show a good fit to the Langmuir isotherm model. The highest q_{max} values for adsorptions of Fe^{2+} and $Cr_2O_7^{2-}$ by activated carbon were 15.50 and 1.68 mg g^{-1}, respectively. The pseudo second-order kinetic model explained better for the kinetic data quite well (R^2 > 0.99). The thermodynamic study revealed that the adsorption process is spontaneous and endothermic.

Kumar and Jena (2017) reported the adsorption of Cr (VI) from aqueous phase by activated carbon prepared from fox nutshell by chemical activation with $ZnCl_2$. The activation was done at temperature of 600 ^{0}C for 1h. The BET surface area was found as 2869 m^2/g and pore volume as1.68 cm^3/g. To find out the optimum condition the experiment were performed in batch mode by varying different parameters such as agitation speed (80-170 rpm), pH (2-7), dose(0.01-0.07 g/100 ml), temperature (298-318K), contact time (0-180 minutes) and initial Cr(VI) concentration (10-25 mg/L). The maximum adsorption of Cr (VI) was found at pH of 2.0 and the maximum adsorption capacity was found as 10 mg/L (99.08% removal efficiency) at temperature

of 30 ^{0}C in 3 h. The different thermodynamic parameters as ΔG°, ΔS° and ΔH° were calculated and the results show that the adsorption of Cr (VI) on activated carbon was feasible, spontaneous and endothermic in nature. In this study the equilibrium data were best fitted by Langmuir isotherm model with having maximum adsorption capacity of 46.21 mg/g.

Niazi et al. (2018) used the effect of Chestnut oak shells activated carbon for Cr (VI) removal from dilute aqueous solutions. The activated carbon was prepared from Chestnut oak shells, chemically activated with H_3PO_4 and at the final carbonization temperature of 450 ^{0}C.The prepared activated carbon was characterized using FTIR, SEM and point of zero charge. The FTIR spectra revelled different function group such as C-O, C=O, CH_3, C=O and O-CH_3 which were responsible for adsorption of Cr (VI). The BET surface area of the chestnut shell increased to 989.4m^2 g^{-1} by the activation process. The pH_{ZPC} of the prepared activated carbon was 3.5 which show that the adsorption was preferred in highly acidic range. For analysis of the effect of operating parameters, the adsorption was studied at pH (2-7), running time of 2 h and initial concentration of Cr (VI) (10-100 mg/L) in batch mode. The maximum adsorption capacity of the prepared activated carbon was 33 mg g^{-1} at pH of 2.0 and the running time was 120 minutes. The equilibrium experimental data were correlated with different isotherm models such as Freundlich, Langmuir, and Dubinin-Raduskevich (D-R) at various temperatures such as 20, 30 and 40 °C. The Langmuir model fitted well the experimental results. The kinetics of chromium (VI) adsorption were analyzed by three common kinetics models, pseudo first order, pseudo second order and Weber-Morris model. The constant parameters and R^2 values for these three models were calculated and the higher co-relation coefficient gave for pseudo second order model.

Norouzi et al. (2018) reported the preparation of activated carbon produced from Date Press Cake which was chemically activated with NaOH. In this study the date press cake was mixed with NaOH in the weight ratio of 2:1 (NaOH:Cake) and chemically impregnated samples were kept in furnace for various final temperatures (450–750 °C) for 90 minutes. They found a high specific surface area (2025.9 m^2 g^{-1}) for prepared activated carbon. FTIR spectra revealed the different functional groups at specific peak location such as C=O at 1722 cm^{-1},-NH group at 1624 cm^{-1}, C-O at 1081 cm^{-1}. After adsorption the peak location of different functional group with deceased intensity was seen due to adsorption of Cr(VI). The batch experiment were examined and the maximum monolayer adsorption capacities as high as 282.8 mg $g^{-1}$was obtained at pH value of 2.0. They also investigated that the kinetic and isotherm study. It was clear from the result that the Cr (VI) adsorption was best described by the Elovich kinetic model and Redlich-Peterson adsorption isotherm.

Doke et al. (2017) studied the adsorption of Cr (VI) adsorption onto activated carbon derived from wood apple shell. For the preparation of activated carbon the powdered wood apple shell was treated by H_2SO_4 and mixed samples were heated in muffle furnace at 600 °C for 2 h. The BET surface area of the prepared activated carbon was found to be 1898 m^2/g. The batch experiments were performed at different operating conditions and the maximum adsorption efficiency was found to be 95.0% at pH 1.8, dose of 1.25 g/L and initial concentration of 75 mg/L. The adsorption process was better explained by the Langmuir isotherm model better compared to Freundlich isotherm and the maximum monolayer adsorption capacity was 151.51 mg g^{-1} at 300 K. They also observed that the dimensionless separation factor (R_L lies between 0 -1) signifying a favorable adsorption of Cr (VI) on the activated carbon. They also studied

the adsorption kinetic at different initial concentration. The adsorption was followed a pseudo-second order chemisorptions as well as intra-particle pore diffusion mechanism.

Kumar and Tamilarasan (2017) studied the sorption of chromium by Prosopis juliflora bark carbon. For preparation of activated carbon the powdered samples of raw Prosopis juliflora bark were mixed in H_2SO_4 solution in 1:1 w/w ratio for proper impregnation of chemical into the pores of powdered samples. After washing and drying the samples were characterized. From the FTIR spectra it was seen that various functional group before and after adsorption these peak had changed the location which revelled the adsorption of Cr (VI) on the surface of activated carbon. They also compared the SEM image before adsorption and after adsorption of Cr (VI). The SEM image showed the micro porous structure of activated carbon which was occupied by adsorbed Cr (VI) ions. They investigated the removal efficiency of chromium at different experimental condition in batch mode. The maximum adsorption capacity of 96.4 mg g^{-1} occurred at pH 5.5 and initial concentration 120 mg/L. The adsorption data were analyzed with two adsorption isotherm models, namely Freundlich and Langmuir and it was found that the Langmuir isotherm model better fitted the experimental data. The pseudo second order model represented the kinetic data.

Zou et al. (2015) examined the adsorption of Cr (VI) on sunflower seed hull derived porous carbon activated with $ZnCl_2$. The raw sunflower hull was mixed with $ZnCl_2$ for 24 h. After mixing the samples were dried at 80 °C for 12 h, and then the dried samples were kept in a tubular furnace at 650 °C for 1h. In this study the characterization results were determined by SEM, FTIR and BET surface analyzer. The FTIR spectra revealed that the peak between 3419–3440 cm^{-1} was due to the stretching vibrations of -OH hydroxyl groups, bands at 1619–1634 was due to the vibration of

aromatic C=C. The BET surface area and pore volume were found to be 1966 m^2/g and1.283 cm^3/g, respectively. The SEM image revealed the porous structure of adsorbent which was responsible for maximum adsorption of Cr (VI).Through batch removal experiments it was observed that the removal efficiency was dependent on solution pH and the adsorption capacity was found to be maximum at pH 2.5-3. Equilibrium data were performed at different temperature and result were explained better by the Langmuir isotherm model a high R^2 value and maximum monolayer adsorption of 162.6 mg/g. They also explained the kinetic data at different initial consternation. The pseudo-second-order kinetic model fitted the adsorption kinetic data.

Enniya et al. (2018) prepared an activated carbon from apple peels and used for the adsorption of chromium. For preparation of activated carbon apple peels were mixed with H_3PO_4 in the ratio of 2.7:1 (volume of H_3PO_4: weight of apple peels).The chemically loaded samples were kept in the muffle furnace at 619 °C for 56 minutes. The FTIR spectra of ACAP before and after Cr (VI) adsorption were obtained and from the graph it was observed that the spectra is near about similar but intensity and peak locations were changed due to adsorption of Cr(VI) on activated carbon. The peak at 1834 cm^{-1} (C=O stretching) had changed the position and it appeared at 1863 cm^{-1} after adsorption. Similarly the peak at 1555 cm^{-1} corresponding to C = C stretching had shifted to 1563 cm^{-1} after capturing the Cr (VI). From SEM image it was observed that the surface of apple peel activated carbon had porous structure which was occurred due to reaction with H_3PO_4 and carbonization. After characterization the samples were used to check the removal efficiency of Cr (VI) at different values operating parameter. The effect of pH was estimated and it was fund that the maximum adsorption of chromium was 34.59 mg/g at pH 2. The effect of adsorbent dose was also examined and it was observed that adsorption percentage of chromium increased from 12% to 95% after

increasing the dose from 0.025g/50 mL to 0.15g /50 mL. The Freundlich adsorption isotherm was fitted to the experimental data fitted (R^2 = 0.99). The Pseudo second order model fitted well in comparison to pseudo first order model to the kinetic data. The thermodynamic parameters as $\Delta G<0$, $\Delta H° = 1.99$ (Kcal/mol) and $\Delta S° = 0.0079$ (Kcal/K mol) which described that the adsorption process was spontaneous and endothermic in nature.

Fan et al. (2019) studied the adsorption of Cr (VI) on activated carbon prepared by co-pyrolysis of rice straw and sewage sludge activated with $ZnCl_2$. The rice straw and sewage sludge were mixed to improve the carbon content. The mixed samples were mixed with $ZnCl_2$ in 1:2 ratio. The dried sample was heated in an electric furnace at 600 °C for 2 h. The effect of pH was studied in the range 2.0 to 7.0 and it was observed that 97.7% removal occurred at pH 2.0. At lower pH the surface of activated carbon were protonated. The effect of contact time and the kinetics were also studied. During initial stage of (0–6 h) the removal of Cr (VI) increased rapidly due to availability of a large number of vacant sties on the activated carbon. To understand the adsorption behaviour the three kinetic models pseudo first order, pseudo second order and intraparticle diffusion model were used. The experiment data fitted better with the pseudo-second-order model (R^2 = 0.99 with adsorption capacity value of 47.7 mg/g in comparison to two others models. It was concluded that the Langmuir-Freundlich model was more suitable in describing the removal behaviour of Cr (VI) with maximum adsorption of 138.69 mg/g at 40 °C. The FTIR spectra were observed before and after adsorption. It was found the different peaks such as at 3410 $cm^{-1}$for O-H and at 3430 cm^{-1} for N-H groups. The peaks at 2925 cm^{-1} and 1610 cm^{-1} were observed and it attributed to C-H vibration and – COOH group, respectively.

Ajmani et al. (2019) reported the adsorption of Cr(VI) on activated carbon prepared from Phanera vahlii fruit biomass. The fruit biomass was activated with H_3PO_4 and $ZnCl_2$ at 353 K for 24 h. The chemically mixed samples were heated in a muffle furnace at temperature of 600 °C for 1 h. The BET surface area and pore volume were found as1424 m^2/g and 1.973cm^3/g, respectively for H_3PO_4 activated carbon (PVPAAC). The $ZnCl_2$ activated carbon (PVZCAC) had the surface area of 1673 m^2/g and pore volume of 1.496cm^3/g. The effect of pH for Cr (VI) removal was studied between the pH range of 2.0 to 7.0 and the maximum adsorption was obtained at pH 2.0. The initial Cr (VI) concentration was varied from 100 to 500 mg/L and experiments were was performed at dose of 05 g/L, time of 3 h, speed of 100 rpm and temperature of 303 K. It was observed that the adsorption capacity increased from 127.8 to 239.7 mg/g for PVPAAC and 149.1 to 272.1 mg/g for PVZCAC. The adsorption isotherm was studied and it was reported that the Freundlich isotherm fitted the data for both PVPAAC and PVZCAC with maximum adsorption capacity of 244.1, and 278.5 mg/g, respectively. The Kinetic study was also done at initial Cr (VI) concentration range of 100 mg/L to 500 mg/L. The pseudo-second order kinetics was found to be best. The thermodynamic studies revealed that the adsorption of Cr (VI) on these activated carbons was endothermic and spontaneous in nature.

Rangabhashiyam et al. (2015) reported the remediation of hexavalent chromium by $ZnCl_2$ activated Sterculia guttata shell. The shell was washed for removal of dirt and then samples were mixed with zinc chloride solution. For proper mixing the samples were stirred at 85 °C for 2 h and kept for 24 h. The activation experiment was done in a stainless tube heated at 400 °C for 60 min in a muffle furnace. The prepared samples showed a BET surface area of 498.29 m^2/g, pore volume of 0.232cm^3/g and pHzpc of 6.79. The C, H and N content of activated carbon was reported as 57.94 %, 2.87% and

0.89% respectively. In the SEM image indicated the different types of cavities and pores due to carbonization effect. The FTIR spectra of activated carbon were done to find out the functional group and it was observed the different functional group such as –OH stretching, -COO, C=O,C-O-C and -CH_3 group. Batch adsorption experiments were carried out to find out the optimum conditions at which the adsorption capacity was maximum. The effect of pH was studied in the range of 2.0 to 8.0 was studied and the maximum adsorption of Cr(VI) was found as 24.97 mg/g at pH value of 2.0. The effect of contact time (0 to 180 minutes) and initial concentration of Cr(VI) (20 -100 mg/L) was also studied. The adsorption capacity was increased from 24.92 to 82.67 mg/g for the initial Cr(VI) concentration of 20 mg/l to 100 mg/l at equilibrium time of 140 minutes. After the comparison of different isotherm parameters the Langmuir isotherm was applicable for this adsorption with maximum adsorption capacity of 90.90 mg/g. The kinetic study at different initial Cr(VI) concentration suggested the validity of pseudo second order model for Cr(VI) removal.

Al-Othman et al. (2012) reported the preparation of KOH activated carbon from peanut shells. The prepared carbon samples were used to absorb Cr (VI) from aqueous phase. The peanut shells were washed for the removal of dirt and then were crushed into desired size. The crushed peanut shell was impregnated with 20% KOH solution for 24 h and dried at 170 °C for 1 h. Then the dried samples were carbonized into tubular furnace at 450 °C for 1h in presence of nitrogen gas. The BET surface area and pore volume were found as 88.85 m^2/g and 0.33 cm^3/g, respectively. It was observed the cavities on the surface of activated carbon due to KOH activation and carbonization. The effect of pH of Cr (VI) solution was studied in the range of 2 to 10. It was observed that the maximum adsorption capacity was reported in acidic region and maximum adsorption was occurred at pH of 2.0. In this adsorption study the effect of contact time

(0 to 48 h) was studied and equilibrium was reached at 24 h. The initial concentration was studied for initial Cr (VI) concentration of 20, 30 and 40 mg/L. It was observed that the amount of Cr (VI) adsorption was increased from 4.31 to 6.25 mg/g. The kinetics of Cr (VI) adsorption on activated carbons were analyzed using pseudo first-order, pseudo second-order and intraparticle diffusion for different initial concentrations. The correlation coefficient (R^2) was maximum for both pseudo first and pseudo second order model. The study of adsorption isotherm was studied for Langmuir and Freundlich isotherm at temperature of 293, 303 and 313 K. For these isotherms the different constants were compared and it was reported that the Langmuir isotherm fitted the data accurately.

Liu et al. (2014) reported the preparation of activated carbon from Zizania caduciflora (ZC) with phosphoric acid together with tartaric acid. The activated carbon was prepared by soaking the Zizania caduciflora powder with 40 % H_3PO_4 and then impregnated with tartaric acid for 24 h. The impregnated samples were carbonized at the temperature of 450 °C for 1 h in muffle furnace. The characterization result of the H_3PO_4 derived activated carbon was reported with high BET surface area (1270 m^2/g) and large total porous volume (1.37cm^3/g). The effect of pH was studied for the removal of Cr (VI) in the pH range of 2-11, and maximum adsorption capacity was fond between pH 2.0-3.0. Equilibrium data for the removal of Cr (VI) was described by Freundlich isotherm. The Langmuir isotherm model fitted better with maximum adsorption capacity (31.0 mg/g).

Al-Othman et al. (2013) studied the adsorption of Cr(VI) by low cost adsorbent produced from peanut shell activated with H_3PO_4.The kinetic, equilibrium isotherm and thermodynamic parameters were also studied. The peanut shell was impregnated with

85% H_3PO_4 for 24 h and the samples were activated in tube furnace at 500 °C for 90 min. The prepared activated carbon was characterized for BET surface area (582.77 m^2/g) and pore volume (0.34 cm^3/g). The experiments were performed in the pH range of 2 to 10 at the temperature of 25° C and the initial Cr (VI) concentration of 80 mg/L. At pH 2.0 the maximum adsorption capacities was found as 24.41 mg/g with76.28 % removal of Cr (VI). The effect of initial concentration of Cr (VI) in the range (40, 60, 80 and 100 mg/L) was studied and it was observed that the adsorption uptake increased from 13.99 to 26.27 mg/g. The experiment was done to find out the equilibrium contact time. For this adsorption process the equilibrium time was found as150 min. The dose optimization was carried out for the range of 0.5 to 5g/L and it was reported that the removal increased from 15.02 to 90.83 %. The kinetic study was studied at different initial concentration. The pseudo second order model represented the data well (R^2 = 0.99) compared to pseudo first order and intra particle diffusion models. The experimental adsorption capacity, q_e was also near to calculated q_e value of pseudo second order model. The different isotherm parameters were also compared and Langmuir isotherm best fitted the data for all temperatures with maximum adsorption capacity of 46.73 mg/g at 323K.

Goswami et al. (2014) studied the equilibrium and kinetics for the adsorption of Cr (VI) by activated carbon prepared matured tea leaves. The porous activated carbon was synthesized by impregnation of tea leaves with 85 % H_3PO_4 and carbonized at 500 °C for 1 h in a muffle furnace. The FTIR absorption peak at 3425 cm^{-1} was due to –OH group and 1645 cm^{-1} corresponded to -COO group. The other functional groups such as C=O, C-H group and-OCH_3 group were also observed at different peak locations in the spectra. The BET surface area of this new porous activated carbon was reported as1313.41 m^2/g and the total pore volume as 1.359 cm^3/g. The SEM image indicated a

porous network. The batch study was performed to investigate the effect of initial metal concentration in the range of 20 to 100 mg/L, the Cr (VI) uptake increased from 15.4 to 28.8 mg/g but percentage removal decreased from 72.21 to 28.89%. The effect of activated carbon dose was studied in the range of from 1 to 3 g/L. The removal of Cr (VI) was increased from 41.26 to 82.27 % for the dose increment from 1 to 3 mg/L. The effect of pH was also observed and it was reported that the lower pH (1.5) was suitable for maximum adsorption (57.57 mg/g) for the contact time of 120 minutes. For the adsorption isotherm, different parameters of Langmuir, Freundlich and Temkin isotherm were compared. The Langmuir isotherm represented the equilibrium data with higher value of correlation coefficient (R^2 = 0.991). The adsorption kinetics at different concentration was reported for pseudo first, pseudo second and intra particle diffusion model. The pseudo second order model fitted best to the experimental value. The positive value of ΔH_0 (28.6 kj/mol) explained the endothermic nature of adsorption.

Gorzin and Ghoreyshi (2013) had studied the synthesis of new activated carbon from activated sludge and used it for the removal of Cr (VI) from aqueous phase. The raw, activated sludge was dried in oven at 100 °C and was then soaked in $ZnCl_2$ in the ratio of 3:1 ($ZnCl_2$: dry sludge). The carbonization was done in a horizontal furnace at 650 °C for 1 h under inert atmosphere. The BET surface area was analysed by surface area analyzer. The BET surface area was reported as 760 m^2/g and pore volume as 0.8383 cm^3/g. The surface morphology and pore structure were observed by SEM-EDX spectrum and it was reported that the adsorbent had porous structure and irregular shapes of cavity which were responsible for higher surface area. In FTIR spectra was observed before and after adsorption of Cr (VI). The spectra exhibited shifting of peak locations for same groups such as carboxyl, hydroxyl and amino groups due to attachment of Cr (VI) on the surface. The effect of pH on the adsorption of metal was

reported in the pH range of 2.0 to 8.0 and maximum adsorption was observed at pH was 2.0. The effect of temperature was studied at 25, 35 and 45 °C. The adsorption of Cr (VI) increased with increasing the temperature of solution which revealed the endothermic nature of adsorption. Maximum Cr (VI) adsorption was determined as 70.15 mg/g at pH value of 2.0, initial concentration of 250 mg/L and contact time of 120 min. The parameters of Langmuir and Freundlich isotherm were compared through nonlinear equation. A higher correlation coefficient (R^2 = 0.99) was found for Freundlich isotherm. From the kinetic experiment it was clear that the pseudo second order model represented the adsorption process quite well.

Chaudhuri and Azizan (2012) reported the synthesis of activated carbon by coconut coir for the removal of Cr (VI) from aqueous phase. The coconut coir was soaked into 10 % KOH for 24 h and then its activation was done at 900 °C for 30 min in the presence of nitrogen. The BET surface area and pore volume were calculated as 826 m^2/g and 0.25 cm^3/g, respectively. The SEM image indicated meso and micro pores structure of activated carbon. In this study, the effect of contact time was performed and the equilibrium was reached in 2.5 h. Maximum adsorption of Cr (VI) was obtained at pH 2.0. The effect of adsorption dose was studied in the range 2 to 8 g/ L of and nearly 100% removal was observed at carbon dose of 8 g/ L. To identify the adsorption kinetics, the two models such as pseudo first and pseudo second order model was used. The value of R^2 (0.99) and adsorption capacity was suitable for pseudo second order model. The Langmuir isotherm explained the experimental data with maximum adsorption capacity of 38.5 mg/g.

2.2 Methylene blue (MB)

Basu et al. (2018) studied the adsorption of methylene blue (MB) by activated carbon prepared from Sterculia foetida. The activated carbon from Sterculia foetida was prepared by mixing it with 40 % phosphoric acid in impregnation ratio of 1:1 and kept for 24 h for proper penetration of chemical into raw material. The chemically activated raw material was heated in a vertical tubular reactor 600 °C for 30 minutes. The prepared activated carbon was washed with deionised water up to neutral pH. After sample preparation the samples were characterized by FTIR spectrum in the range of 4000–450 cm^{-1}. The BET surface area and pore volume of this sample was found to be 302.59 m^2/g and 0.2571 cm^3/g, respectively. The adsorption experiments were carried out in batch mode to investigate the removal capacity of activated carbon. They had performed the experiment at various pH ranges (2.0–12.0), adsorbent dosage (1 -4 g/L) for running time (0-24 h), initial methylene blue concentration (50–500 ppm), and at 200 rpm agitation speed. For adsorption equilibrium data were tested with the four different isotherm models such as Langmuir, Freundlich, Temkin and Dubinin–Radushkevich at different temperature (298–328 K).The maximum monolayer adsorption was found to be 181.81 mg/g by the Langmuir model and this model was best fitted for experimental data. For range of concentration, the pseudo second order mode fitted well with a having high value of correlation coefficient.

Baysal et al. (2018) reported the methylene blue removal by activated carbon prepared from sunflower piths. For preparation of activated carbon, chemical activation with KOH and NaOH was done in 1:3 ratio and carbonization was carried out at 700 °C for 1 h (10 °C/min heating rate). The FTIR spectra in the spectral range of range of 4000–550 cm^{-1}indicated different functional groups such as C=0, C=C, O-H in raw

sunflower piths but after activation and carbonization most of functional groups disappeared. The BET surface area was found to be 2690 m^2/g with NaOH activation and 2090 m^2/g with KOH activation. The respective total pore volumes were 1.75 and 1.24 cm^3/g, respectively. The Lanngmuir and Freundlich were tested for determination of equilibrium adsorption mechanism. From the result it was observed that the maximum adsorption capacity (Qm) of the N-SPAC was equal to 965.349 mg/g for Langmuir isotherm having coefficient of determination, R^2 = 0.899.In comparison to NaOH activated KOH activated carbon followed the Freundlich isotherm for adsorption of methylene blue. The adsorption kinetics was studied for Pseudo first order, pseudo second order, Elovich and Inter particle diffusion model. The pseudo fist order is fitted well at the lower MB concentration up to 500 mg/L and for the higher concentration range the Elovich model with intra particle diffusion as one of the rate-determining steps.

Baytar et al. (2018) studied for the preparation of activated carbon from sunflower seed husk and it was used for methylene blue adsorption from aqueous phase. The husk was kept in microwave at power of range of 200–1000 W for of 5-40 minutes. After that the sample was impregnated with $ZnCl_2$ and the mixed sample was then heated at 400 to 600 °C for 45 minutes. The prepared samples were washed with distilled for the removal of all salt and metal. The maximum surface area and total pore volume for the prepared activated carbon were 1511 m^2/g and 0.35 cm^3/g, respectively. The effect of pH on adsorption was studied.The adsorption capacity increased from 81 to 89 mg/g with increase in pH from 2 to 8 at dose of 0.1g/100 mL and initial MB concentration of 100 mg/L. The different adsorption isotherms were also studied but the experimental data was best explained by Langmuir isotherm with maximum monolayer capacity of 240 mg/g at 30 °C. The pseudo first order model data was closer to the experimental

data with correlation coefficient 0.989 in comparison to 0.697 for the pseudo second order model. The thermodynamic value of ΔH° and ΔS° were calculated as 0.95 J/mol and 301 J/mol/K; respectively showing that the adsorption of MB was endothermic.

Karacetina et al. (2014) investigated the adsorption of methylene blue by activvtaed carbon prepared from hazelnut husk with $ZnCl_2$ activation. The hazelnut husks was washed and dried at 105 °C then the powdered sample of husk were mixed with $ZnCl_2$ in the ratio of 1:1 by weight and kept for 24 h. After mixing the samples was dried and then placed in a muffle furnace at temperature of 700 °C for 4 h. The BET, SEM, elemental analysis and FTIR spectra of prepared samples were also reported. The BET surface area was calculated as 1369 m^2/g. The FT-IR spectra at 3400–3700 cm^{-1} indicated the -OH group. The other peak locations such as 1700–1900 cm^{-1} band for carboxylic acid group and 1600–1800 cm^{-1} band aromatic C= O were also observed. The effect of pH was examined and it was observed that adsorption capacity increased from pH value 3 to 6 and after pH 6 was no change in adsorption capacity. The Langmuir model described the experimental data more closely and the maximum monolayer adsorption capacity was 476.2 mg g^{-1}. The rate determining step was explained by both intra-particle diffusion and diffusion to external surface. The analysis of kinetic data at different concentration of MB also revealed that the rate of adsorption followed the pseudo second order model closely in comparison to the pseudo first order model.

Spagnoli et al. (2017) reported the removal of methylene blue by high surface area activated carbon prepared by cashew nut shell with $ZnCl_2$ activation. In this study activated carbon was prepared by mixing the raw cashew nut shell with $ZnCl_2$ in different ratio (0.5:1 to 2:1, $ZnCl_2$: cashew nut shell).The soaked samples of cashew nut

shells were heated at 400 °C for 4 h. FTIR spectra analysis of samples was done. The spectral peak at position 1620 and 1560 cm^{-1} represents the C = C group in aromatic ring with stretching vibrations and peak between 1300 and 900 cm^{-1} is related to C-O stretching in alcohols. The BET surface area and total pore volume of prepared activated carbon was found 1478 m^2/g and 0.973cm^3/g. The experiments were performed in a pH range from3 to 10. For this experiment, Langmuir was satisfied the experimental data with 352 mg/g of monolayer adsorption.

Mahamad et al. (2015) carried out the preparation and characterization of activated carbon using pineapple waste biomass and used it for the removal of methylene blue from aqueous solution. The pineapple waste was treated with $ZnCl_2$ for 24 h in ratio of 1:1 and carbonized at 500 °C for 1h. The carbonized samples were washed to removal all acid and salt for further study of methylene blue removal. In this study they reported the characterization of prepared activated carbon with the help of FTIR, SEM and BET surface analyser. From the FTIR spectra it was concluded that the different functional groups such as small peaks appearing at 1625 cm^{-1} and 1630 cm^{-1} could be assigned to the C = O axial deformation of aldehyde and carboxyl groups. The BET surface area was 915 m^2/g and pore volume was 0.56 cm^3/g which was responsible for higher adsorption. The elemental analysis, C, H, N and S content of activated carbon was found as 69.77, 5.03, 1.54 and 0.05 %, respectively. The SEM analysis of raw and activated samples of pineapple showed more porous structures on te surface of activated carbon due to the dehydration effect of $ZnCl_2$ and the oxidation of organic matter during the carbonization step. In this study the effect of initial concentration of MB (5-400 mg/L) and contact time (0-180 min) were reported. It was found that after 120 minutes there was no change in adsorption. The maximum adsorption capacity of 39.74 mg/g was found at the initial concentration of 400 mg/L after 120 min of contact time.

The different adsorption isotherms such as Langmuir, Freundlich and Redlich-Peterson were applied. From the comparison of all parameters it was confirmed that the Langmuir isotherm represented the experimental data more accurately with the maximum adsorption of 288.34 mg/g.

Pezoti Jr. et al. (2014) studied the adsorption of methylene blue on $ZnCl_2$ activated carbon produced from Buriti fruits. The fruits were broken into small size range and heated in a horizontal stainless steel reactor at 500 °C for 2 h. The activation of samples was done with $ZnCl_2$ using the impregnation ratio of 3:1 (wt:wt). After mixing the samples were carbonized at 700 °C for 1.5 h. The prepared samples were washed with HCl and distilled water till neutral pH. The produced buriti shells activated carbon had a surface area of 843m^2/g. The SEM image of raw and prepared activated carbon showed the change in the morphology of the material after activation due to carbonization steps. For determination of surface groups the FT-IR analysis was performed and results showed that some peak of functional group were disappeared after carbonization. The kinetics parameters were evaluated using pseudo first-order, pseudo-second order model and Elovich model. It was seen that the experimental data fitted the pseudo second order model well (R^2 = 0.9688 to 0.9872). The isotherm parameters for Langmuir, Freundlich and Redlich–Peterson were calculated at different temperatures. It was seen that the Langmuir isotherm was the most suitable isotherm to describe the adsorption of MB onto activated carbon with a maximum monolayer adsorption capacity (q_m) of 274.62 mg/g.

Danish et al. (2018) used banana trunk waste for production of activated carbon which was used for the adsorption of methylene blue. For production of activated carbon, the dried banana trunk powder was soaked with 5.09 mol/L of phosphoric acid

(H_3PO_4). After proper mixing up to 24 h the mixture was heated in a muffle furnace at 845 °C for 50 min. For adsorption experiment, the effect of adsorbent dosage (0.3g/L to 1.5 g/L) and contact time (0 to 10 minutes) on MB adsorption was studied. It was found that the optimum dose of 1.5 g/L was sufficient for maximum adsorption in 20 minutes contact time. The pseudo- second order model described the kinetic data quite well (R^2 > 0.99). The isotherm data were tested against different models to describe the adsorption characteristics. For the data it was concluded that the Dubinin-Radushkevich model closely fitted the experimental data with having better correlation coefficient. From this model the value of maximum adsorption q_{max} was calculated to199.87 mg/g; whereas the maximum adsorption capacity of activated carbon was 166.51 mg/g by experimental method.

Uner (2019) reported the removal of methylene blue dye on activated carbon prepared from Arundo donax activated with $ZnCl_2$ in the ratio of 1.5:1 ($ZnCl_2$: cane, w/w).The mixed samples were carbonized at 400 °C for 1 h in a muffle furnace. After cooling the samples were washed for removal of residual metal and salt. The BET surface (1778 m^2/g) and total pore volume (1.113 cm^3/g) was calculated by N_2 adsorption/desorption method. From elemental analysis the C, H, N content was found as 72, 2.75 and 1.41%, respectively. The effect of adsorbent doses was examined for different concentrations and it was found that the dose of 0.45g/100 ml was the optimum dose for 100 % removal from 100 mg/L MB solution at 25 °C. The effect of initial concentration of MB on adsorption was also investigated. The percentage removal varied from as 98.49 to 42.38% for the initial MB concentration of 100 to 400 mg/L at the dose of 0.40 g / 100 ml. The MB removal percentage changed from 78.73 to 82.70 % for pH 3.00 to 6.72 but after pH 10.2 the percentage removal was seen as 100 %. In this study it was also reported the kinetic data for pseudo first order, pseudo

second order and Elovich model. From analysis of kinetic parameters it was concluded that the pseudo second order model was suitable for explaining the experiment data for all concentration. From comparison of different isotherm it was confirmed that the Freundlish isotherm represented the equilibrium adsorption data for all temperatures.

Nasrullah et al. (2019) used Mangosteen peel waste as a precursor for high surface area mesoporous activated carbon for removal of methylene blue. The peel was chemically activated with $ZnCl_2$ in the ratio of 1:4 and carbonized at 600 for 30 min. The elemental analysis of activated carbon was done to find out the C, H, N, S and O content. From the result it was found that 62.85% C, 2.78% H, 1.69% N, 0.203% S and 32.48% O. The FTIR study revealed that the board peak between 3500 to 3100 cm^{-1} was due to O-H group in cellulose and lignin. It was seen from SEM image that the surface of AC was porous and had pores various sizes. The BET surface area, average pore diameter, and total pore volume of activated carbon were found as 1621.8 m^2/g, 4.4 nm, and 1.805 cm^3/g, respectively. The point of zero charge of this activated carbon was found at pH value of 3.8. In this study with an increase in pH from 3 to 11 the adsorption capacity was increased up to 592 mg/g at pH value of 9. The equilibrium data were checked with Langmuir and Freundlich isotherm models but the data was best fitted to the Langmuir isotherm with maximum adsorption capacity of 1166 mg/g. The kinetic of adsorption was evaluated at different MB concentration such as 200, 300 400 and 500 mg/l for both pseudo first and second order model. From the result it was reported that the adsorption kinetics was explained by the pseudo-second-order kinetic model.

Novais et al. (2018) reported the efficient removal of methylene blue adsorption on activated carbon prepared from corck and paper waste. The corck and paper wastes were impregnated with NaOH and kept for 12 h at 80 °C. The samples were heated in

furnace at temperature of 900 °C for the time of 30 min. The chemical activation and heating of cork had produced a activated carbon with very high specific surface area (1670 m^2/g) and pore volume of 1.14 cm^3/g. The activation process had changed the microstructure of raw cork and many holes and pores were seen on the surface due to activation. In this the effect of contact time was studied and for this the experiments were performed for 10 to 60 minutes. The result showed that the removal of MB dye was 99.997 % at contact time 60 minutes. The result denoted that the adsorption of dye was very fast at initial stage of adsorption. The effect of initial concentration (between 10 mg/L to 700 mg/L) was studied and it was seen that the removal was 100 % up to the 500 mg/l initial concentration. The experiment for dose optimization was done in range of 2g/L to 3.5 g/L and it was found that the dose of 2g/L was enough for maximum adsorption capacity 350 mg/g and 99.97 % removal. To understand the adsorption mechanism the two isotherm model Langmuir and freundlich were studied and a high correlation coefficient (R^2 = 0.979) was obtained for Freundlich isotherm.

Beakou et al. (2017) reported the preparation of activated carbon from Manihot esculenta Crantz and used it for the removal of Methylene Blue. For preparation of activated carbon the raw material and phosphoric acid were mixed in 1: 1 ratio and then the mixture was heated at 120 °C for 14 h. The prepared sample was soaked in NaOH for 24 h for the removal residual acid and it was also washed with distilled water till neutral pH. The FTIR spectroscopic analysis was done to investigate the functional groups in activated carbon. The specific surface area of activated carbon was area 2.4 m^2/g. For kinetic study experiments were carried out with different concentrations of MB and it was found in good agreement with the for pseudo-second order kinetic (R^2 =0.997). The Redlich-Peterson's model correlated the equilibrium adsorption data in best manner. For maximum capacity the experimental data were fitted for Langmuir

isotherm model and from this model the maximum adsorption was found as 565 mg/g at 25 °C. The thermodynamic study was studied and it gave the positive value of ΔH^0 (17.4 kJ mol^{-1}) indicating endothermic nature of adsorption.

Islam et al. (2017) used Karanj fruit hulls for the preparation of activated carbon and the same used for the removal methylene blue dye from waste water. The seed-free karanj fruit hulls (KFH-R) were placed in a tubular furnace at 600 °C for 1h and then the carbonized samples were impregnated with KOH into the ratio of 1:3 (wt. of hull: wt. of KOH). The BET surface and pore volume of samples were reported as 828.30 m^2/g and 0.36 cm^3/g, respectively. The adsorption experiments were performed in batch mode by changing various parameters such as pH (3-13), MB concentration (25-400 mg/l), contact time (0-28 h) and temperature (30 – 50 °C) with agitation speed 120 rpm. The SEM image represented large surface area and more porosity than the raw material. The FTIR analysis was carried out before and after MB adsorption. The spectra peak at 1408, 1056, and 852 cm^{-1} represented the different functional group such as O –H bending, C –OH stretching and C-H gropes, respectively. The effect of pH was observed and the MB uptake increased for the increase in pH from 4 to 7. The MB uptake increased because the point of zero charge, pH for this adsorbent was 4. The Langmuir isotherm model represented the experimental data with high correlation coefficient and maximum adsorption was obtained as 154.8, 203.4, and 239.4 mg/g at 30, 40 and 50 °C, respectively. The rate of adsorption was studied by Pseudo first and pseudo second order model in the initial MB concentration range of 25 to 400 mg/l. After analysis of result it was concluded that the pseudo second order model was best fitted to experimental data with $R^2 = 0.9993$.

Kumar et al. (2014) reported preparation of activated carbon by chemical activation with HCl and its use for the adsorption of methylene blue dye. The Acacia fumosa seed shell was selected as raw material. The HCl mixed samples were placed into the muffle furnace at 450 °C for 6 h. The FTIR characteristics peaks at 2354.49 cm^{-1}, 1539.97 cm^{-1} and 1230.01 cm^{-1} corresponding to C ≡≡ N, C=O, and –OH group respectively. After adsorption peak positions and intensity changed due to strong attachment of MB dye on the surface of adsorbent. Batch adsorption studies were conducted for varying operating conditions time (10-90 min), pH (2-10), dose (0.5-0.25g/100 ml), and concentration of (4-20 mg/l). The maximum percentage removal was observed at pH 6, for dose of 0.1 g/100ml and time of 90 minutes. The Langmuir and Freundlich isotherms were used to fit the equilibrium data and Langmuir isotherm fitted best (R^2 = 0.998) with maximum monolayer adsorption capacity of 3.47 mg/g. The positive value of ΔH^0 (3.66 kj/mol) and negative value of ΔG^0 (- 0.29 kj/mol) represented the endothermic and spontaneous nature of adsorption. The pseudo second order kinetic equation was satisfied the experimental data.

Agarwal et al. (2016) studied the adsorption of methylene blue on activated carbon prepared from Ephedra strobilacea saw dust and activated by $ZnCl_2$ and H_3PO_4 in the ratio of (1:1). The mixed samples were carbonized at 450 °C for 5 h. The prepared samples were washed with distilled water. The effect of pH was studied in the pH range of 2 to 10 and it was seen that the maximum percentage removal occurred at pH 6 for phosphoric acid activated carbon and at pH 9 for $ZnCl_2$ activated carbon. The experiments were preformed using the initial MB concentration range of 30-100 mg/l and it was observed the 60 mg/l MB concentration was optimum value. The equilibrium adsorption data were fitted in the Langmuir, Freundlich and Tempkin isotherms. It was concluded that the Langmuir isotherm correlated the experimental

data more correctly with maximum adsorption capacity of 21.92 mg/g for H_3PO_4 and 37.174 mg/g for $ZnCl_2$ activation. The adsorption kinetics was studied using pseudo first order, pseudo second order and intra particle diffusion model. From comparing the q_e experimental and q_e calculated values, it was clear that the pseudo second order model was the best with R^2=0.999.

El-Shafey et al. (2016) reported the preparation and characterization of activated from date palm leaflets. They used it for the removal of methylene blue. The raw material was charred in a carbon steel tube and this charred material was then soaked in KOH in the ratio of 1:3. The KOH impregnated samples were kept in muffle furnace at the temperature of 550 °C for 1h under nitrogen atmosphere. The carbon thus obtained has a surface area of 823 m^2/g and the pore volume of 0.467 cm^3/g. The SEM images were observed which show well-developed pores on the surface of the activated carbon. FTIR spectra indicated presence of functional group like as –CH, C=O, C=C,-COO and C-N bond. The C and H content was observes as 80.4% and 2.2 % respectively. The maximum adsorption was obtained in acidic range because the point of zero change was at the pH value of 5.5. The data was analysed using pseudo zero, pseudo first and pseudo second order models. The R^2 values for pseudo zero and pseudo first order model were very low so pseudo second order model best fitted the adsorption data. The sorption parameters for both Langmuir and Freundlich isotherms were calculated. From the higher value of R^2 it was confirmed that the Langmuir isotherm hold good with a maximum adsorption capacity of 270 mg/g.

Wang et al. (2018) prepared and characterized activated carbon prepared from distiller grain and for the removal of methylene blue. For manufacturing the activated carbon, the raw distiller grain was soaked with KOH solution in the ratio of 1:3 (w/v).

The chemically loaded samples were heated at desired temperature of 900 °C for 90 min. It was reported that the developed activated carbon had rough surface and more pores in comparison to raw distiller grain due to KOH action on the surface of raw material and evaporation of some material. The BET surface area of the prepared activated carbon was found to be 1430 m^2/g, The FTIR spectra revealed different functional group such as O-H, C-H and C-O. After adsorption of MB the peak location were changed. Batch experiments were carried out at different conditions for the removal of methylene blue. The adsorbent dosage was varied from .04 to 0.7 g/L. The equilibrium isotherm was best described by the Langmuir isotherm with maximum adsorption capacity of 934.6 mg/g at 55 °C. It was also reported that the mass transfer model was able to describe the adsorption for the initial 5 min, and after that the internal diffusion was the main resistance for adsorption.

Table.2.1 Application of activated carbon as adsorbent for removal of Cr(VI) from water and waste water

Raw material/ agro waste	Activat -ion agent	Carbonization Condition (Temperature and time)	BET Surface Area (m^2/g)	Pore Volume (cm^3/g)	Adsorption Parameters (pH, adsorbent dose, contact time, temperature)	Adsorption Capacity (mg/g)	Adsorption Isotherm	Reaction Type	References
Longan seed	NaOH	600 °C, 1.5h	1511.8	0.7420	pH-3.0, dose-0.2g/L, contact time- 240 min, temperacture-318.2 K	169.49	Langmuir isotherm	Pseudo-second order	Yang et al. (2015)
Aegle Marmelos fruit shell	$ZnCl_2$	500 °C, 1h	1339	0.480	pH-2.0, contact time - 240 min, dose-3.0, temperacture-50 °C	43.54	Freundlich isotherm	Pseudo-second order	Gottipati and Mishra (2016)
Combretum quadrangulare Kurz	H_3PO_4	500 °C, 1h	374.2	0.29	pH-2.0,contact time-60 min,dose-0.1g/L,temperacture-298.1K	1.68	Langmuir model	Pseudo-second order	Maneechakr et al. (2017)
Fox nutshell	$ZnCl_2$	600 °C, 1h	2869.0	1.68	pH-2.0,contact time 180 min,dose-0.05g/100 ml, temperature- 30 °C	46.21	Langmuir model	Pseudo second-order	Kumar and Jena (2017)
Chestnut oak shells	H_3PO_4	450 °C, 2.5h	989.4	0.71	pH-2.0,contact time-180 min,dose-7g/l,	33.0	Langmuir model	Pseudo second-	Niazi et al. (2018)

					temperature-30 °C, rpm-150 rpm			order	
Date Press Cake	NaOH	650 °C,1.5h	2025.90	0.932	pH-2.0,contact time-min, dose-, temperature- °C, rpm-200	282.8	Redlich-Peterson	Elovich	Norouzi et al. (2018)
Wood apple shell	H_2SO_4	650 °C,2 h	1898.0	-	pH-1.8,contact time-100 min,dose-1.25 g/l, temperature -300 K	151.51	Langmuir model	Pseudo second-order	Doke and Khan (2017)
Prosopis juliflora bark	H_2SO_4	450 °C	-	-	pH-6.0, contact time-90 min, dose-0.1g/l, temperacture-343 K	96.4	Langmuir model	Pseudo secondorder	Kumar and Tamilarasan (2017)
Sunflower seed hull	$ZnCl_2$	650 °C,1 h	1966	1.283	pH-2.5, contact time-300 min, dose-1.0 g/l, temperacture-25 °C	162.6	Langmuir model	Pseudo-second-order	Zou et al. (2015)
Apple peels	H_3PO_4	619 °C, 56 min	-	-	pH-2.2, contact time-300 min, dose-0.15 g/l, temperacture-40 °C	34.59	Freundlich isotherm	Pseudo-second-order	Enniya et al. (2018)
Rice straw and Sewage Sludge	$ZnCl_2$	650 °C,2 h	-	-	pH-2.0, contact time-24 h, dose-2.0 g/l, temperacture-40	138.69	Langmuir-Freundlich model	Pseudo-second-order	Fan et al. (2019)

					°C,rpm-150				
Phanera vahlii fruit	H_3PO_4	650 °C,1 h	1424	1.973	pH-2.0, contact time-180 min, dose-1.5 g/l, temperacture-303 K, rpm-100	244.1	Freundlich isotherm	Pseudo-second-order	Ajmani et al. (2019)
Sterculia guttata shell	$ZnCl_2$	400 °C,1 h	498.29	0.232	pH-2.0, contact time-160 min, dose-0.03 g/l, temperacture-333 K, rpm-120	90.90	Langmuir model	Pseudo-second-order	Rangabhashiyam et al. (2015)
Peanut shell	KOH	450 °C,1 h	88.85	0.33	pH-2.0, contact time-24 h, dose-0.1 g/40 ml, temperacture-313 K, rpm-200	14.31	Langmuir model	Pseudo-second-order	Al-Othman et al. (2012)
Zizania caduciflora	H_3PO_4	450 °C,1 h	1270	1.37	pH-3.0, contact time-48 h, dose-40mg/50 ml,temperacture-295K	31.0	Freundlich isotherm		Liu et al. (2014)
Peanut shell	H_3PO_4	500 °C,1.5 h	582.77	0.34	pH-2.0, contact time-240 min, dose-3 g/l, temperacture-323K, rpm-200	46.73	Langmuir model	Pseudo-second-order	Al -Othman et al. (2013)
Tea leaves	H_3PO_4	500 °C,1 h	1313.41	1.359	pH-1.5, contact time-120 min, dose-1 g/l, temperacture-323K,	57.57	Langmuir model	Pseudo-second-order	Goswami et al. (2014)

					rpm-200				
Activated sludge	$ZnCl_2$	500 °C,1 h	760	0.8383	pH-1.5, contact time-120 min, dose-1 g/l, temperacture-323K, rpm-200	70.15	Langmuir model	Pseudo-second-order	Gorzin and Ghoreyshi (2013)
Coconut coir	KOH	900 °C,30 min	826	0.25	pH-1.5, contact time-2.5 h, dose-8 g/l, temperacture-323K, rpm-200	38.5	Langmuir model	Pseudo-second-order	Chaudhuri and Azizan (2012)

Table.2.2 Application of activated carbon as adsorbent for removal of methylene blue (MB) from waste water

Raw material/ agro waste	Activat-ion agent	Carbonization Condition (Temperature and time)	BET Surface area (m^2/g)	Pore Volume (cm^3/g)	Adsorption Parameters (pH, adsorbent dose, contact time, temperature)	Adsorption Capacity (mg/g)	Adsorption Isotherm	Reaction Type	References
Sterculia foetida	H_3PO_4	600 °C,30 min	302.59	0.2571	pH-10.0, contact time- 24 h, dose-2 g/L, temperacture-298K	181.81	Langmuir model	Pseudo-second-order	Basu et al. (2018)
Sunflower piths	NaOH	700 °C,1h	2690.0	1.75	contact time-180 min, dose-2 g/L, temperacture-298K, rpm-200	965.349	Langmuir model	Elovich model	Baysal et al. (2018)
Hazelnut husk	$ZnCl_2$	700 °C,4 h	1369.0	-	pH-7.0, contact time- 120 min, dose-0.05g/100 mL	476.20	Langmuir model	Pseudo-second-order	Karacetina et al. 2014
Cashew nut shell	$ZnCl_2$	400 °C,4 h	1478.0	0.973	pH-7.0,contact time-120 min, dose-1.25 g/l	352	Langmuir model	-	Spagnoli et al. (2017)
Pineapple waste	$ZnCl_2$	500 °C,1 h	914	0.56	contact time- 240 min, dose-0.50 g/L,	288.34	Langmuir model	-	Mahamad et al. (2015)

Buriti fruit	$ZnCl_2$	700 °C,1.5 h	834		contact time- 180 min, dose-1.0 g/L,rpm-220	274.64	Langmuir model	Pseudo-second-order	Pezoti Jr. et al. (2014)
Banana trunk waste	H_3PO_4	8400 °C, 50 min	1173.16	-	contact time- 20 min, dose-1.5 g/L,rpm-220	199.87	Dubinin-Radushkevich	Pseudo-second-order	Danish et al. (2018)
Arundo donax	$ZnCl_2$	400 °C,1 h	1778	1.113	pH-10.2, contact time- 500 min, dose-0.45 g/100 ml, temperacture-318 K	416.67	Freundlich model	Pseudo second order	Uner (2019)
Mangosteen peel waste	$ZnCl_2$	600 °C,30 min	1621.8	1.805	pH-9, contact time-400 min, dose-0.333g/L, temperacture-298 K	1166	Langmuir isotherm	Pseudo second order	Nasrullah et al. (2019)
Corck and paper waste	NaOH	900 °C,30 min	1670	1.14	pH-9, contact time-60 min, dose-2.0 g/L, temperacture-293 K	350	Freundlich isotherm	-	Novais et al. (2018)
Manihot esculenta Crantz	H_3PO_4	1200 °C,14 h	2.4	-	pH-8, contact time-40 min, temperacture-318 K	565	Redlich-Peterson	Pseudo second order	Beakou et al. (2017)
Karanj fruit hulls	KOH	600 °C,1h	828.30	0.36	pH-7, contact time-40 min, dose-	239.4	Langmuir isotherm	Pseudo second	Islam et al. (2017)

					0.1g/100 mL, temperacture-323 K			order	
Acacia fumosa seed shell	HCl	450 °C,6 h	-	-	pH-6, contact time-90 min, dose-0.1g/100 ml, temperacture-323 K	3.47	Langmuir isotherm	Pseudo second order	Kumar et al. (2014)
Ephedra strobilacea saw dust	$ZnCl_2$	450 °C,5 h	-	-	pH-9, contact time-120 min, dose-0.05 g/50 mL, temperacture-318 K	37.174	Langmuir isotherm	Pseudo second order	Agarwal et al. (2016)
Date palm leaflets	KOH	550 °C,1 h	823	0.467	pH-7, contact time-60 h, dose-0.1 g/50 mL, rpm-100, temperacture-298K	270	Langmuir isotherm	Pseudo second order	El-Shafey et al. 2016
Distiller grain	KOH	900 °C,30 min	1430	-	pH-6.6, contact time- 4 h, dose-0.1 g/L, rpm-150 temperacture-293 K	934.6	Langmuir isotherm	intra-particle diffusion	Wang et al. (2018)

Finding of literature review

From the review of the published literature on the use of un-conventional adsorbents for the removal of toxic metals and dyes it is observed that most of the reported adsorption studies are carried out using the activated carbon prepared from low cost agrowaste materials such as sunflower piths, hazelnut husk, cashew nut shell, pineapple waste, banana trunk waste, karanj fruit hulls and many others. It is clearly seen that such low cost adsorbents have significant potential for the removal of toxic metals like hexavalent chromium and dyes like methylene blue from aqueous solutions. However, limited information is available on the preparation of activated carbon from fruit wastes like mango seed kernel and almond shell and their use for the removal of hexavalent chromium, methylene blue dye and the like. This knowledge gap provided the necessary motivation to plan for the present research work.

It was planned to use the locally available mango seed kernel and almond shell, carbonize them with chemical activation, characterize the resultant activated carbon and use it as adsorbent for the removal of Cr(VI) and methylene blue from simulated wastewater. The results obtained and other relevant details are presented in the following sections.

Objective of present research work

From the literature review it is clearly seen that a few workers have used almond shell for preparing activated carbon for use as adsorbent for the removal of pollutants like Cr (VI) and methylene blue. No reported information is available on the preparation of activated carbon from mango seed kernel, abundantly available as fruit processing industry waste in India. It would be interesting to use this agro-waste for obtaining activated carbon and use the same as adsorbent for water and wastewater treatment, etc. In view of this the present was planned and executed with following specific goals in mind:

- Collection and preparation of mango seed kernels and almond shells for preparation of activated carbon.
- Characterization of the prepared activated carbons using standard protocols
- Use of the prepared activated carbons for the removal of Cr(VI) and methylene blue (MB) from simulated wastewater (aqueous solutions prepared in the laboratory)
- Determination of the effects of various process parameters such as pH, adsorbent dose, initial concentration, contact time and temperature on the removal efficiency of prepared activated carbons using batch experiments,
- Study of the adsorption kinetics and evaluation of the data using different kinetic models, and
- Comparison of the equilibrium adsorption data with different adsorption isotherms and evaluation of thermodynamic parameters.