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Removal of Colour from Textile Dyeing Effluent Using Temple Waste Flowers as Ecofriendly Adsorbent

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Abstract: *In the present investigation easily available raw material, temple waste flowers(TWF) were used as ecofriendly adsorbent for removal of colour from textile dyeing effluent. The activated carbon from temple waste flowers were prepared by direct pyrolysis process, sodium sulphate (Na_2SO_4) and potassium hydroxide (KOH) process respectively and also physico-chemical parameters including pH, conductivity, moisture content, ash content, volatile content, fixed carbon, bulk density, porosity, specific gravity, water soluble matter, acid soluble matter, iodine number, methylene blue number, yield and Brunauer-Emmett-Teller (SBET) surface area of activated carbon were analyzed and compared. The structure, surface morphology and chemical compositions of carbon were determined by Field emission Scanning Electron Microscopy (FeSEM), and Energy Dispersive X-ray Spectroscopy (EDS) respectively. The prepared activated carbon is utilized for the removal of colour from textile dyeing effluent at different adsorbent dosage and contact time. Also the physico chemical parameters of textile effluent such as colour, pH, total hardness, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), turbidity, chlorides, sulphides, silica, calcium, iron, oil and grease were analyed. The results of the analysis were correlated with the water quality standards of BIS (Bureau of Indian Standard). The maximum colour removal efficiency of activated carbon was found to be 98.17% at 200 mg dose of adsorbent at normal pH and temperature conditions.*

Keywords: *Temple waste flowers, activated carbon, textile dyeing effluent, physico-chemical parameters, BET, SEM, EDX.*

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I. Introduction

The wealth of the nation depending on environmental factors such as clean air, water and land. But now a days all environmental factors are highly polluted due to dumping of wastes on environment from various places such as industries, factories, mills, hospitals, hotels, temples, domestic places, recreational centres etc. In India, almost 95% of rural population depending on ground water for domestic purposes[1] but due to the discharging of wastes into waste land without proper treatment the ground water is also contaminated. In India around 70% of the water has become polluted severely due to dumping of domestic sewage and industrial effluents into natural water source, such as rivers, streams as well as lakes[2]. Many industries in India are located along the river areas for easy availability of water and also waste water directly discharged into it. The untreated water systems may cause serious problems in availability and quality of water[3]. Industries plays a major role in polluting the environment. Textile industry is one among them and it is one of the largest industries in the world[4], in terms of its production and employment. India’s second largest employment producing area is textile industry and about 35 million people both skilled and unskilled get direct employment. India’s leading and oldest industrial sectors about 81% of total industries are located in Tamil Nadu, Gujarat, Punjab and Maharashtra[5] and estimating about 20% of the total industrial production. In the year 2010-11 India furnished a large production of textile about 325 lakh bales[6]. According to Ministry of Textiles, 2,500 textile weaving factories and 4,135 textile finishing factories are functioning in India. Textile industry plays a major role in Indian economical growth because in the year 2010, the share of textiles in total exports was 11.04% hence it partially fulfills the Indian economical thrust. There are more than 8,000 chemical products associated with the dyeing process and over 100,000 commercially available dyes exist with over 7×10^5 metric tons of dyestuff produced annually[7]. Around the world, more or less 10,000 separate dyes and pigments are utilized industrially and in excess of 0.7 million tons of synthetic dyes are produced every year.

Although textiles contribute significantly toward the economy of developing countries such as India, it pollutes the environment particulary aquatic environment largely through discharging of wastewaters at various steps such as dyeing and printing process. Nearly, 1,000-3,000 m3 of water is let out after processing about 12-20 tonnes of textiles per day. These effluents contains more dyes and chemicals which is severely affect health and environment if not maintained properly[8] due to the presence of non-biodegradable and carcinogenic substances. Wastewater generated in different production steps of a textile mill have high pH, temperature, detergents, oil, suspended and dissolved solids, dispersants, leveling agents, toxic and non-biodegradable matter, color and alkalinity[9]. Chemical pollutants present in textile wastewater are dyes containing various chemical substances including carcinogenic amines, toxic heavy metals, pentachlorophenol, chlorine-bleaching, halogen carriers, free formaldehyde, biocides, fire retardants and softeners[10]. The textile wastewaters are characterized by highest variations in many parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH and colour[11]. Also dyes are complex compounds which are difficult to degrade biologically. One of the major classes of dyes used in textile industry are azo dyes and the use of azo dyes have been growing extremely as of their ease and cheapest in synthesis than natural dyes[12,13]. Some of azo dyes are either toxic or mutagenic and carcinogenic[14]. Therefore removal of dyes from water is of significant importance from environmental point of view.

Dye removal process contains mainly of a combination of various techniques[15]. The majority of physical, chemical and biological color removal techniques undergo either by concentrating the color into sludge, solid supports, or by the complete disintegrate the dye molecule. Recently, adsorption process is being focused at a greater extent due to simple operation, effectiveness, and economical in removing dyes, metal, organic compounds from wastewater. The process of removing substances from either gaseous or liquid solutions with the help of solids is known as adsorption. According to US Environmental Protection Agency the adsorption process by activated carbon[16] is successful method in all areas such as water, air purification process etc due to ease of use and availability of raw materials. Currently many researchers working on agricultural by-products as precursor materials[17,18,19] in the preparation of activated carbon by some form of activation process. Activated carbon (AC) is a non-graphitic form of black carbonaceous material which is solid, tasteless and microcrystalline with a porous structure[20,21] and it has been regarded as a unique and worldwide accepted adsorbent due to its excellant surface area, microporous structure, high adsorption capacity and high degree of surface reactivity[22,23,24].

Area of study

The textile dyeing effluent is collected from Coimbatore district, Kongu Nadu region of Tamil Nadu, India for the present investigation. The city Coimbatore is also known as Manchester of South India, Textile Capital of South India etc. Enormous amount of wastes such as organic, inorganic,bio degradable, non biodegradable, medical wastes etc generated from various industries, hospitals, hotels, houses, temples, recreational activities etc., has been indiscriminately dumped into land, water etc without getting proper approval from pollution control board. In Tamil Nadu there are large number of industries located in various districts like Vellore, Erode, Dindugal and Coimbatore in an unorganized manner. Among them, Coimbatore is the second largest industrial centre in Tamil Nadu. The major industries include textile, dyeing, electroplating, motor and pumpset, foundry and metal casting industries. Around 500 textiles, 200 electroplating industries, 300 dyeing units and 100 foundries are present in Coimbatore district and apart from these industries unorganized sets of sewers[25] numbering 21,000 are present in various zones and the wastes are discharging into the sewage farm situated in Ukkadam, which has been used for irrigating the nearby fields. Effluents emerging from these industries are going to pollute water resources in and around Coimbatore district. Although all Indian industries function under the strict guidelines of central pollution control board[26] (CPCB) but still the situation of environmental pollution is far from satisfactory. Different rules and regulations, norms and guidelines are given for industries depending upon the pollution potential. Most of the major industries have treatment facility and running under the fixed guidelines, but this is not the case for small scale industries, which cannot afford enormous investment in pollution control equipments and instruments as their profit margin is slender. As a result in India there are sufficient evidences available regarding mismanagement of Industrial waste[27,28,29] . Hence the present work is aimed to prepare the activated carbon from temple waste flowers (TWF) in Coimbatore district by direct pyrolysis process, sodium sulphate (Na_2SO_4) and potassium hydroxide(KOH) process respectively and also physico-chemical parameters and the structure, surface morphology and chemical compositions of carbon were studied and compared by BET, SEM and EDS. The physicochemical parameters of textile dyeing effluents were analyzed and results of effluent correlated with BIS limits. Mainly the colour of the textile dyeing effluent was removed by adsorption process by TWF as adsorbent at different contact time and different dosage of adsorbent.

II. Methodology

Prinary process

The waste flowers were collected from temples in and around Coimbatore district, Tamilnadu, India. The waste flowers were washed with distilled water and sun dried. The dried materials were ground to a fine powder using mixer and used as starting material.

Direct pyrolysis process

The starting material (10.0 g) is taken in crucible and heated at 550^0C for 2 h then it was cooled to room temperature and the product was washed with distilled water then it was dried in the oven at 110 ^{0}C for 6 h. The dried material was ground to a fine powder using mortar and pestle and it was passed through sieves to obtain product (FW_D) with uniform particle size 110 μm which was kept in an air tight vial and used for the present study.

Production of activated carbon by chemical activation with Na_2SO_4 and KOH

A carefully weighed 10.0 g starting material is treated with 50 ml of 0.1N of sodium sulphate. The materials were kept aside for 24 hours at room temperature for complete charring. After impregnation, the excess solution was decanted. Then this material was transferred into a clean crucible of known weight and it was then heated in a muffle furnace maintaining temperature at 450 °C for a period of 2 h for carbonizing. The carbonized material was cooled to room temperature then the product was washed with distilled water (pH = 7) to remove colour and impurities and dried in the oven at 110 ^{0}C for 3 h. The dried material was ground to a fine powder using mortar and pestle and it was passed through sieves to obtain sample (FW_P) with uniform particle size 110 μm which was kept in an air tight vial and used for the present investigation. The same procedure was repeated for potassium hydroxide solution and the product was represented as FW_S.

The effluent sample was collected in cleaned plastic container and it was subjected to physico-chemical parameters by using standard procedures[30,31,32,33,34] and removal of colour by adsorption process. The physico-chemical parameters of effluent given in Table 3 and Table 4.

Batch Adsorption experiments

The batch adsorption experiments were carried out to study optimum removal of colour from textile effluent. Required quantity of different doses of activated carbon produced from temple waste flower added to Erlenmeyer flasks with 50 ml textile industry waste effluent. The bottles were kept in orbital shaker at 30^0C temperature at 260 r.p.m. The contents were filtered using whatman filter paper no. 42. The equilibrium time and optimum dose of adsorbent were optimised by repeating the same experiment at different conditions.

Effect of adsorbent dose

The different doses of adsorbent was taken such as 25 mg to 300 g with 50 ml textile effluent in Erlenmeyer flasks in orbital shaker at about 30^0C and 260 rpm.

Effect of time

To study the effect of time on efficient removal of colour from textile waste the study was carried out. The effect of contact time was investigated for 10 - 120 minute at pH 7 .

III. Results And Discussion

Surface characterization of activated carbon

The physico-chemical characteristic values of activated carbons FW_D, FW_S and FW_P are recorded in Table 1. Too high pH instructed us more contamination while too low pH indicates that acid wash was not complete. The pH of activated carbons FW_D, FW_S and FW_P was determined to be 7.63, 7.34 and 6.87 respectively. According to Ahmedna and Okieimen[35,36] that for most applications, carbon pH 6-8 is acceptable. The quality of activated carbon is related to proximate analyses of moisture, ash and volatile content of the carbon. From Table 1 the carbon FW_D has low amount of moisture, ash and volatile matter than the carbons FW_S and FW_P respectively which shows that the carbon FW_D has more surface area and therefore adsorption is high. The carbon should be insoluble in water and acid or solubility of carbon should be low. From Table 1, the solubility of carbon is in the order $FW_D < FW_P < FW_S$.

The porosity of FW_D, FW_S and FW_P were calculated as 65.0, 53.93 and 59.18 respectively. It has been observed that the carbon FW_D has higher porosity, therefore the adsorption will be more. According to AWWA[37], lower limit of bulk density is 0.25 g/cm3 for granular activated carbon could be put into practical use. The Higher bulk density increases the mechanical strength[38] also higher the bulk density the better the filterability of activated carbon. However, activated carbon with bulk density of 0.5 g/cm3 is more enough for decolourization of sugar[39]. From Table 1, there is a slight difference of the bulk density has been recorded for the carbon FW_D, FW_S and FW_P. Specific gravity of prepared carbons are in the order $FW_P > FW_S > FW_D$.

Iodine number is an important parameter to measure the micropore content of the activated carbon. The micropores are developed during the activation process and it gives the idea about surface area of activated carbon. The value of iodine number obtained for FW_D is 642.0 mg/g which is within the limit set by ASTM (600 – 1100 mg/g). The methylene blue values gives yhe inforation of macropores of the activated carbon. Macropores are easily adsorb the large dye molecues in the solution. From the Table 1 methylene blue values are in the order $FW_D > FW_S > FW_P$. The value of fixed carbon and yield of carbon FW_D recorded as 73.4% and 63.7% respectively which is good than the carbons FW_S and FW_P. From the overall physico-chemical characteristics analysis, it is concluded that the activated carbon prepared by direct pyrolysis process is best method for the present investigation. The pores and surface area of activated carbon can be analyzed by BET, which is one of the important characteristic study in adsorption process. The BET surface area of the resulting activated carbons FW_D, FW_S and FW_P was calculated as 672.2, 272 and 232.2 m^2/g respectively. From the comparison of BET values the carbon FW_D is within the limit set by ASTM (600 - 1200 m^2/g) than the carbons FW_S and FW_P respectively. Hence the results of BET revealed that the carbon FW_D prepared by direct pyrolysis process is chosen for present investigation.

Field emission Scanning Electron Microscopy (FeSEM)

The surface morphology of activated carbon FW_D, FW_S and FW_P can be determined by FeSEM which is represented in Figure 1, 2 and 3. From the figures, it is observed that the activated carbon FW_D containing high pores, caves type openings and large surface area than those prepared using sodium sulphate and potassium hydroxide respectively.

Energy Dispersive X-ray Spectroscopy (EDS)

It is used to gives the chemical compositions of carbon and it consist of spectra showing peaks which is represented inb Figure 4, 5 and 6. The elements of carbon FW_D, FW_S and FW_P given in Table 2, which shows the carbon FW_D has rich amount of carbon 99.45% and traces of Na, Mg, Ca and O therefore purity is high.

The carbon FW_D prepared by direct pyrolysis is satisfied all physico chemical characteristics hence the carbon FWDchosen for present investigation for treatment of textile industrial effluent by adsorption process.

Physico-chemical parameters of water effluent

It is important to study all features of the textile effluent to improve environmental performance and also to sustain considerable quality of the individual companies. The physico- chemical parameters of textile effluent have been analyzed and the experimental results compared with standard BIS limits. The results of the analysis are presented in Table 4.

Temperature of the effluent was found to be 53°C. Higher temperature induces chemical and biological reactions in effluent water. It will also affects the solubility of oxygen and produces bad odor due to anaerobic reactions. pH of the effluent was found to be 7.96 which is alkaline. Many chemical and biological reactions are depends on the pH of the sample. At low pH, most of the metals become soluble in water and at high pH metals become insoluble therefore it could be hazardous to the environment.

The color is the basic and most obvious indicators in water pollution and it is worldwide accepted primary pollutant in wastewater. The discharge of highly colored synthetic dye effluents is aesthetically displeasing and can damage the receiving water body by impeding penetration of light[40]. Colours are easily visible to human eyes even at very low concentration. Hence, colour from textile wastes carries significant aesthetic importance. The effluent selected for the present study is brownish blue colour and colour units were found to be 4800 on Pt-Co scale. The effluent was highly colored indicating high content of different dyes and colour producing compounds. The high color may be the combined result of pH, temperature and acidic conditions that do not allow the chromophore group of dye to disintegrate during dyeing process and making the effluent highly colored. Colour reduces the photosynthesis activity of aquatic life and it affects other parameters such as DO, BOD etc. In general colour is difficult to remove by the conventional treatment methods. Hence adsorption process by activated carbon is one of best method to remove colour in the effluent.

The BOD is due to the presence of organic matter of textile effluents in water bodies. The low BOD indicates good quality water, whereas a high BOD shows the water is highly contaminated and not recommended for drinking purposes. BOD of the effluent was found to be 760 ppm, which is much higher as compared to BIS limits indicating very low amount of oxygen for living organisms for utilizing organic matter. COD of the effluent was found to be 2180 ppm, 10 times high as compared to limits set by BIS. It is observed that toxic conditions and the presence of biologically resistant organic substances in water effluent. Higher COD concentration indicates presence of industrial wastes such as detergents, softeners, non biodegradable dyeing chemicals, formaldehyde based dye fixing agents etc. Hence the effluent is incompatible for the survival of water living organisms due to the reduction of DO content[41]. Divalent metallic cations particularly Ca^{+2}, Mg^{+2}, Sr^{+2}, and Fe^{+2} are responsible for hardness in polluted water . According to BIS, the maximum permissible limit of hardness is 500 mg/L. In the present investigation hardness of the effluent sample was found to be 810 mg/L which is much higher as compared to values prescribed by BIS. Hence softning methods should be adopted in industries to remove hardness in effluent.

The values determined for all the above parameters exceed the limits set by the BIS except total hardness, indicating that the effluent needs to be treated before its discharge into the receiving bodies.

In the present study TDS was determined to be 18220 mg/L which is much higher due to the fixing, bleaching and dyeing agents used for fabric processing on different stages. The high TDS value of water not recommended for drinking and irrigation purposes as it may cause salinity problem. The total dissolved solids in sugar mill effluent, tannery waste and textile industries were also reported in the level of 400 - 1650 ppm[42], 1000 - 2850 ppm[43] and 8500 – 15000 ppm[44] respectively. TSS contains carbonates, bicarbonates, chlorides, phosphates and nitrates of Ca, Mg, Na, K, organic matter, salt and other particles. The TSS value of effluent was found to be 5992 mg/L which is beyond the permissible limit. The highest suspended particles in effluent increases the TSS which produces the negative impacts on water bodies. The value of turbidity is recorded as 69.5 NTU which have been found to be higher than the BIS limit. The colour, TSS and oily compounds produces turbidity in water which gives bad appearance and foul smell. Also it prevents the sunlight penetration and oxygen transfer process with marine water as a result photosynthesis reaction is stopped. Devi[45], recorded total plankton, which showed a sterling parallelism with suspended solid. Thus turbidity should be measured and treated carefully before disposed into water system.

The higher amount of chloride, 31287 mg/L in effluent water was recorded which is commonly accepted as pollution effect. The higher value might be the use of chlorine compounds such as hydrochloric acid, hypochloric acid and chlorine gas in various processes[46] like bleaching, washing and disinfecting agents. Excess chloride (> 250 mg/L) gives a bitter taste to water and people who are more intake of high chloride water may be subjected to negative impacts on health and also it leads to high corrosiveness to metallic pipes. Mainly high chloride water destroy some microorganisms which are necessary to maintain food chains in aquatic life[47] and it was found to be favour to EC, TDS, TSS, alkalinity and sulfate. Therefore excess usage of chlorine should be removed properly in textile processing.

In the present study the value of silica determined as 891 mg/L and it makes water turbid and increases salinity problem as a result the water is unfit for domestic and irrigation purposes. Therefore the effluent water should be treated before it is discharged into the water bodie

In the present investigation, sulphides, calcium and iron in textile effluents are measured as 0.21, 118.2 and 0.14 mg/L respectively. These values are lower than the permissible limits.

It is defined as a group of related materials rather than a specific chemical compound extractable by certain solvents, such as hexane[48,49,50]. These compounds are non-polar and hydrophobic in nature. Oil and grease value is recorded to be 12 mg/L which is quite higher than BIS limits. The presence of oil and grease in water bodies prevents transfer of oxygen from atmosphere to water medium as a result reduces the amount of dissolved oxygen (DO) at the bottom of the water bodies[51] and disturbs the process of food chain in the aquatic life. In animals, oil coating can eradicate the padding properties of fur and feathers. So detergents spill over water to remove oil layer but it creates foaming, and can harm to invertebrates and fish as they are a major source of phosphates. Therefore several strategies adopted for minimal usage in textile processing and treated cautiously before their final disposal into water bodies.

Colour removal

In the present investigation, the brownish blue colour sample was collected from industries in Coimbatore district, Tamilnadu, India.

Effect of adsorbent dose

The different doses of adsorbent taken such as 25 mg to 300 mg with 50 ml textile effluent in Erlenmeyer flasks in orbital shaker at about 30^0C and 260 rpm. It was found that maximum colour removal efficiency of activated carbon was 98.17% at 200 mg dose of adsorbent and adsorption reaches 100% at 225 mg of adsorbent for 2 hrs. The graphical representation is shown below in Figure 7. It was found that adsorption was attained saturation with increase in dosage.

Effect of time

To study the effect of time on efficient removal of colour from textile waste the study was carried out. The wastewater sample was taken in a Erlenmeyer flasks and kept in a orbital shaker at temperature 30^0C and 260 r.p.m. The sample was withdrawn from the beaker at pre-determined time interval of 10 min each and results are compared with original colour concentration of waste water to know the colour removal efficiency of adsorbents. It is found that, from the time plays an important role in colour removal, the optimum time duration required for colour removal is 120 mins. The colour removal was 95.83 % with 100 min, the results for efficiency of adsorbents with respect to time are given in Figure 8.

IV. Conclusion

The temple waste flowers are available freely in the environment and it gives negative impacts on environment and human health. So the present investigation is one of the waste minimization method by reducing temple waste flowers into activated carbon by direct pyrolysis, Na_2SO_4, and KOH process at optimum conditions and used for present investigation. The physico-chemical parameters of prepared activated carbon is analysed and found that the activated carbon prepared by direct pyrolysis process is excellant and chosen for the present investigation. The city Coimbatore is highly affected by various industries, textile industry is one among them. The physico chemical parameters of textile effluent was analyzed and found the nature and types of pollutant concentration present in the effluent. Based on the above results it is concluded that all the parameters are high in concentration than the standards given by BIS except calcium, sulfide, and iron. Also the colour removal efficiency is calculated with the addition of different dosage of adsorbent and contact time. It was found that colour removal efficiency was achieved maximum of 98.17 at 200mg. The colour removal was high 95.83 % at 100 min. Hence the temple waste flowers are excellant raw materials to prepare activated carbon and colour removal was achieved from textile effluent.

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Table no 1 Physico-chemical parameters of activated carbon FW_D, FW_S and FW_P

Parameters	FW_D	FW_S	FW_P	Standard values as per ASTM and AWWA
pH	7.63	7.34	6.87	6-8
Conductivity at 25°C, S/m	0.29	0.13	0.18	Depends upon the raw material used
Moisture content, %	5.2	6.3	8.9	5-8
Ash content, %	4.0	5.2	6.9	5-15
Volatile matter, %	17.4	19.4	20.75	37. 5 ± 0.03
Matter soluble in water, %	0.81	1.11	0.99	< 1
Matter soluble in acid, %	0.94	1.36	1.16	< 3
Bulk density, g / mL-1	0.48	0.52	0.42	0.25
Specific Gravity	0.80	0.89	0.98	≈1.8
Porosity, %	65.0	53.93	59.18	40-85
Methylene Blue Number, mg /g	511.5	339.0	246.0	≈450
Iodine Number, mg /g	642.0	412.0	285.0	600 to 1100
Fixed Carbon, %	73.4	65.2	63.45	Depends upon the raw material used
Yield, %	63.7	51.0	50.8	Depends upon the raw material used
BET surface area (m^2 / g)	672.2	272	232.2	600 – 1200

Table no 2 Elemental analysis of activated carbon FW_D, FW_S and FW_P by EDS

Activated Carbon	Elements Present	Percentage
FW_D	C	99.45
	Na	0.17
	Mg	0.23
	Ca	0.15
	O	0.00
	Total	100
FW_S	C	98.01
	Mg	0.66
	P	0.16
	K	0.30
	Ca	0.87
	O	0.00
	Total	100
FW_P	C	98.64
	Mg	0.69
	K	0.11
	Ca	0.57
	O	0.00
	Total	100

Table no 3 Methodology of the study using standard procedures

Physico-chemical parameters	Methods
Colour , Hazen	Spectrophotometer, Merck
pH at 30^0 C	pH meter, Merck
Total Hardness	Complexometric titration
BOD, mg/l	Incubating the sample at 30^0C for 5 days followed by titration
COD, mg/l	Closed reflux method
TDS, mg/l	Gravimetric, oven drying at 105^0 C
TSS, mg/l	Gravimetric, oven drying at 105^0 C
Turbidity, NTU	Nephlometer
Chlorides, as Cl-, mg/l	Argentometric titration
Sulphides, as S2-, mg/l	Iodometric method
Silica, as SiO2, mg/l	Spectrophotometer, Merck
Calcium, as Ca, mg/l	Complexometric titration
Iron, as Fe, mg/l	Spectrophotometer, Merck
Oil and grease, mg/l	Partition-gravimetric method

Table no 4 Results of the physico - chemical parameters of textile effluent

Parameters	Observed Values	BIS Limits
Colour , Hazen	4800	25
pH at 30^0 C	7.96	5.5-9
Total Hardness	810	500
BOD, mg/l	760	100
COD, mg/l	2180	250
TDS, mg/l	18220	2,100
TSS, mg/l	5992	100
Turbidity, NTU	69.5	10
Chlorides, as Cl-, mg/l	31287	600
Sulphides, as S2-, mg/l	0.21	2
Silica, as SiO2, mg/l	891	250
Calcium, as Ca, mg/l	118.2	200
Iron, as Fe, mg/l	0.14	3
Oil and grease, mg/l	12	10

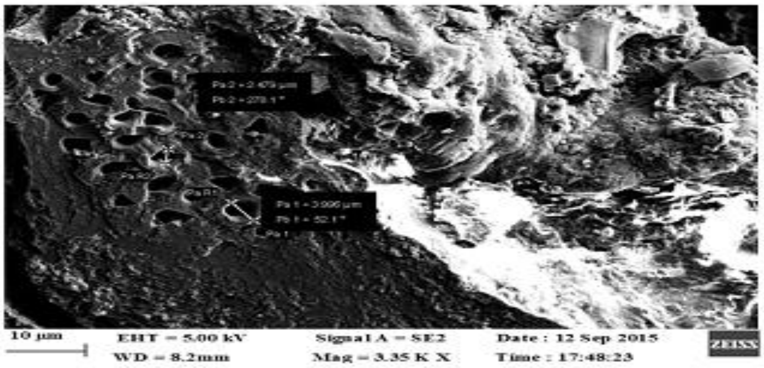

Fig. 1 SEM images of FW_D

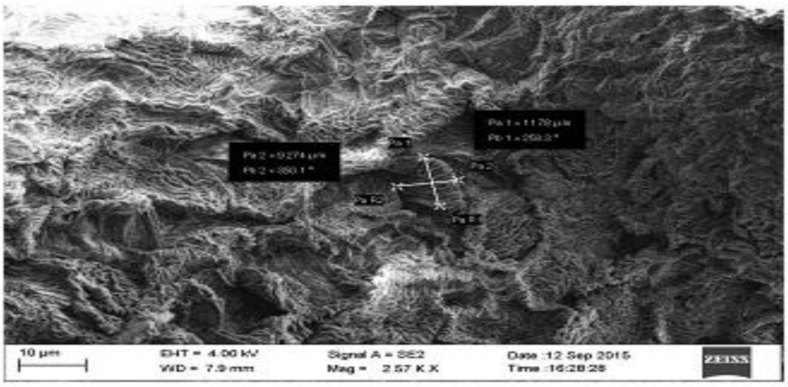

Fig. 2 SEM images of FW_P

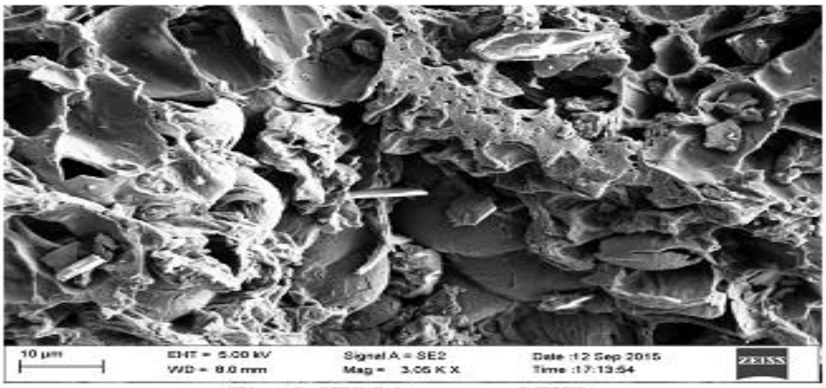

Fig. 3 SEM images of FW_S

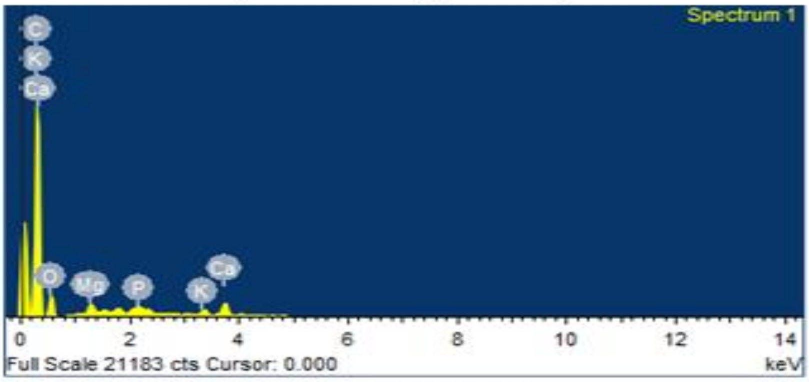

Fig. 4 EDS of FW_S

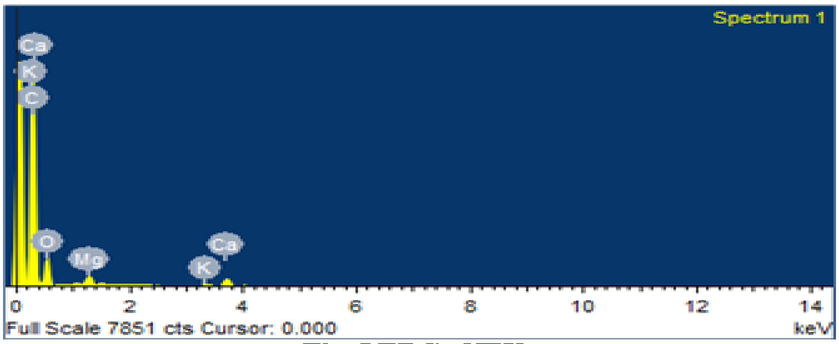

Fig. 5 EDS of FW_P

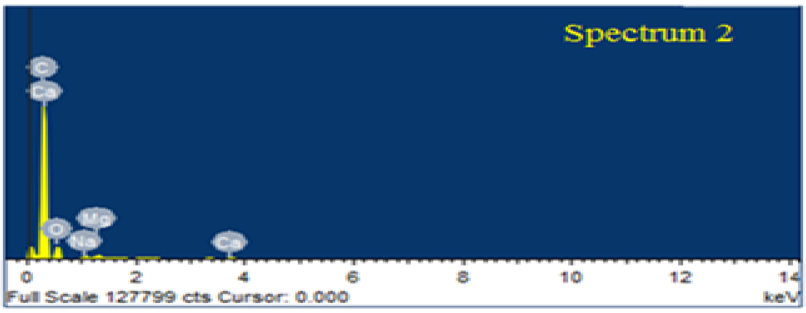

Fig. 6 EDS of activated carbon FW_D

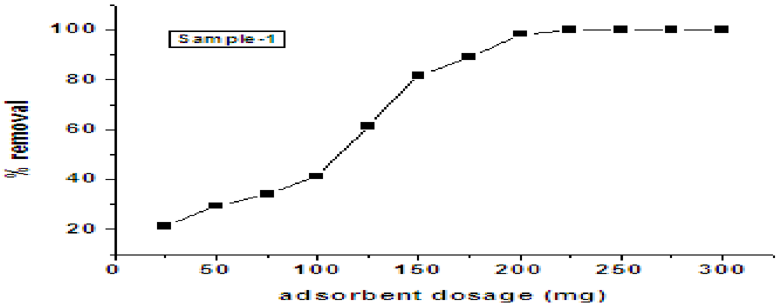

Fig. 7 Effect of adsorbent dosage

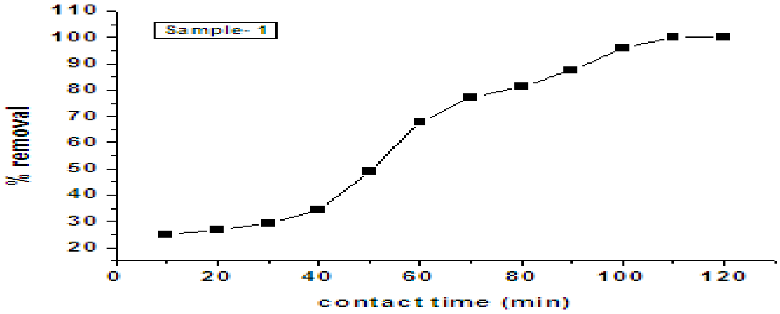

Fig. 8 Effect of contact time

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