PREPARATION AND CHARACTERIZATION OF GRANULAR ACTIVATED CARBON FROM RICE HUSK FOR THE TREATMENT OF TEXTILE EFFLUENT

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Preparation and Characterization of Granular Activated Carbon from Rice Husk for the Treatment of Textile Effluent

by

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Declaration

This is to certify that this thesis work entitled "Preparation and Characterization of Granular Activated Carbon from Rice Husk for the Treatment of Textile Effluent" has been carried out by Md. Mahmudur Rahman in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Dedicated

To

my parents who taught me
honesty, simplicity and responsibility

Abstract

Importance of activated carbon for utilization in treatment of liquids especially water and wastewater has been increasing due to its high adsorption capacity of different impurities. In this study an attempt has been undertaken to produce activated carbon from rice husk applying simple technology and to apply them for the treatment of textile wastewater. In this study production, characterization and application for effluent treatment is observed. For production three low-cost furnaces are designed and fabricated in the workshop of this university and named as Type A, B & C. Thermal activation is adopted for the production of carbon. Different treatment options are applied to treat the two types of effluent collected from textile industry.

Different selected tests are done in the laboratory for the characterization of activated carbon. Physical properties of the activated carbon like ash content, volatile content, moisture content, fixed carbon content are performed. Specific characteristics of activated carbon like adsorption study; kinetic study; column study is also performed using different color, dye and reactive dye. Before using the effluent their physical-chemical tests are also done. Several batch experiments are done in laboratory for the treatment of textile effluents. It is observed from the study that the activated carbons prepared in Type A, B and C furnaces are found 48%, 76% and 35% of total raw material, respectively. The production cost of Type A, B and C furnace are about 500.00 BDT, 40.00 BDT, and 35.00 BDT per kg of activated carbon, respectively. The ash contents of produced activated carbon are 56%, 42% and 58%, respectively and the volatile contents are 4.0%, 7.94% and 6.0%, respectively. The bulk density of the produced activated carbon is 0.38 g/cc, mean pore diameter is 43 Å and the adsorption capacity is 0.96 g/100g Methylene blue. The maximum adsorption of color occurred at an optimum temperature of 40°C with the retention time of 60 minutes. These properties of produced activated carbon are similar to other activated carbon as described in literature.

The color adsorption capacity of the produced activated carbon during application in diluted textile effluent is found to be 80.60% whereas for locally available activated carbon, the adsorption capacity is 62.96% for the same time interval. Adsorption studies with activated carbon derived from rice-husk gave comparable better performance than that of industrial grade activated carbon for decolorization of textile effluent which is 75~90% and 12~35%, respectively. The produced activated carbon also reduce 99% color, 67~80% COD, 20~70%

acidity, 50~56% Manganese, 63~87% Phosphate and 50~60 % Chloride from enzyme wash and desizing wash wastewater. Therefore the produced activated carbon can successfully be applied for the treatment of textile effluents especially the color parameter.

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Nomenclature

All the notation and symbols are defined where they first appear in the text or figures. For convenience, the more frequently used symbols and their meanings are listed below.

AC : Activated carbon
PRHAC : Produced rice husk activated carbon
ΔG : Change in free energy
ΔH : Change in heat content
ΔS : Change in entropy
T : Temperature
a : Amount of gas adsorbed
P : Pressure
A : Weight of original sample
B : Weight of dried sample
VC : Volatile content
U : Moisture content
Ash : Ash content
x/m : Mass of adsorbent
Ce : Concentration of remaining color solution after adsorption
K : Adsorption capacity
n : Intensity of adsorption
a : Bond energy
b : Adsorption capacity

CHAPTER ONE
INTRODUCTION

1.1 General

Textile industry plays an important role in the economy of our country. Uncontrolled and untreated disposal from these industries create severe water pollution in the urban and industrial areas. Out of various activities in textile industry, chemical processing contributes about 70% of pollution. It is well known that cotton mills consume large volume of water for various processes such as sizing, desizing, scouring, bleaching, mercerization, dyeing, printing, finishing and ultimately washing. Due to the nature of various chemical processing of textiles, large volumes of wastewater with numerous pollutants are discharged. Since these streams of water affect the aquatic eco-system in number of ways such as depleting the dissolved oxygen content or settlement of suspended substances in anaerobic condition, a special attention needs to be paid (www.fibre2fashion.com). Cotton provides an ecologically friendly textile, but more than 50% of its production volume is colored with reactive dyes. The effluents generated from textile industry are heavily colored, contain high concentrations of salts, and exhibit high biological oxygen demand (BOD) values. These dyes are unfavorable from an ecological point of view if discharged without treatment (Babu et al., 2007).

There are almost 400 textile industries in and around the Dhaka city and the number is increasing day by day (Habib et al, 2006). In the dyeing industries, above 30-60 Liters of water are consumed per kg of cloth dyed and large quantities of the effluents are released during processing. It amounts is about 16% of the total water consumed in each factory (Habib et al., 2006).

Color is one of the characteristics of an effluent which is easily detected and readily traced back to source. Most of the dyes are produced from different chemicals and not suitable for biological degradation. Color affects the nature of the water and inhibits sunlight penetration into the stream and reduces photosynthetic action. Because of hot and strongly colored textile effluents, it is difficult to treat. Some of the dyes are carcinogenic and mutagenic. Various chemicals are present in the effluent, such as phenols, benzene, toluene and other hydrocarbons, many of which are potential carcinogens. Toxicity of various azo dyes especially benzidine based dyes are well known because of their mutagenicity and carcinogenicity. The textile dyeing wastewater contains a large amount of suspended solids, high COD concentration and with a highly fluctuating pH. The presence of chemicals like hydrogen sulphide, sulphide and sulphur dyes causes rapid depletion of dissolved oxygen, affecting aquatic life adversely. Hence, there is a need to remove dyes from textile wastewater before it disposes to municipal sewer or to receiving water bodies (Habib et al., 2006). Adsorption is a popular method for treating aqueous effluents, which are important for by-product water re-use and conservation. (Aloko et al., 2007).

The conventional methods for removal of dyes may not be efficient and economical for the Bangladesh context. Pollard et al, (1992) and Namasivayam, (1995) have reviewed low cost conventional and non-conventional adsorbents or activated carbon for the treatment of industrial wastewaters. Low cost non-conventional adsorbents used include agricultural solid wastes such as coir pith (Namasivayam and Kadirvelu, 1997), banana pith (Namasivayam et al., 1997), coconut husk (Low and Lee, 1990), sawdust (Asfour et al., 1985), biogas residual slurry (Namasivayam and Yamuna, 1994), peat moss and rice hulls (Nawar and Doma, 1989) and industrial solid wastes such as fly ash and red mud (Namasivayam and Arasi, 1997) and Fe/Cr (III) hydroxide (Namasivayam et al., 1994).

The adsorbents are not easily and economically available. They are expensive in cost compare with its adsorption capacity. Hence much research interests have been on the investigation of the adsorption characteristics of locally available and economical materials (Bhargava and Sheldarkar, 1993).

1.2 Objective of the Study

The main objectives of this research are stated as follows:

- To prepare activated carbon from rice-husk in a low cost method.
- To characterize the produced rice husk activated carbon (PRHAC) by adsorption, desorption and column test using different standard color.
- To determine the effectiveness of the PRHAC for treating textile effluents under different treatment options.

1.3 The Research Scheme

To achieve the above mentioned objectives the following tasks were carried out:

- Fabrication of three type's furnace for producing rice husk activated carbon.
- Selection of most effective process of producing rice husk activated carbon.
- Characterization of PRHAC and compare with other types of activated carbon.
- Laboratory batch study with different options for color removal.
- Detail laboratory analysis, model tests and evaluation of removal efficiency of color with produced activated carbon and comprise with different types of activated carbon.

1.4 Structure of the Dissertation

This thesis paper presents the detail analysis, results and findings of the study in eight chapters and Appendix as shown below. In addition a reference of related publications has also been presented.

Chapter 1 includes the introduction with background of the study, specifies the objectives of the study, research scheme with basic information and structure of dissertation.

Chapter 2 is literature review which states the present situation of textile effluent in Bangladesh, effect of untreated textile effluent, causes of textile effluent. This chapter emphasizes the adsorption characteristics, effluent treatment process by adsorption. The technologies of Producing activated carbon, its characteristics, and applications are also discussed in this chapter.

Chapter 3 is research methodology that includes the steps of methodology with full conception and description, the development of low-cost furnaces.

Chapter 4 states processes of production of activated carbon from rice husk in those low-cost furnaces are described in previous chapter.

Chapter 5 describes the characteristics of PRHAC such as adsorption study, effect of temperature, contact time, adsorbent dose, and column study.

Chapter 6 represents the treatment of textile effluent with various processes. Comparisons of different activated carbon are also described in this chapter.

Chapter 7 states the discussion of the whole study.

Chapter 8 concludes the findings of the study on Production of low-cost activated carbon and treatment of textile effluent. The necessary recommendations are also provided in this chapter.

Appendix is the complementary part of this report that contains the initial data and information on basis of which the thesis report has been prepared accordingly.

Other contents are listed in page VII with captioned as 'Table of Content' and arranged accordingly at the beginning of this report. The list of references is placed at the end of conclusion from which necessary and relevant information is quoted for the research study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Textile effluent pollution scenario of Bangladesh

The ready-made garment sector has become one of the largest manufacturing sectors in Bangladesh with approximately 4490 apparel manufacturing units registered under the Bangladesh Garment Manufactures and Exporters Association (BGMEA) in 2008. The growth in this sector, and other small and medium scale enterprises undoubtedly have a positive effect on national economic development but there are also negative implications. In particular, the large volumes of water consumed and the water pollution generated through the dyeing process can have a severe impact on the local environment (Khan et al., 2009). The rapid but unplanned growth of industrial clusters with several factories discharging large amounts of untreated or poorly treated wastewater, has led to serious localized water pollution. As a result, water bodies and agricultural land are displaying reduced productivity and the biological diversity of these ecosystems is threatened. The result is not only environmental degradation but also a reduction in the nutrition and income of families that traditionally depend on these resources; and they are not always the same people who get benefit from the jobs created by the factories (Khan et al., 2009).

Textile industry involves wide range of raw materials, machineries and processes to engineer for the required shape and properties of the final product. Waste stream generated in this industry is essentially based on water-based effluent generated in the various activities of wet processing of textiles. The main cause of generation of this effluent is the use of huge volume of water either in the actual chemical processing or during re-processing in preparatory, dyeing, printing and finishing. In fact, in a practical estimate, it has been found that 45% material in preparatory processing, 33% in dyeing and 22% are re-processed in finishing (www.fibre2fashion.com).

The textile dyeing industry consumes large quantities of water and produces large volumes of wastewater from different steps in the dyeing and finishing processes. Wastewater from printing and dyeing units is often rich in color, containing residues of reactive dyes and chemicals, and requires proper treatment before being released into the environment shown in Figure 2.1. The toxic effects of dyestuffs and other organic compounds, as acidic and alkaline contaminant, from industrial establishments on the general public are widely accepted. Increasing public concern about environmental issues has led to closure of several small-scale industries (Babu, 2007). Khan et al. (2006) reported that a semi-automated composite textile industry of 10 ton capacity produces 1250 m^3 of effluent each day, which contains an assortment of chemicals including salts, dyes and bleaches.

Cotton provides an ecologically friendly textile, but more than 50% of its production volume is dyed with reactive dyes. Unfortunately, dyes are unfavorable from an ecological point of view, because the effluents generated are heavily colored, contain high concentrations of salts, and exhibit high biological oxygen demand/chemical oxygen demand (BOD/COD) values (Babu et al., 2007).

In dyeing textiles, ecological standards are strictly applied throughout the processing from raw material selection to the final product. This has become more critical since the German environmental standards regarding dye effluents became effective (Robinson et al, 1997). The main challenge for the textile industry today is to modify production methods, so they are more ecologically friendly at a competitive price, by using safer dyes and chemicals and by reducing cost of effluent treatment/disposal. Recycling has become a necessary element, not because of the shortage of any item, but because of the need to control pollution. There are three ways to reduce pollution: (1) use of new, less polluting technologies; (2) effective treatment of effluent so that it conforms to specified discharge requirements; and (3) recycling waste several times over before discharge (Sule and Bardhan, 1999), which is considered the most practical solution.

Dye effluents are among the major pollutants discharged into the environment. Azo dyes predominate and are the largest class of dyes, thus the greatest variety of colors. They have become a great concern in effluent treatment due to their color and potential toxicity to animals and humans (Levine, 1991). Brightly colored, water soluble reactive, and acid dyes are the most problematic, as they tend to pass through conventional treatment systems unaffected (Aksu, 2005 and Willmott, 1998).

Figure 2.1: Effluent discharge from textile industry outlet (Picture taken from Shorj Garments Ltd. Wastewater discharging outlet)

Table 2.1: Discharge quality standards for classified industries composite textile plants

Parameter Limit	(mg/l)
pH	6.5-9
Total Suspended Solid (TSS), (mg/l)	100
BOD5 20_C, (mg/l)	50/150*
COD (mg/l)	200**
Oil and Grease, (mg/l)	10
Total Dissolved Solid (TDS), (mg/l) 2100	
Waste Water Flow	100 L/Kg of fabric processing
Special parameters based on classification of dyes used	
Total Chromium (as Cr molecule), (mg/l) 2	
Sulfide (as S molecule), (mg/l) 2	
Phenolic compounds as C6H5OH, (mg/l) 5	

*BOD limit of 150 mg/l implies only with physico-chemical processing

**No official standard for COD of textile effluent but the general standard for discharge to inland surface water is 200 mg/l

One solution is to ensure that all the effluent is properly treated before it is discharged. The Bangladesh Environment Conservation Act (1995) and Rules (1997) make provision for this, categorizing factories according to their ability to pollute and stating the measures that must be taken to address this, including treatment. Under the 1997 Rules fabric dyeing and chemical processing industries are categorized as "Red industries", which is the highest category in the Rules and for which an effluent treatment plant (ETP) is mandatory. Under these Rules factories must treat as well as monitor the quality of their wastewater and stay within national discharge quality standards shown in Table 2.1.

Despite these laws, factories often show a reluctance to invest money in proper treatment because they consider it to be a non-productive use of money in an industry that is still emerging and striving to remain profitable in the highly competitive global market. Even where industries already have ETPs, there is often unwillingness to operate the plant correctly because of the high running costs or a lack of experience to do so effectively.

2.2 Categorization of Waste Generated in Textile Industry

Textile waste is broadly classified into four categories, each of having characteristics that demand different pollution-prevention and treatment approaches. Such categories are discussed in the following sections:

2.2.1. Hard to Treat Wastes

This category of waste includes those that are persistent, resist treatment, or interfere with the operation of waste treatment facilities. Non-biodegradable organic or inorganic materials are the chief sources of wastes, which contain color, metals, phenols, certain surfactants, toxic organic compounds, pesticides and phosphates. The chief sources are:

- Color and metal dyeing operation
- Phosphates preparatory processes and dyeing
- Non-biodegradable organic materials surfactants

Since these types of textile wastes are difficult to treat, the identification and elimination of their sources are the best possible ways to tackle the problem. Some of the methods of prevention are chemical or process substitution, process control and optimization, recycle/reuse and better work practices.

2.2.2 Hazardous or Toxic Wastes

These wastes are a subgroup of hard to treat wastes. But, owing to their substantial impact on the environment, they are treated as a separate class. In textiles, hazardous or toxic wastes include metals, chlorinated solvents, non-biodegradable or volatile organic materials. Some of these materials often are used for non-process applications such as machine cleaning.

2.2.3. High Volume Wastes

Large volume of wastes is sometimes a problem for the textile processing units. Most common large volume wastes include:

- High volume of waste water
- Wash water from preparation and continuous dyeing processes and alkaline wastes from preparatory processes
- Batch dye waste containing large amounts of salt, acid or alkali

These wastes sometimes can be reduced by recycle or reuse as well as by process and equipment modification.

2.2.4. Dispersible Wastes

The following operations in textile industry generate highly dispersible waste:

- Waste stream from continuous operation (e.g. preparatory, dyeing, printing and finishing)
- Print paste (printing screen, squeeze and drum cleaning)

- Lint (preparatory, dyeing and washing operations)
- Foam from coating operations
- Solvents from machine cleaning
- Still bottoms from solvent recovery (dry cleaning operation)
- Batch dumps of unused processing (finishing mixes)

2.3 Textile operations

The textile industry comprises a diverse and fragmented group of establishments that produce and/or process textile-related products (fiber, yarn, and fabric) for further processing into apparel, home furnishings, and industrial goods. Textile establishments receive and prepare fibers; transform fibers into yarn, thread, or webbing; convert the yarn into fabric or related products; and dye and finish these materials at various stages of production (Ghosh and Gangopadhyay, 2000).

The process of converting raw fibers into finished apparel and non-apparel textile products is complex, so most textile mills are specialized. There is little difference between knitting and weaving in the production of man-made cotton and wool fabrics (Hasheme et al., 2005). Textiles generally go through three or four stages of production that may include yarn formation, fabric formation, wet processing, and textile fabrication. Some of the steps in processing fibers into textile goods are shown in Figure 2.2. Lists of some wastes that may be generated at each level of textile processing are provided in Table 2.2.

2.3.1 Desizing

The presence of sizing ingredients in the fabric hinders processes, such as dyeing, printing, and finishing. For example, the presence of starch can hinder the penetration of the dye into the fiber, which necessitates removal of starch prior to dyeing or printing. Starch is removed or converted into simple water soluble products either by hydrolysis (by enzymatic preparations or dilute mineral acids) or by oxidation (by sodium bromide, sodium chlorite, etc.) (Batra, 1985).

Table 2.2: List of some of the waste materials generated at each level of cotton textile processing (Babu et al, 2007)

Process	Air emission	Wastewater	Residual wastes
Fiber preparation	Little or no air emissions generated	Little or no wastewater generated	Fiber waste; packaging waste; hard waste
Yarn spinning	Little or no air emissions generated	Little or no wastewater generated	Packaging waste; sized yarn; fiber waste; cleaning and processing waste
Slashing/sizing	Volatile organic compounds	BOD; COD; metals; cleaning waste size	Fiber lint; yarn waste; packaging waste; unused starch-based sizes.
Weaving	Little or no air emissions generated	Little or no wastewater generated	Packaging waste; yarn and fabric scraps; off-spec fabric; used oil.
Knitting	Little or no air emissions generated	Little or no wastewater generated	Packaging waste; yarn and fabric scraps; off-spec fabric;
Tufting	Little or no air emissions generated	Little or no wastewater generated	Packaging waste; yarn and fabric scraps; off-spec fabric;
Desizing	Volatile organic compounds from glycol ethers	BOD from water-soluble sizes; synthetic size; lubricants; biocides; anti-static compounds	Packaging waste; fiber lint; yarn waste; cleaning materials, such as wipes, rags and filters; cleaning and maintenance wastes containing solvents.
Scouring	Volatile organic compounds from glycol ethers and scouring solvents	Disinfectants and insecticide residues; NaOH; detergents; fats; oils; pectin; wax; knitting lubricants; spin finishes; spent solvents	Little or no residual waste generated
Bleaching	Little or no air emissions generated	Hydrogen peroxide, sodium silicate or organic stabilizer; high pH	Little or no residual waste generated
Singeing	Small amounts of exhaust gasses from the burners	Little or no wastewater generated	Little or no residual waste generated
Mercerizing	Little or no air emissions generated	High pH; NaOH	Little or no residual waste generated
Heat setting	Volatilization of spin finish agents applied during synthetic fiber manufacture	Little or no wastewater generated	Little or no residual waste generated
Dyeing	Volatile organic compounds	Metals; salts; surfactants; toxics; organic processing assistance; cationic materials; color; BOD; sulfide; acidity/ alkalinity; spent solvents.	Little or no residual waste generated
Printing	Solvents, acetic acid from dyeing and curing oven emissions; combustion gasses; particulate matter	Suspended solids; urea; solvents; color; metals; heat; BOD; foam	Little or no residual waste generated
Finishing	Volatile organic compounds; contaminants in purchased chemicals; formaldehyde vapor; combustion gasses; particulate matter	BOD; COD; suspended solids; toxics; spent solvents	Fabric scraps and trimmings; packaging waste
Product fabrication	Little or no air emissions generated	Little or no wastewater generated	Fabric scraps

In general, about 50% of the water pollution is due to waste water from desizing, which has a high BOD that renders it unusable. The problem can be mitigated by using enzymes that degrade starch into ethanol rather to anhydroglucose. The ethanol can be recovered by distillation for use as a solvent or fuel, thereby reducing the BOD load. Alternatively, an oxidative system like H_2O_2 can be used to fully degrade starch to CO_2 and H_2O (Babu et al, 2007).

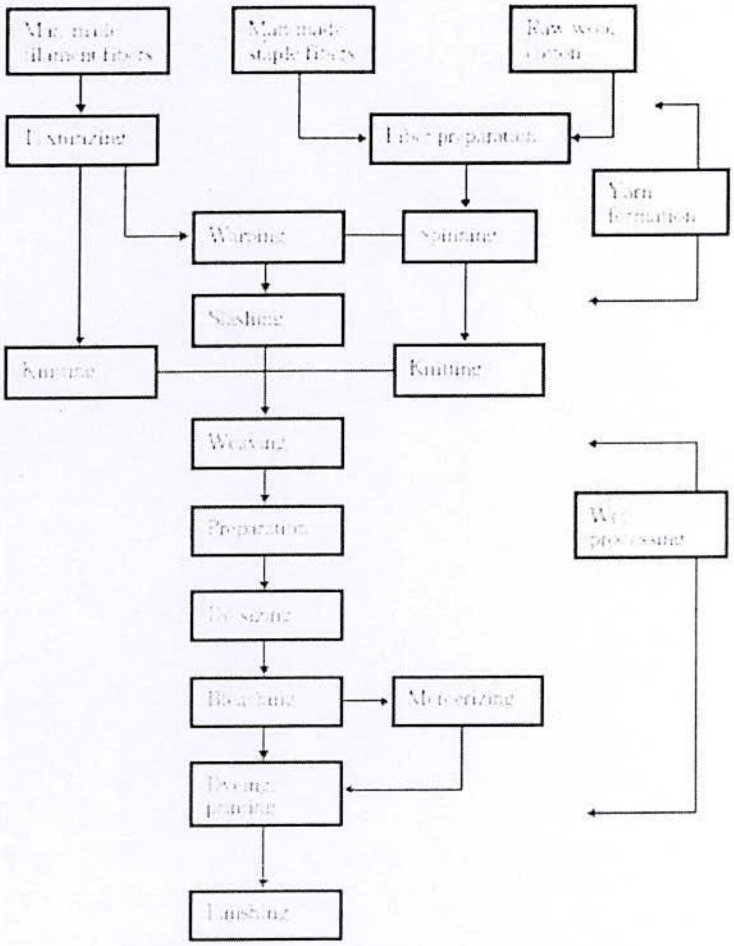


Figure 2.2: A flow diagram for various steps involved in processing textile in a cotton mill (Babu et al, 2007)

Electro-oxidation on RuO2/Ti or PbO2/Ti electrodes is an effective method for the treatment of starch effluent. An anaerobic plate-column reactor capable of retaining high concentrations of biomass was studied using a synthetic wastewater that contained starch. The total organic carbon (TOC)-loading rate, hydraulic retention time (HRT), and temperature were kept constant. The initial conditions were a biomass concentration of approximately 0.5 mg/ml N (5 mg/ml volatile suspended solids), 20 °C, an HRT of 30 h, and a TOC-loading rate of 0.8 g/l/day. A removal efficiency of dissolved organic carbon exceeding 90% was realized. At the end of the treatment, the removal efficiency reached a steady-state value of 98%, at which the biomass concentration in the reactor was 2.3 mg/ml N.

Cornstarch waste is easily degraded by treatment in a mixed activated sludge system. The bio-kinetic coefficients were calculated from the two-level activated sludge operational processes using influent COD concentrations and four values of solid retention time. The results indicate that the effluent COD is related to the influent COD concentration. It is also proportional to the product of the influent COD and the specific growth rate. A multiple-substrate model was developed to predict the effluent COD under variable influent COD concentrations (Bortone et al., 1995). There was no sludge-bulking problem apparently because of high dissolved oxygen (DO) concentrations, a buffered system, and a balanced Carbon: Nitrogen: Phosphorus ratio; however, the critical DO concentration at which the sludge volume index began to rise increased as the food for microorganism (F/M*)* ratio increased. A cost analysis was provided for a hypothetical wastewater plant with a flow rate of 300 m^3/ day (Meier et al, 2002). Synthetic sizing formulations based on polyvinyl acrylic (PVA) and acrylic resins, instead of starch, are expensive. Considering the cost of effluent treatment, the cost of synthetic sizing formulations is negligible. Today, advances in nano-filtration and ultra-filtration techniques allow recovery and reuse of PVA (Meier et al, 2002).

Compared with reverse osmosis, nanofiltration is less energy intensive and can be used for the treatment of various industrial effluents (Meier et al., 2002). Moreover, a higher retention of dyes and other low molecular weight organic compounds (MW: 200–1000) is achievable by nanofiltration. The saltrich permeate can be reused in the preparation of dye baths, which minimizes the amount of wastewater that needs to be processed. The basic problems involved in any membrane-based process are a drop in flux and membrane fouling. To overcome this problem and to achieve a high quality separation, combinations of various separation methods have been adopted in recent years (Pigmon et al, 2003; Abdessemed and Nezzal, 2002; Dhale and Mahajani, 2000 and Xu et al., 1999).

2.3.2 Mercerization

In order to impart luster, increase strength, and improve dye uptake, cotton fiber and fabric are mercerized in the gray state after bleaching. Essentially, mercerization is carried out by treating cotton material with a strong solution of sodium hydroxide (about 18–24%) and washing-off the caustic after 1 to 3 min, while holding the material under tension. Cotton is known to undergo a longitudinal shrinkage upon impregnation with this solution. This can be prevented by stretching it or holding it under tension. The material acquires the desired properties of luster, increased strength, dye uptake, and increased absorbency. The large concentrations of NaOH in the wash water can be recovered by membrane techniques. Use of $ZnCl^2$ as an alternative method leads to an increase in the weight of fabric and in dye uptake, and allows easy recovery of NaOH. Moreover, the process is ecologically friendly and does not require neutralization by acetic or formic acid (Karim et al., 2006).

2.3.3 Bleaching

Natural color matter in the yarn imparts a creamy appearance to the fabric. In order to obtain white yarn that facilitates producing pale and bright shades, it is necessary to decolorize the yarn by bleaching. Hypochlorite is one of the oldest industrial bleaching agents. The formation of highly toxic chlorinated organic by-products during the bleaching process is reduced by adsorbable organically bound halogen (AOX).

Over the last few years, hypochlorite is being replaced by other bleaching agents (Rott, 1999). An environmentally safe alternative to hypochlorite is peracetic acid. It decomposes to oxygen and acetic acid, which is completely biodegradable. One of the advantages of peracetic acid is higher brightness values with less fiber damage (Rott and Minke, 1999). Recently, a one-step preparatory process for desizing, scouring, and bleaching has helped to reduce the volume of water.

Cooper (1989) suggested an economical and pollution-free process for electrochemical mercerization (scouring) and bleaching of textiles. The process does not require conventional caustic soda, acids, and bleaching agents. The treatment is carried out in a low-voltage electrochemical cell. The base required for mercerization (scouring) is produced in the cathode chamber, while an equivalent amount of acid is produced in the anode chamber, which is used for neutralizing the fabric. Gas diffusion electrodes simultaneously generate hydrogen peroxide for bleaching. With a bipolar stack of electrodes, diffusion electrodes can be used as anode or cathode or both. The process does not produce hydrogen bubbles at the cathode, thereby avoiding hazards involving the gas (Lin and Peng, 1994).

An electrochemical treatment was developed for the treatment of cotton in aqueous solution containing sodium sulphate. In this technique, the current density was controlled between two electrodes. At the cathode, water is reduced to hydrogen and base, while at the anode it is oxidized to oxygen and acid. Favorable results on mercerization (scouring) and electrochemical sanitation of unmercerized (grey) cotton have been reported (Naumczyk et al., 1996).

2.3.4 Neutralization

According to Bradbury et al. (2000), replacement of acetic acid by formic acid for neutralization of fabric after scouring, mercerizing, bleaching, and reduction processes is effective, economical, and environment-friendly. The procedure also allows a sufficient level of neutralization in a short period of time, needs low volumes of water, and results in low levels of BOD.

2.3.5 Dyeing

Treatment of fiber or fabric with chemical pigments to impart color is called dyeing. The color arises from chromophore and auxochrome groups in the dyes, which also cause pollution (Azymezyk et al, 2007). In the dyeing process, water is used to transfer dyes and in the form of steam to heat the treatment baths. Cotton, which is the world's most widely used fiber, is a substrate that requires a large amount of water for processing. For example, to dye 1 kg of cotton with reactive dyes, 0.6–0.8 kg of NaCl, 30–60 g of dyestuff, and 70–150 L of water are required (Chakraborty et al., 2005). More than 80,000 tonnes of reactive dyes are produced and consumed each year. Once the dyeing operation is over, the various treatment baths are drained, including the highly colored dye bath, which has high concentrations of salt and organic substances. The wastewater must be treated before reuse. Coagulation and membrane processes (nanofiltration or reverse osmosis) are among processes suggested for treatment of this water; however, these treatments are effective only with very dilute dye baths. Dye baths are generally heavily polluted. For example, wastewater produced by reactive dyeing contains hydrolyzed reactive dyes not fixed on the substrate (representing 20 to 30% of the reactive dyes applied on an average of 2 g/L). This residual amount is responsible for the coloration of the effluents, and cannot be recycled. Dyeing auxiliaries or organic substances are non-recyclable and contribute to the high BOD/COD of the effluents.

Membrane technologies are increasingly being used in the treatment of textile wastewater for the recovery of valuable components from the waste stream, as well as for reusing the aqueous stream. A number of studies deal with application of various pressure-driven membrane filtration processes in the treatment wastewater from the dyeing and finishing process (Chen et al., 2005).

Measures adopted for the abatement of pollution by different dyes are use of low material-to-liquor ratios, use of trisodiumcitrate (Fiebig et al., 1992), replacement of reducing agent (sodium hydrosulphite) with a reducing sugar or electrochemical reduction (Maier et al., 2004), and use of suitable dye-fixing agents to reduce water pollution loads. Padma et al. (2006) first reported the concept of totally ecologically friendly mordents or natural mordents during dyeing with natural dyes. Deo and Desai (1999) were the first to point out that natural dye shades could be built-up by a multiple dip method that renders natural dyeing more economical. Dyeing of natural and synthetic fibers with natural dyes has been the subject of several studies. Development of ecologically friendly non-formaldehyde dye fixative agents for reactive dyes was recently reported (Bechtold et al., 2005; Sekar, 1995).

2.3.6 Printing

Printing is a branch of dyeing. It is generally defined as 'localized dyeing,' i.e. dyeing that is confirmed to a certain portion of the fabric that constitutes the design. It is really a form of dyeing in which the essential reactions involved are the same as those in dyeing. In dyeing, color is applied in the form of a solution, whereas in printing color is applied in the form of a thick paste of the dye. Table 2.3 shows the pollution loads for a printing and finishing operation (50 polyester/50 cotton). The fixation of the color in printing is brought about by a suitable after-treatment of the printed material (El-Molla and Schneider, 2006).

Textile fabric printing produces hydrocarbon effluents that must be removed before they reach the atmosphere. Limits on emissions will become more restrictive in the future, which makes cleaning exhausts an environmental necessity. In India, a majority of textile printing units prefer to use kerosene in printing because of the brilliant prints and ease of application. In India alone, about 122 million liters of kerosene is released into the atmosphere annually during printing, drying, and curing. The resulting pollution of the atmosphere and wastage of hydrocarbon products is colossal. Air-laden kerosene is harmful to human beings, as well as to the flora and fauna, in the neighborhood. Therefore, it is imperative that as much kerosene as possible is recovered from the exhaust pipes of the printing industry. Zachariah (1995) developed a process for the recovery of thin kerosene vapor. In this process, the percentage of recovery of kerosene from the printing drier was 78.5%, and the total percentage of recovery of kerosene consumed for the preparation of print paste was 58.8%.

Table 2.3: Pollution loads for printing and finishing operations for 50% polyester/50% cotton blend fabric (Babu et al., 2007)

Process	pH	Biological oxygen demand		Total dissolvable solids	
			Per 1000 kg of product		
Printing					
Pigment (woven goods)	6-8	1.26	5.0	0.13	2.5
Pigment (knot goods)	6-8	1.26	5.0	0.13	2.5
Vat dye (woven goods)	10.0	21.5	86	25	34
Vat dye (knit goods)	10.0	21.5	86	25	35
Resin finishing (woven goods)	6-8	-	-	-	22
Resin finishing flat curing (woven goods)	6-8	6.32	25	12	17.3

The most common chemical in reactive dye printing is urea, which leads to a high pollution load. A number of attempts have been made to limit or eliminate the use of urea in the print paste to reduce effluent load. Geeta and Musale, (2004) developed a urea-free process in which caprolactam, PEG-400, and PEG-600 partially or completely replaced urea in the dyeing and printing of reactive dyes on cotton fabrics. Caprolactam in many reactive dyes can fully replace urea, while PEG-400 and PEG-600 replaced approximately 50% of the dyes required for fixation. Other substitutes for urea include glycerin, cellosolve, sorbitol, polycarboxylic acid, PEG-200, and PEG-4000.

Printing is mainly done by a flat or rotary screen, and after every lot of printing some residual paste is left in the wastewater. This can be reused for printing of similar shades by adding new stock. Recently, screen free printing methods, such as ink-jet printing and electrostatic printing, have been developed that make use of an electronic control of color distribution on fabric. Screen-free printing methods are attractive for pollution mitigation (Lukanova and. Ganchev, 2005).

2.3.7 Finishing

Both natural and synthetic textiles are subjected to a variety of finishing processes. This is done to improve specific properties in the finished fabric and involves the use of a large number of finishing agents for softening, cross-linking, and waterproofing. All of the finishing processes contribute to water pollution.

Among the products that are used in textile finishing, the most ecologically friendly ones are formaldehyde-based cross-linking agents that bestow desired properties, such as softness and stiffness that impart bulk and drape properties, smoothness, and handle, to cellulosic textiles. It can also lead to enhanced dimensional stability. A free surface characteristic of the fabric shows the evolution of un-reacted formaldehyde. This obviates the use of formaldehyde in the product and liberation of chemical products, and results in considerable reduction in the amount of formaldehyde during the cross-linking reaction that leads to toxicity and stream pollution.

Generation of formaldehyde during vacuum extraction has been used in the storage of resin-finished fabrics and garments. The formaldehyde resin used as a cross-linking agent is a pollutant and a known carcinogen. Much effort has been expended in the search for a substitute for formaldehyde (Hashem et al., 2005).

Since the late 1980s, there has been an increase in the demand for easy-care, wrinkle-resistant (durable press), 100% cotton apparel. Formaldehyde-based chemical finishes such as dimethylol dihydroxyethylene urea and its etherified derivative with lower formaldehyde concentrations, are used to impart easeof-care characteristics and durable-press properties to cotton apparel. They are cost-effective and efficient (Hashem et al., 2005). The free formaldehyde on the finished fabric is a major drawback given the adverse effects of formaldehyde, which ranges from a strong irritant to carcinogenic. In addition, washing the apparel pollutes the washing liquor. Because of its carcinogenic properties, the concentration of formaldehyde allowed in the workplace air space is limited to 0.1 ppm. Furthermore, worker health must be monitored in the textile industry when formaldehyde is used. This is strictly stated in recent actions by federal regulatory agencies in most industrialized countries. The restrictions have sprouted renewed interest in nonformaldehyde textile finishing substances in the cotton textile industry (El-Tahlawya et al., 2005). Moreover, formaldehyde-based finishing is energy-intensive. A variety of cellulose cross-linking agents, such as polycarboxylic acids, have been investigated to provide non-formaldehyde easy-care finishing.

Natural polymeric substances, such as natural oil and wax, have been used for water-proofing; however, textiles made from natural fibers are generally more susceptible to biodeterioration compared with those made from synthetic fibers. Products, such as starch, protein derivatives, fats, and oils, used in the finishing or sizing bath can also promote microbial growth. An ideal anti-bacterial finish should 1) not support growth of bacteria or fungi on the cloth, 2) be effective over the lifetime of the treated sample, 3) be durable against wash and bleaching, 4) pose no risk of adverse dermal or systemic effects, 5) have no detrimental influence on fabric properties, such as yellowing, handle, and strength, 6) be compatible with colorants and other finishes, such as softeners and resins, and 7) have low environmental impact of heavy metals, formaldehyde, phenols, and organic halogens.

There are few anti-bacterial fibers. There are a number of antibacterial chemicals are available (Son et al., 2006; Singh et al., 2005; El-Tahlawya et al., 2005), but they are man-made. There are many natural plant products that are known to slow down bacterial growth. Anti-bacterial properties have been detected in chemicals extracted from the root, stem, leaves, flowers, fruits, and seeds of diverse species of plants (Kannan and Geethamalini, 2005). Sachan and Kapoor (2004) used natural herbal extracts for developing bacteria-resistant finishes for cotton fabric and wool felting. Years ago, wool was treated with chlorine, hypochlorite, and sulfuryl chloride. Bio-polishing using cellulose enzymes is an environmentally friendly method to improve soft handling of cellulose fibers with reduced piling, less fuzz, and improved drape (Thilagavathi et al., 2005).

2.4 Dye

A dye can generally be described as a colored substance that has an affinity to the substrate to which it is being applied. The dye is generally applied in an aqueous solution, and may require a mordant to improve the fastness of the dye on the fiber. Both dyes and pigments appear to be colored because they absorb some wavelengths of light preferentially. In contrast with a dye, a pigment generally is insoluble, and has no affinity for the substrate. Some dyes can be precipitated with an inert salt to produce a lake pigment, and based on the salt used they could be aluminum lake, calcium lake or barium lake pigments.

Dyes are soluble at some stage of the application process, whereas pigments, in general, retain essentially their particulate or crystalline form during application. A dye is used to impart color to materials of which it becomes an integral part. An aromatic ring structure coupled with a side chain is usually required for resonance and thus to impart color (www.ifc.org).

2.4.1 Classification of Dye

The first human-made (synthetic) organic dye, mauveine, was discovered by William Henry Perkin in 1856. Many thousands of synthetic dyes have since been prepared (Shenai, 1979).

Synthetic dyes quickly replaced the traditional natural dyes. They cost less, they offered a vast range of new colors, and they imparted better properties to the dyed materials. Dyes are now classified according to how they are used in the dyeing process. A listing of dyes by use classification comprises the following:

***Acetate rayon dyes**:* developed for cellulose acetate and some synthetic fibers

Acid dyes: used for coloring animal fibers via acidified solution (containing sulfuric acid, acetic acid, sodium sulfate, and surfactants) in combination with amphoteric protein. This dyes are water-soluble anionic dyes that are applied to fibers such as silk, wool, nylon and modified acrylic fibers using neutral to acid dye baths. Attachment to the fiber is attributed, at least partly, to salt formation between anionic groups in the dyes and cationic groups in the fiber. Acid dyes are not substantive to cellulosic fibers. Most synthetic food colors fall in this category.

Azoic dyes: contain the azo group (and formic acid, caustic soda, metallic compounds, and sodium nitrate); especially for application to cotton. It is a technique in which an insoluble azo dye is produced directly onto or within the fibre. This is achieved by treating a fibre with both diazoic and coupling components. With suitable adjustment of dyebath conditions the two components react to produce the required insoluble azo dye. This technique of dyeing is unique, in that the final color is controlled by the choice of the diazoic and coupling components.

Basic dyes: These dyes are water-soluble cationic dyes that are mainly applied to acrylic fibers, but find some use for wool and silk. Usually acetic acidis added to the dyebath to help the uptake of the dye onto the fiber. Basic dyes are also used in the coloration of paper.

Direct dyes: azo dyes, and sodium salts, fixing agents, and metallic (chrome and copper) compounds; used generally on cotton-wool, or cotton- silk combinations

Mordant or chrome dyes: metallic salt or lake formed directly on the fiber by the use of aluminum, chromium, or iron salts that cause precipitation in situ. These require a mordant, which improves the fastness of the dye against water, light and perspiration. The choice of mordant is very important as different mordants can change the final color significantly. Most natural dyes are mordant dyes and there is therefore a large literature base describing dyeing techniques. The most important mordant dyes are the synthetic mordant dyes, or chrome dyes, used for wool; these comprise some 30% of dyes used for wool, and are especially useful for black and navy shades. The mordant, potassium dichromate, is applied as an after-treatment. It is important to note that many mordants, particularly those in the heavy metal category, can be hazardous to health and extreme care must be taken in using them.

Lake or pigment dyes: form insoluble compounds with aluminum, barium, or chromium on molybdenum salts; the precipitates are ground to form pigments used in paint and inks

Sulfur or sulfide dyes: contain sulfur or are precipitated from sodium sulfide bath; furnish dull shades with good fastness to light, washing, and acids but susceptible to chlorine and light.

Sulfur dyes are two parts "developed" dyes used to dye cotton with dark colors. The initial bath imparts a yellow or pale chartreuse color; this is aftertreated with a sulfur compound in place to produce the dark black we are familiar with in socks for instance. Sulfur Black 1 is the largest selling dye by volume.

Vat dyes: It is impregnated into fiber under reducing conditions and reoxidized to an insoluble color. These are essentially insoluble in water and incapable of dyeing fibres directly. However, reduction in alkaline liquor produces the water soluble alkali metal salt of the dye, which, in this leuco form, has an affinity for the textile fibre. Subsequent oxidation reforms the original insoluble dye. The color of denim is due to indigo, the original vat dye.

Reactive dyes: These are utilized in a chromophore attached to a substituent that is capable of directly reacting with the fibre substrate. The covalentbonds that attach reactive dye to natural fibers make them among the most permanent of dyes. "Cold" reactive dyes, such as Procion MX,Cibacron F, and Drimarene K, are very easy to use because the dye can be applied at room temperature. Reactive dyes are by far the best choice for dyeing cotton and other cellulose fibers at home or in the art studio.

Disperse dyes: These were originally developed for the dyeing of cellulose acetate, and are water insoluble. The dyes are finely ground in the presence of a dispersing agent and sold as a paste, or spray-dried and sold as a powder. Their main use is to dye polyester but they can also be used to dye nylon, cellulose triacetate, and acrylic fibres. In some cases, a dyeing temperature of 130 °C is required, and a pressurised dyebath is used. The very fine particle size gives a large surface area that aids dissolution to allow uptake by the fibre. The dyeing rate can be significantly influenced by the choice of dispersing agent used during the grinding.

Chemical classification is based on chromogen. For example, nitro dyes have the chromophore -NO2. The Color Index (C.I.), published by the Society of Dyers and Colourists (United Kingdom) in cooperation with the American Association of Textile Chemists and Colorists (AATC), provides a detailed classification of commercial dyes and pigments by generic name and chemical constitution (www.ifc.org).

2.5 Activated Carbon

"Activated Carbon", also called activated charcoal or activated coal is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions.

The word *activated* in the name is sometimes replaced with *active*. Due to its high degree of micro porosity, just 1 gram of activated carbon has a surface area in excess of 500 m^2 (about one tenth the size of a football field), as determined typically by nitrogen gas adsorption. Sufficient activation for useful applications may come solely from the high surface area, though further chemical treatment often enhances the absorbing properties of the material. Activated carbon is usually derived from charcoal (http://en.wikipedia.org).

It is an amorphous form of carbon, which is specially treated to produce vary large surface area ranging from 300 to 2000 m^2g^{-1}. This large surface area implies that the internal pore structure has been very highly developed; it is this structure, which provides activated carbon with the ability to adsorb gases and vapor from gases and dissolved or dispersed substances from liquids (Aloko et al., 2007).

2.5.1 Preparation of Activated carbon

The preparation of activated carbon with different pore sizes can be achieved by using physical or chemical activation process. In both methods, the development of porosity is different in term of practical procedures and mechanism. In physical activation the generation of porosity took place via selective elimination of the more reactive carbon of the structure and further gasification led to the production of the activated carbon with the sought pore structure.

In chemical activation process, the precursor is mixed with a chemical such as $ZnCl_2$ or $H_3PO_{4,}$ carbonized and washed to produce the activated carbon. Following the thermal decomposition of the precursor, the chemical reacts with the product causing reduction in the evolution of volatile matter and inhibition of the particle shrinkage. Once the chemical is removed by exhaustive washing, a large amount of porosity is formed (Abdullah et al., 2001).

2.5.2 Classification of Activated carbon

Activated carbons are complex products which are difficult to classify on the basis of their behavior, surface characteristics and preparation methods. However, some broad classification is made for general purpose based on their physical characteristics.

2.5.2.1 Powdered activated carbon (PAC)

Traditionally, active carbons are made in particular form as powders or fine granules less than 1.0 mm in size with an average diameter between .15 and .25 mm (http://en.mimi.hu). Thus they present a large surface to volume ratio with a small diffusion distance. PAC is made up of crushed or ground carbon particles, 95–100% of which will pass through a designated mesh sieve or sieve. Granular activated carbon is defined as the activated carbon being retained on a 50-mesh sieve (0.297 mm) and PAC material as finer material, while ASTM classifies particle sizes corresponding to an 80-mesh sieve (0.177 mm) and smaller as PAC. PAC is not commonly used in a dedicated vessel, owing to the high head loss that would occur. PAC is generally added directly to other process units, such as raw water intakes, rapid mix basins, clarifiers, and gravity filters.

2.5.2.2 Granular activated carbon (GAC)

Granular activated carbon has a relatively larger particle size compared to powdered activated carbon and consequently, presents a smaller external surface. Diffusion of the adsorbate is thus an important factor. These carbons are therefore preferred for all adsorption of gases and vapours as their rate of diffusion are faster. Granulated carbons are used for water treatment, deodourisation and separation of components of flow system. GAC can be either in the granular form or extruded. GAC is designated by sizes such as 8×20, 20×40, or 8×30 for liquid phase applications and 4×6, 4×8 or 4×10 for vapour phase applications. A 20×40 carbon is made of particles that will pass through a U.S. Standard Mesh Size No. 20 sieve (0.84 mm) (generally specified as 85% passing) but be retained on a U.S. Standard Mesh Size No. 40 sieve (0.42 mm) (generally specified as 95% retained). AWWA (1992) B604 uses the 50-mesh sieve (0.297 mm) as the minimum GAC size. The most popular aqueous phase carbons are the 12×40 and 8×30 sizes because they have a good balance of size, surface area, and head loss characteristics.

2.5.2.3 Extruded activated carbon (EAC)

Extruded activated carbon combines powdered activated carbon with a binder, which are fused together and extruded into a cylindrical shaped activated carbon block with diameters from 0.8 to 130 mm. These are mainly used for gas phase applications because of their low pressure drop, high mechanical strength and low dust content.

2.5.2.4 Impregnated carbon

Porous carbons containing several types of inorganic impregnant such as iodine, silver, cations such as Al, Mn, Zn, Fe, Li, Ca have also been prepared for specific application in air pollution control especially in museums and galleries. Due to antimicrobial/antiseptic properties, silver loaded activated carbon is used as an adsorbent for purification of domestic water. Drinking water can be obtained from natural water by treating the natural water with a mixture of activated carbon and $Al(OH)_3$, a flocculating agent. Impregnated carbons are also used for the adsorption of H_2S and thiols. Adsorption rates for H_2S as high as 50% by weight have been reported.

2.5.2.5 Polymer coated carbon

This is a process by which a porous carbon can be coated with a biocompatible polymer to give a smooth and permeable coat without blocking the pores. The resulting carbon is useful for hemoperfusion. Hemoperfusion is a treatment technique in which large volumes of the patient's blood are passed over an adsorbent substance in order to remove toxic substances from the blood.

2.5.2.6 Other

Activated carbon is also available in special forms such as cloths and fibres. The "carbon cloth" for instance is used in personnel protection for the military. Two distinct types are recognized commercially namely, liquid phase (decolorizing carbon) is generally light fluffy powders and gas phase or vapor adsorbent carbons are hard, dense granular or pellets (Dietz, 1944).

2.5.3 Properties

A gram of activated carbon can have a surface area in excess of 500 m^2, with 1500 m^2 being readily achievable (http://cgpl.iisc.ernet.in). Carbon aerogels, while more expensive, have even higher surface areas, and are used in special applications.

Under an electron microscope (Figure 2.3), the high surface-area structures of activated carbon are revealed. Individual particles are intensely convoluted and display various kinds of porosity; there may be many areas where flat surfaces of graphite-like material run parallel to each other, separated by only a few nanometers or so. These micropores provide superb conditions for adsorption to occur, since adsorbing material can interact with many surfaces simultaneously. Tests of adsorption behavior are usually done with nitrogen gas at 77 Kunder high vacuum, but in everyday terms activated carbon is perfectly capable of producing the equivalent, by adsorption from its environment, liquid water from steam at 100 °C and a pressure of 1/10,000 of an atmosphere. In Figure 2.4 and 2.5 shows the adsorption processes on the surface of the activated carbon.

Physically, activated carbon binds materials by van der Waals force or London dispersion force. Activated carbon does not bind well to certain chemicals, including alcohols, glycols, strong acids and bases, metals and most inorganics, such as lithium, sodium, iron, lead, arsenic, fluorine, and boric acid. Activated carbon does adsorb iodine very well and in fact the iodine number, mg/g, (ASTM D28 Standard Method test) is used as an indication of total surface area. Contrary to a claim repeated throughout the web, activated carbon can capture gaseous ammonia. In fact, it is utilized for that very function in many diazo copier machines. Carbon monoxide is not well absorbed by activated carbon. This should be of particular concern to those using the material in filters for respirators, fume hoods or other gas control systems as the gas is undetectable to the human senses, toxic to metabolism and neurotoxic. Substantial lists of the common industrial and agricultural gases absorbed by activated carbon can be found online (www.sentryair.com).

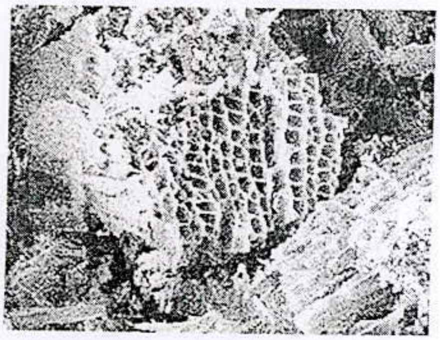


Figure 2.3: Activated carbon, as viewed by an electron microscope

(http://wpcontent.answcdn.com)

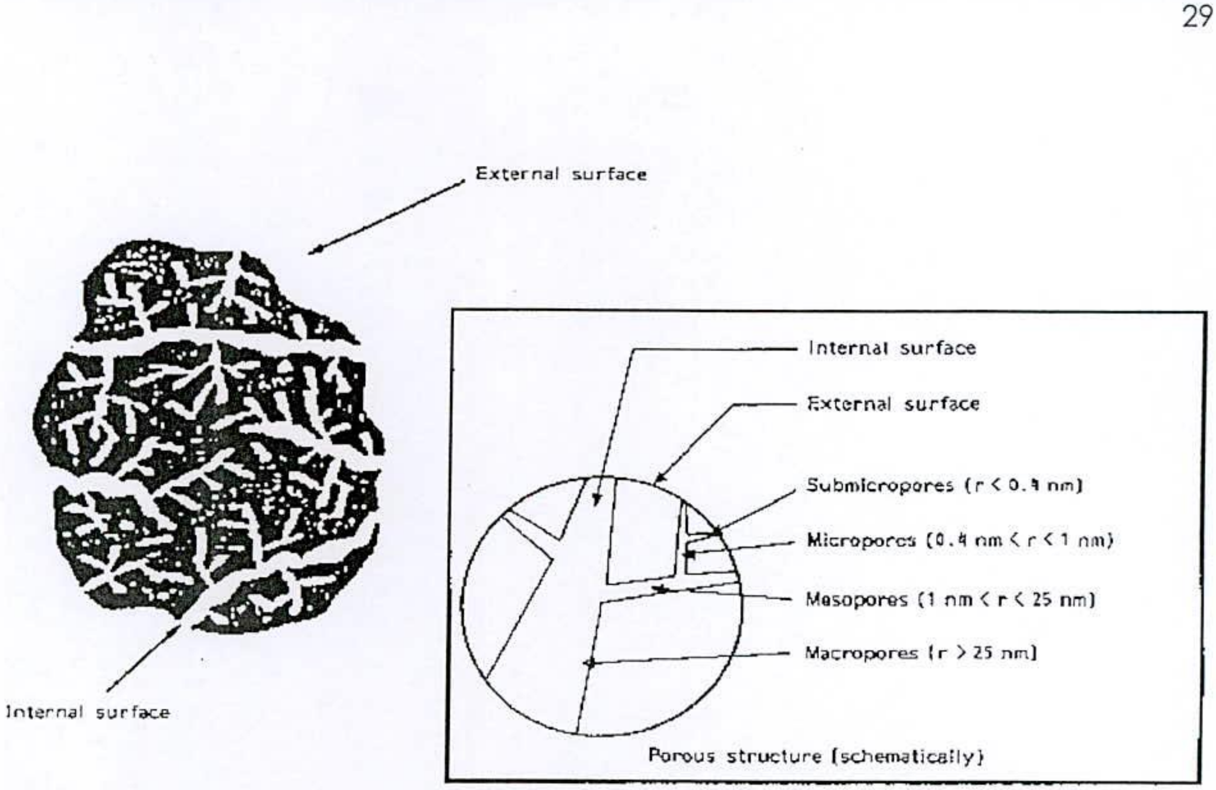


Figure 2.4: Schematic activated carbon model (http://www.activated-carbon.com)

2.5.3.1 Iodine number

Many carbons preferentially adsorb small molecules. Iodine number is the most fundamental parameter used to characterize activated carbon performance. It is a measure of activity level (higher number indicates higher degree of activation), often reported in mg/g (typical range 500–1200 mg/g). It is a measure of the micropore content of the activated carbon (0 to 20 Å, or up to 2 nm) by adsorption of iodine from solution. It is equivalent to surface area of carbon between 900 m^2/g and 1100 m^2/g. It is the standard measure for liquid phase applications (http://en.wikipedia.org).

Iodine number is defined as the milligrams of iodine adsorbed by one gram of carbon when the iodine concentration in the residual filtrate is 0.02 normal. Basically, iodine number is a measure of the iodine adsorbed in the pores and, as such, is an indication of the pore volume available in the activated carbon of interest. Typically, water treatment carbons have iodine numbers ranging from 600 to 1100. Frequently, this parameter is used to determine the degree of exhaustion of a carbon in use. However, this practice should be viewed with caution as chemical interactions with the adsorbate may affect the iodine uptake giving false results. Thus, the use of iodine number as a measure of the degree of exhaustion of a carbon bed can only be recommended if it has been shown to be free of chemical interactions with adsorbates and if an experimental correlation between iodine number and the degree of exhaustion has been determined for the particular application.

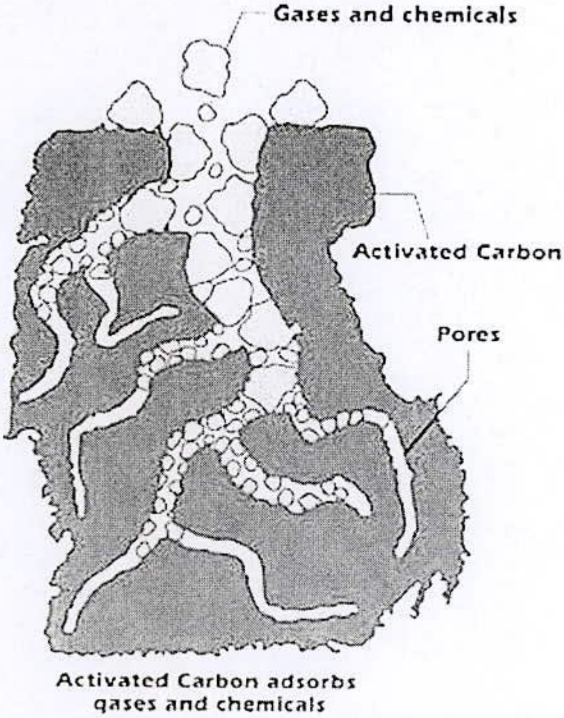


Figure 2.5: Adsorption of gases and chemicals by Activated Carbon (http://www.peakpureair.com)

2.5.3.2 Molasses

Some carbons are more adept at adsorbing large molecules. Molasses number or molasses efficiency is a measure of the mesopore content of the activated carbon (greater than 20 Å, or larger than 2 nm) by adsorption of molasses from solution. A high molasses number indicates a high adsorption of big molecules (range 95–600). Caramel dp (decolorizing performance) is similar to molasses number. Molasses efficiency is reported as a percentage (range 40%–185%) and parallels molasses number (600 = 185%, 425 = 85%). The European molasses number (range 525–110) is inversely related to the North American molasses number (http://en.wikipedia.org).

Molasses Number is a measure of the degree of decolorization of a standard molasses solution that has been diluted and standardized against standardized activated carbon. Due to the size of color bodies, the molasses number represents the potential pore volume available for larger adsorbing species. As the entire pore volume may not be available for adsorption in a particular waste water application, and as some of the adsorbate may enter smaller pores, it is not a good measure of the worth of a particular activated carbon for a specific application. Frequently, this parameter is useful in evaluating a series of active carbons for their rates of adsorption. Given two active carbons with similar pore volumes for adsorption, the one having the higher molasses number will usually have larger feeder pores resulting in more efficient transfer of adsorbate into the adsorption space.

2.5.3.3 Tannin

Tannins are a mixture of large and medium size molecules. Carbons with a combination of macropores and mesopores adsorb tannins. The ability of a carbon to adsorb tannins is reported in parts per million concentrations (range 200 ppm–362 ppm) (http://en.wikipedia.org).

2.5.3.4 Methylene blue

Some carbons have a mesopore (20 Å to 50 Å, or 2 to 5 nm) structure which adsorbs medium size molecules, such as the dye methylene blue. Methylene blue adsorption is reported in g/100g (range 11–28 g/100g) (http://en.wikipedia.org).

2.5.3.5 Dechlorination

Some carbons are evaluated based on the dechlorination half-value length, which measures the chlorine-removal efficiency of activated carbon. The dechlorination half-value length is the depth of carbon required to reduce the chlorine level of a flowing stream from 5 ppm to 3.5 ppm. A lower half-value length indicates superior performance (http://en.wikipedia.org).

2.5.3.6 Apparent density

Higher density provides greater volume activity and normally indicates better quality activated carbon (http://en.wikipedia.org).

2.5.3.7 Bulk density

The bulk density of activated carbon is 20 pounds per cubic foot (http://www.mpd-inc.com) or 0.32 g/cc (http://www.asiinstr.com).

2.5.3.8 Hardness/abrasion number

It is a measure of the activated carbon's resistance to attrition. It is an important indicator of activated carbon to maintain its physical integrity and withstand frictional forces imposed by backwashing, etc. There are large differences in the hardness of activated carbons depending on the raw material and activity level (http://en.wikipedia.org).

2.5.3.9 Ash content

It reduces the overall activity of activated carbon. It reduces the efficiency of reactivation. The metal oxides (Fe_2O_3) can leach out of activated carbon resulting in discoloration. Acid/water soluble ash content is more significant than total ash content. Soluble ash content can be very important for aquarists, as ferric oxide can promote algal growths; a carbon with low soluble ash content should be used for marine, freshwater fish and reef tanks to avoid heavy metal poisoning and excess plant/algal growth (http://en.wikipedia.org).

2.5.3.10 Carbon tetrachloride activity

Measurement of the porosity of an activated carbon by the adsorption of saturated carbon tetrachloride vapor is achieved (http://en.wikipedia.org).

2.5.3.11 Particle size distribution

The finer the particles size of an activated carbon, the better the access to the surface area and the faster the rate of adsorption kinetics. In vapor phase systems this needs to be considered against pressure drop, which will affect energy cost. Careful consideration of particle size distribution can provide significant operating benefits (http://en.wikipedia.org).

2.5.4 Application of Activated Carbon

The application of activated carbon covers a wide spectrum of systems such as air purification, water and wastewater treatments, and food, beverage, pharmaceutical and chemical industries (Marsh, 2001 and Moreno-Castilla, 2004). It has been recently extended to in-situ stabilization of marine and freshwater sediments contaminated by polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) (Zimmerman et al. 2004 and Werner et al. 2005). The aqueous concentrations and bioavailability of the organic contaminants could be significantly reduced by adsorption of contaminants on activated carbon. Activated carbon is commonly manufactured from coal, wood, peat, petroleum coke, and coconut shells. For instance, Calgon Filtrasorb® 400 (F400), a widely used commercial activated carbon, is produced from metallurgical-grade bituminous coal. In view of widespread engineering application and high efficacy of activated carbon, an attempt to convert organic waste materials with high carbon content into activated carbon is gaining popularity, because wastes that are otherwise disposed can be recycled and the raw materials for activated carbon production can be conserved for other purposes.

Activated carbon is used in gas purification, gold purification, metal extraction, water purification, medicine, sewage treatment, air filters ingas masks and respirators, filters in compressed air and many other applications. One major industrial application involves use of activated carbon in the metal finishing field. It is very widely employed for purification of electroplating solutions. For example, it is a main purification technique for removing organic impurities from bright nickel plating solutions. A variety of organic chemicals are added to plating solutions for improving their deposit qualities and for enhancing properties like brightness, smoothness, ductility, etc. Due to passage of direct current and electrolytic reactions of anodic oxidation and cathodic reduction, organic additives generate unwanted break down products in solution. Their excessive build up can adversely affect the plating quality and physical properties of deposited metal. Activated carbon treatment removes such impurities and restores plating performance to the desired level (http://en.wikipedia.org).

Activated carbon adsorption has proven to be more versatile and cost-effective in removing a variety of dyes from industrial wastewater than other technologies such as advanced oxidation and membrane separation (Derbyshire et al. 2001; Jain et al. 2003 and Faria et al. 2004).

2.6 Adsorption

It has been known that the surface of a liquid is in a state of strain or unsaturation due to the unbalanced or residual forces which act along the surface of the liquid. Similar to it, the surface of solid may also have residual forces or valencies. Thus the surface of a solid has a tendency to attract and to retain molecules of other species (gas or liquid) with which such surfaces come in contact. This phenomenon of surface is termed as adsorption.

In other words, adsorption is a technical term coined to denote the taking up of gas, vapor, liquid by a surface or interface.

2.6.1 Basic concept

The basic adsorption phenomena require definitions. In experimental adsorption system, the gas or vapor of a gas phase, or the solute in a solution, is called the adsorptive (when not in the adsorbed state). It is called the adsorbate when existing as an adsorbed phase within a solid and the solid referred to as adsorbent. The variation of extent of adsorption with relative pressure (P/P^0) of the adsorptive at a constant temperature, when plotted, make up the adsorption isotherm (Figure 2.6 a). The variation of extents of adsorption with temperature (T) of adsorption, at constant relative pressure, is the adsorption isobar (Figure 2.6 b). The variation of relative pressure of the adsorptive (P/P^0), with adsorption temperature (T), to maintain a constant amount of adsorbate adsorbed on the adsorbent is the adsorption isostere (Figure 2.6 c).

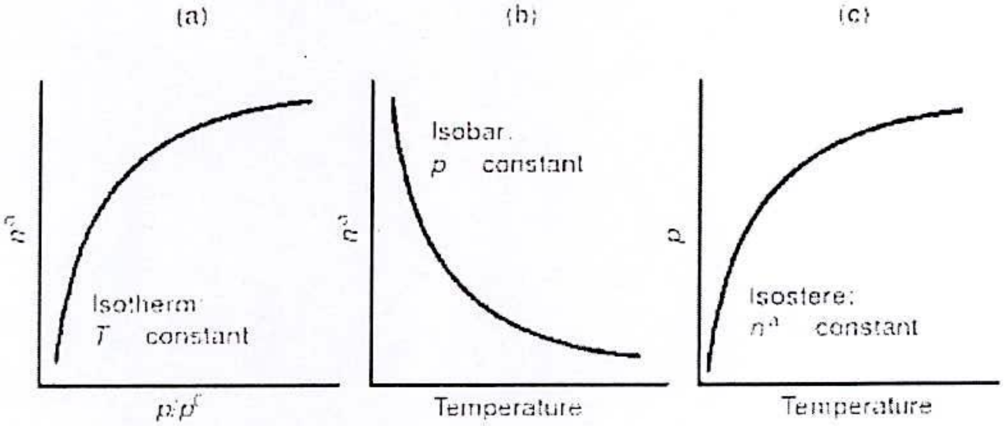


Figure 2.6: Definition of terms used to describe adsorption phenomena (Haque and Nawab, 1974)

2.6.2 Differences between Adsorption, Absorption and Sorption

Adsorption is a surface phenomenon whereas absorption is a bulk phenomenon in which the substance assimilated is uniformly distributed throughout the body of a solid or liquid to form a solution or a compound.

The phenomenon of adsorption and absorption are illustrated in Figure 2.7.

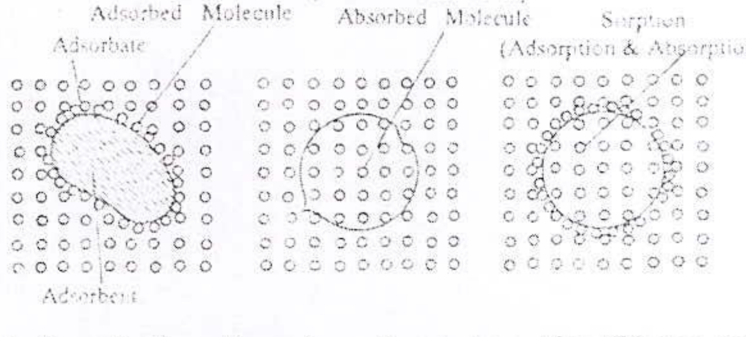


Figure 2.7: Illustration of adsorption, absorption and sorption (Haque and Nawab, 1974)

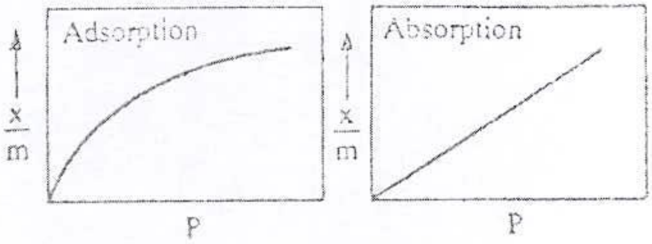
Adsorption should be distinguished carefully from absorption

(i) In absorption, the substance is distributed throughout the body of a solid or a liquid to form a solution or a compound. On the other hand, adsorption only takes place on the surface and not in the body of adsorbent. Thus, adsorption is a surface phenomenon and absorption is a bulk phenomenon.

(ii) In absorption, the concentration of the adsorbed molecules is always found to be greater in the immediate vicinity of the surface (Adsorption) than in the free phase (Adsorbate). On the contrary, adsorption involves bulk penetration of the molecules into the structure of the solid or liquid by some process of diffusion.

(iii) In case of adsorption, the equilibrium is easily attained in a very short time whereas in absorption the equilibrium takes place slowly.

(iv) Typical isotherm for adsorption and absorption shown in Figure 2.8.



(a) (b)

Figure 2.8: Typical isotherms for (a) adsorption and (b) absorption respectively

If x/m is plotted against p or c, the graph should be a straight line in adsorption [Figure 2(a)] and a typical curve for absorption as shown in the Figure 2(b) (Haque and Nawab, 1974).

2.6.3 Characteristics of Adsorption

The various characteristics of adsorption are as follows:

1. Adsorption is a spontaneous process and takes place in no time.

2. The phenomenon of adsorption can occur at all surface and five types of interfaces can exist: gas-solid, liquid-solid, liquid-liquid, solid-solid and gas-solid. The gas-solid interface has probably received the most attention in the literature and is the best understood. The liquid-solid interface is now receiving much attention because of its importance in many electrochemical and biological systems.

3. It is accompanied by a decrease in the free energy of the system, i.e., ΔG. The adsorption will continue to such an extent that ΔG continues to be negative. Eventually, magnitude of ΔG decreases to zero. When ΔG for further adsorption reaches a value for zero, adsorption equilibrium is said to be established.

4. As the process of adsorption involves loss of degree of freedom of the gas in passing from the free gas to the adsorbed film there is a decrease in the entropy of the system. It follows from the Gibbs-Helmholtz equation

$$\Delta G = \Delta H - T\Delta S$$
$$\text{or } \Delta H = \Delta G + T\Delta S$$

Where ΔG is the change in free energy, ΔH is the change in heat content, ΔS is the change in entropy and T is the temperature of the system.

As the entropy and free energy decrease in adsorption, the value of ΔH decreases. This decrease in heat constant (ΔH) appears as heat. Hence the adsorption process must always be exothermic.

2.6.4 Factors on which Adsorption depends

The phenomenon of adsorption depends upon the following factors:

(i) Nature of the adsorbent and adsorbate

The amount of gas adsorbed depends upon the nature of the adsorbent and the gas (adsorbate) which is to be adsorbed.

Gases like SO_2, NH_3, HCl and CO_2 which liquefy more easily are adsorbed more readily than the permanent gases like H_2, N_2 and O_2 which do not liquefy easily. This is because the easily liquefiable gases have greater van der Waal's or the molecular forces of attraction or cohesive forces.

As the critical temperature of the easily liquefiable gases are more than the permanent gases, it follows that higher the critical temperature o the gas (adsorption), the greater the extent of adsorption.

(ii) Surface area of the adsorbent

The extent of adsorption of gases by solids depends upon the exposed surface area of the adsorbent. It is well known that larger the surface area of the adsorbent, the large will be the extent of adsorption under given conditions of temperature and pressure. It is for this reason that silica gel and charcoal obtained from different animal and vegetable sources become activated because they posses a porous structure and thereby render a larger surface.

(iii)The partial pressure of the gas in the phase

For a given gas a given adsorbent, the extent of adsorption depends on the pressure of the gas. Adsorption of a gas is followed by a decrease of pressure. Therefore, in accordance with Le Chatelier's principle, the magnitude of adsorption decreases with the decrease in pressure and vice-versa. The variation of adsorption with pressure at constant temperature is expressed graphically by a curve known as adsorption isotherm.

(iv)Effect of temperature

For a given adsorbate and an adsorbent, the extent of adsorption depends upon the temperature of the experiment. As discussed earlier, adsorption usually takes place with the evolution of the heat. Therefore, according to Le Chatelier's principle, the decrease in temperature will increase the adsorption and vice-versa.

2.6.5 Types of Adsorption

Based on the nature of forces between the gas and the solid surface, there are two types of adsorption:

2.6.5.1 Physisorption or Physical Adsorption

If the physical forces of attraction hold the gas molecules to solid, the adsorption is known as physical adsorption or physisorption. The forces of attraction bringing about physical adsorption are:

i. Permanent dipole moment in the adsorbed molecule
ii. Polarisation
iii. Dispersion effects
iv. Short range repulsive effect

In case of physisorption, the forces of attraction which hold the gas molecules to the solid are very weak. Therefore, it is characterized by a low heat of adsorption, usually of the order of 40 kJ per mole. This value is of the same order of magnitude as the heat of vaporization of the adsorbate and lends credence to the concept of a weak 'physical' bonding. Physical adsorption is usually observed at low temperatures or on relatively 'inert' surfaces.

2.6.5.2 Chemisorption or Chemical adsorption

If the chemical forces hold the gas molecules to the surface of the adsorbent, the adsorption is known as chemisorptions. In this case the adsorbate undergoes a strong chemocal interaction with the unsaturated surface and gives rise to a high heat of adsorption, usually of the order of 400 kJ per mole. Chemisorptions is often characterized by taking place at elevated temperatures and is often an activated process. It may be dissociative, non-dissociative or reactive in nature.

2.6.6 Differences between Physisorption and Chemisorption

The various differences between Physisorption and chemisorptions are as follows:

2.6.6.1 Specificity

Physisorption are non-specific. Thus every gas is adsorbed to a lesser or a greater extent on all solid surfaces. On the other hand, chemisorptions are more specific in nature. A gas will be chemisorbed on such solids only with which it can combine chemically.

2.6.6.2 Speed

Physisorption are instantaneous. Chemisorptions may sometimes be quite slow depanding upon the nature of chemical reaction involved. A rough estimate is that adsorbable impurities of air are adsorbed by gas masks in a contact of less than 0.01 second.

2.6.6.3 Reversibility

Physisorption equilibrium is reversible and is rapidly established. Chemisorptions is irreversible. On the other hand the removal of a chemisorbed layer, however, requires much more rugged conditions such as high temperatures etc.

2.6.6.4 Heat of adsorption

Physical adsorption is generally characterized by low heats of adsorption which is about 40 kJ per mole or less. Chemisorption is characterized by high heats of adsorption, viz, 40 to 400 kJ per mole which indicates that forces are similar to those involved in chemical reactions. Therefore, it is highly probable that gas molecules from a chemical compound with the surface of the adsorbent.

2.6.6.5 Nature of the adsorbate and adsorbent

Physical adsorption like condensation can occur with any gas-solid system provided only that the conditions of temperature and pressure are suitable. The chemisorptions will take place only if the gas is capable of forming a chemical bond with the surface atoms.

2.6.6.6 Effect of pressure

As the pressure of the adsorbate increases, the rate of physical adsorption increases. The rate of chemisorptions decreases with the increase of pressure of adsorbate.

2.6.6.7 Effect of temperature

Physical adsorption occurs to an appreciable extent at temperatures close to those required for liquefaction of adsorbed gases. Generally, chemisorptions occur at high temperatures. But certain examples are known in which it occurs at low temperatures. Chemisorptions increases at first and then falls off with rising temperature.

A graph drawn between amount of adsorbed (x/m) and temperature (T) at a constant equilibrium pressure of adsorbate gas is called an adsorption isobar. Adsorption isobars of physisorption and chemisorptions show one important difference (Figure 2.9) and this difference is used for experimentally distinguishing chemisorptions from physisorption. While the physical adsorption isobar shows a decrease in x/m along the rise in temperature, the chemisorptions isobar shows an initial increase shows that, like the chemical reactions, chemisorptions also needs activation energy. However, the latter decrease indicates that at higher temperature desorption does occur in chemisorptions process. Frequently during the high temperature desorptions the evolved gas carries with it some atoms of the adsorbent as well in a chemically bound form.

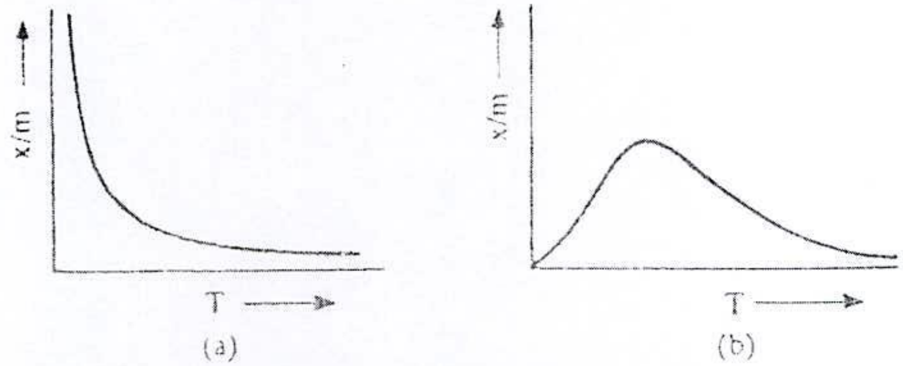


Figure 2.9: Adsorption isobars: (a) Physical adsorption, (b) chemisorptions (Haque and Nawab, 1974)

2.6.7 Types of adsorption curves

The magnitude of adsorption depends on the pressure of the gas and the temperature of the experiment for a given gas and a given adsorbent. Hence, the amount of the gas adsorbed is a function of temperature and pressure only. Mathematically, it can be expressed as

$$a = f(\mathrm{P},\mathrm{T})$$

where a is the amount of gas adsorbed, P is the pressure and T is the temperature.

Adsorption Isotherm

If the temperature is kept constant and pressure is changed, the curve between a and p is known as adsorption isotherm.

$a = f(p)$ if T is constant

Adsorption Isobar

If pressure is kept constant and temperature is varied, the curve between a and T is called Isobar.

$a = f(\mathrm{T})$ if p is constant

Adsorption Isostere

If the amount adsorbed is kept constant, the curve between p and T is known as adsorption isostere.

$p = f(\mathrm{T})$ if a is constant

2.6.8 Types of Adsorption Isotherms (Physical)

Seven types of physical adsorption isotherms have been reported. These are given below in Figure 2.10.

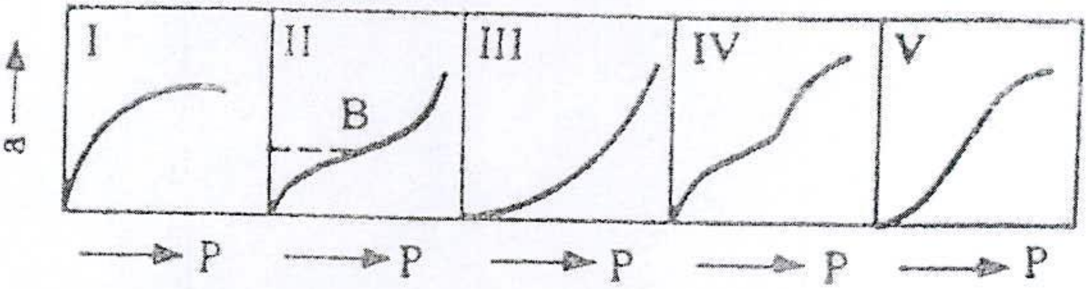


Figure 2.10: Different types of physical adsorption isotherm (Haque and Nawab, 1974)

Type I

This type of curve is obtained in such cases where mono-molecular layer is formed on the surface of adsorbent.

This curve shows that a saturation state is reached. It means that there is no change in the value of 'a' (the amount adsorbed) with the increase in pressure onwards. This type of the curve is rare. Example is the adsorption of nitrogen on charcoal at -195°C.

Type II

This type of isotherm has a transition point 'B' which represents the pressure at which the formation of monomolecular layer is complete and that of the multi-molecular layer is being started. For many years it was the practice to take point B at the knee of the curve as the point of completion of a monolayer and the surface areas obtained by the method are fairly consistent with those found using adsorbates that give type I isotherms. Example is the adsorption of nitrogen on silica gel at -195°C.

Type III

In this type of isotherm there is no transition point. In this the multi-molecular layer formation starts even before the formation of monomolecular layer is complete. An example is the adsorption of bromine or iodine vapors on silica gel at 79°C.

Type III is relatively rare and a recent example of this is that of the adsorption of nitrogen on ice. This type seems to be characterized by a heat of adsorption equal to or less than the heat of liquefaction of the adsorbate.

Type IV

In this case there is tendency for a saturation state to be reached in the multi-molecular region as well. In fact this can be regarded as a duplication of the II type. Example is adsorption of benzene vapors on ferric oxide gel at 50°C.

Type V

This isotherm indicates multi-molecular layer formation in the beginning. At higher pressure, there is a tendency for 'a' (amount adsorbed) to remain constant. It means that the saturation state has been reached. Example is the adsorption of water vapor on charcoal at 100°C.

2.7 Rice Husk

Rice husk is an agricultural residue abundantly available in rice producing countries. The annual rice husk produce in India amounts is generally approximately 12 million tons. Rice husk is generally not recommended as cattle feed since its cellulose and other sugar contents are low. Furfural and rice bran oil are extracted from rice husk. Industries use rice husk as fuel in boilers and for power generation. Among the different types of biomass used for gasification, rice husk has a high ash content varying from 18 – 20 %. Silica is the major constituent of rice husk ash and the following tables gives typical composition of rice husk and rice husk ash. With such a large ash content and silica content in the ash it becomes economical to extract silica from the ash, which has wide market and also takes care of ash disposal. Table 2.4 shows the composition of rice husk on dry basis.

2.7.1 Chemical Composition of Rice Husk

The rice husk was one of lignocelluloses material which consist of lignin, cellulose and xylon which apart of biomass material with high content of carbon and silica. The conversion of the composition and phase involves of primary decomposition of lignocellulosic matrix that is composed of three interconnected polymeric materials: cellulose, hemicellulose, and lignin. The pyrolysis process will form high carbon content with deformation on the surface condition (surface area). Table 2.5 shows the theoretical percent of cellulose, hemicellulose and lignin compound in virgin rice husk.

Table 2.4: Composition of Rice husk on dry basis (http://cgpl.iisc.ernet.in)

Element	Mass Fraction %
Carbon	41.44
Hydrogen	4.94
Oxygen	37.32
Nitrogen	0.57
Silicon	14.66
Potassium	0.59
Sodium	0.035
Sulfur	0.3
Phosphorous	0.07
Calcium	0.06
Iron	0.006
Magnesium	0.003

Table 2.5: Percent of Compound in Rice Husk (http://cgpl.iisc.ernet.in)

Material	Cellulose	Hemicellulose	Lignin	Extra.
Rice husks	30	25	12	18

CHAPTER THREE
METHODOLOGY

3.1 General

The research was mainly done by three steps. These steps are as follows:

1. Development of furnace and production of Activated Carbon
2. Characterization of Produced Activated Carbon
3. Treatment of textile wastewater

A brief description of the methodology that was followed in concluding the laboratory study and field application is given below.

3.2 Development of furnace and production of Activated Carbon

Three different types of model furnace were made. These furnaces were classified as Type A, Type B, Type C. These classifications were made on the basis of the capacity of the raw material that may be used in the production at a time. The furnaces were fabricated and examined in the laboratory. Several batch tests were carried out in each furnace to obtain optimum condition of the production of the Activated Carbon. Economical analysis in terms of cost-benefit ratio was studied for the Production of Activated Carbon.

3.3 Characterization of Produced Activated Carbon

Activated carbon produced in the laboratory from rice husk is named here as Produced Rice Husk Activated Carbon (PRHAC). Detailed characterization of PRHAC was studied. To study the characteristics the following parameter were analyzed:

- Ash content determination of PRHAC
- Moisture content determination of PRHAC

- Volatile content determination of PRHAC
- Fixed carbon determination of PRHAC
- Adsorption studies
    - *Kinetic study*
    - *Effect of temperature on adsorption*
    - *Effect of adsorbent dose and equilibrium study for Isotherm*
- Column studies
- Scanning Electron Microscopic (SEM) photograph

3.4 Proximate analysis of activated carbon

The volatile content, moisture content, ash content and fixed carbon content were determined as follows:

3.4.1 Moisture content determination

1g activated carbon was taken in a capsule. Then the capsule was placed in a preheated oven (100 to 105°C) for 24 hours. The capsule and its content was retrieved and cooled in room temperature. The moisture content determined from (Aloko et al., 2007):

$$\text{Moisture content (MC)} = [(A-B)/A]*100$$

Where,

A = Weight of wet sample
B = Weight of dried sample

3.4.2 Volatile content determination

1g activated carbon was taken in closed porcelain crucible and then the sample was heated at about 550 °C for 7 min in a muffle furnace. The crucible and its content was retrieved and cooled in desiccators. The volatile content was determined from (Aloko et al., 2007):

$$\text{Volatile content} = [(A-B)/A]*100$$

Where,

A = Weight of dried sample

B = Weight of burnt sample

3.4.3 Ash content determination

1g activated carbon was taken in porcelain crucible and then heated the sample at about 750 °C for at least one hour in a muffle furnace. The crucible and its content was retrieved and cooled in room temperature. The ash content was determined from (Aloko et al., 2007) :

$$\text{Ash content} = (B/A)*100$$

Where,

A = Weight of dried sample

B = Weight of burnt sample

3.4.4 Fixed carbon determination

The Fixed Carbon content (FC) is determined as (Aloko et al., 2007) :

$$\text{Fixed carbon content} = 100 - VC - MC - Ash$$

Where,

VC = Volatile content (%)
MC = Moisture content (%)
Ash = Ash content (%)

3.5 Sample preparation

The experimental sample solutions were prepared by dissolving 24 mg of methylene blue in 1000 mL distilled water i.e. 24 mg/L to produce color of 450-500 Pt-co.

3.6 Adsorption studies

All batch adsorption studies were conducted with 3 numbers of 100 mL experimental samples (in triplicate) in 250 mL capacity conical fluxes.

3.6.1 Kinetic study

In conical fluxes, 100 mL of each experimental sample was taken and 0.5, 1.0, 1.5 and 2.0 gm of each of PRHAC were added to every flux. The contents in fluxes were then subjected to mixing in an orbital shaker at 200 rpm. At every 5 minutes time interval, samples were withdrawn and percentages transmittance of filtered sample was determined using spectrophotometer at 455 nm wavelength.

3.6.2 Effect of temperature on adsorption

In Conical fluxes, 100 mL of each experimental sample was taken and 2.0 g each of PRHAC was added every flux. Effect of temperature on adsorption was studied at different temperatures of 30 °C, 32.5 °C, 35 °C, 37.5 °C, 40 °C, 42.5 °C, 45 °C, 50 °C, 55 °C and 60 °C. At specified temperature, the bottles were mixed in an orbital environmental shaker at 200 rpm till maximum time for adsorption was attained. Percent transmittance of each filtered sample for each temperature studied was measured.

3.6.3 Effect of adsorbent dose and equilibrium study for Isotherm

A series of studies of volume 100 mL were taken in conical fluxes for optimum color adsorption. Predetermined dose in gm of activated carbon as 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25, 1.30, 1.35, 1.40, 1.45, 1.50, 1.55, 1.60, 1.65, 1.70, 1.75, 1.80, 1.85, 1.90, 1.95, 2.00, 2.05, 2.10, 2.15, 2.20 and 2.25 were added into the fluxes. The contents of fluxes were subjected to mixing in an orbital shaker at 200 rpm for maximum adsorption time (equilibrium time) at predetermined optimum temperature. Percent transmittances of sample for each dose of activated carbon were measured.

3.7 Column studies

Column studies were conducted in a glass column of 50 cm length and 1.25 cm inner diameter. In this study, effect of varying bed depth of activated carbon on color removal using methylene blue solution was studied, with the bed depth as 10 cm, 20 cm and 30 cm. The PRHAC was packed according to the above depths, respectively in column with a cotton packing at the bottom. The cotton packing was provided to retain the PRHAC inside the column and to filtrate the sample after absorbed by the PRHAC. Activated carbon weighing 2.5 g, 5.0 g and 7.5 g was found to suffice the above mentioned bed depths. For 10 cm packing of adsorbent the flow rate was adjusted to 6 mL/minute and for 20 and 30 cm packing, the flow rate was adjusted to 2.6

mL/minute. Sample was collected at every 10 minutes time interval for 20 and 30 cm bed depths and 5 minutes time interval for 10 cm bed depth.

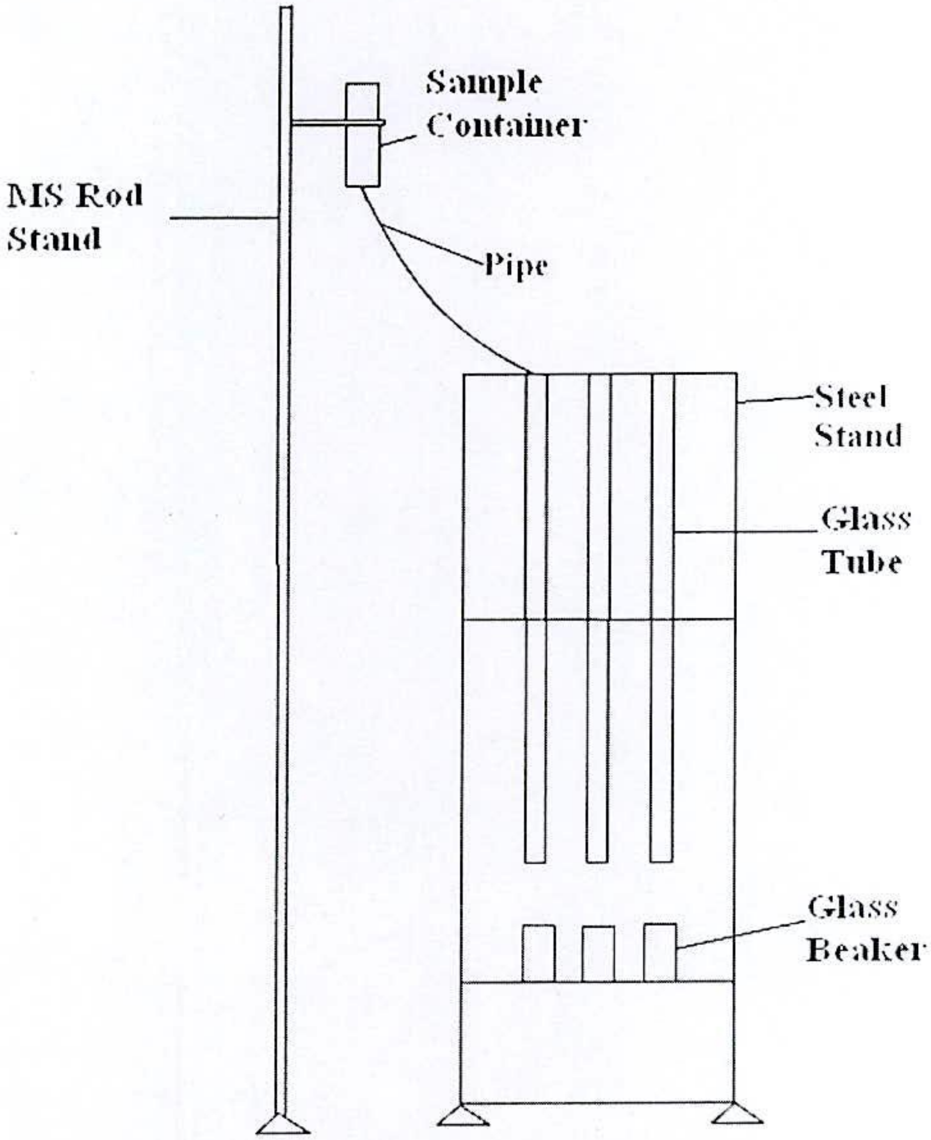
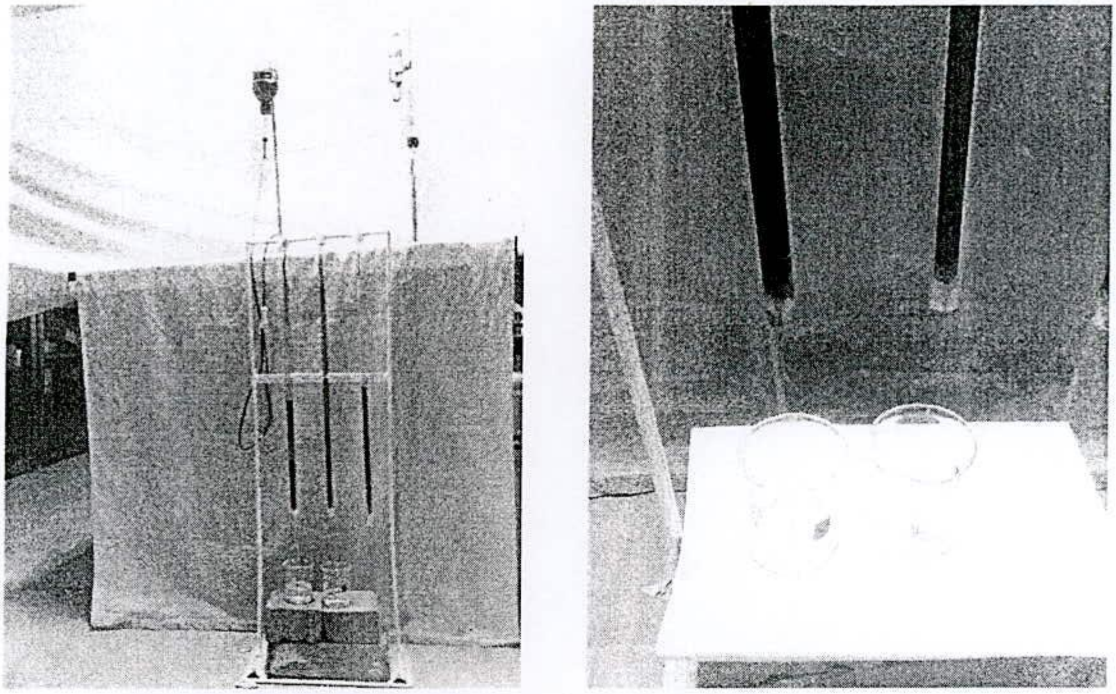


Figure 3.1: Schematic diagram of column setup



(a) Column setup (b) Clear water after pass through column

Figure 3.2: Experimental set-up of Column test

3.8 Treatment of textile wastewater

In final step the effectiveness of the produced Activated Carbon for the treatment of textile wastewater were studied. Combination of different treatment options like sedimentation, filtration, coagulation and adsorption with Activated Carbon were studied in batch process.

3.9 Batch tests to treat textile wastewater

Series of eight batch tests were conducted to evaluate the effective option. Each batch tests consist of several selected unit processes. The treatment options are given in Figure 3.3.

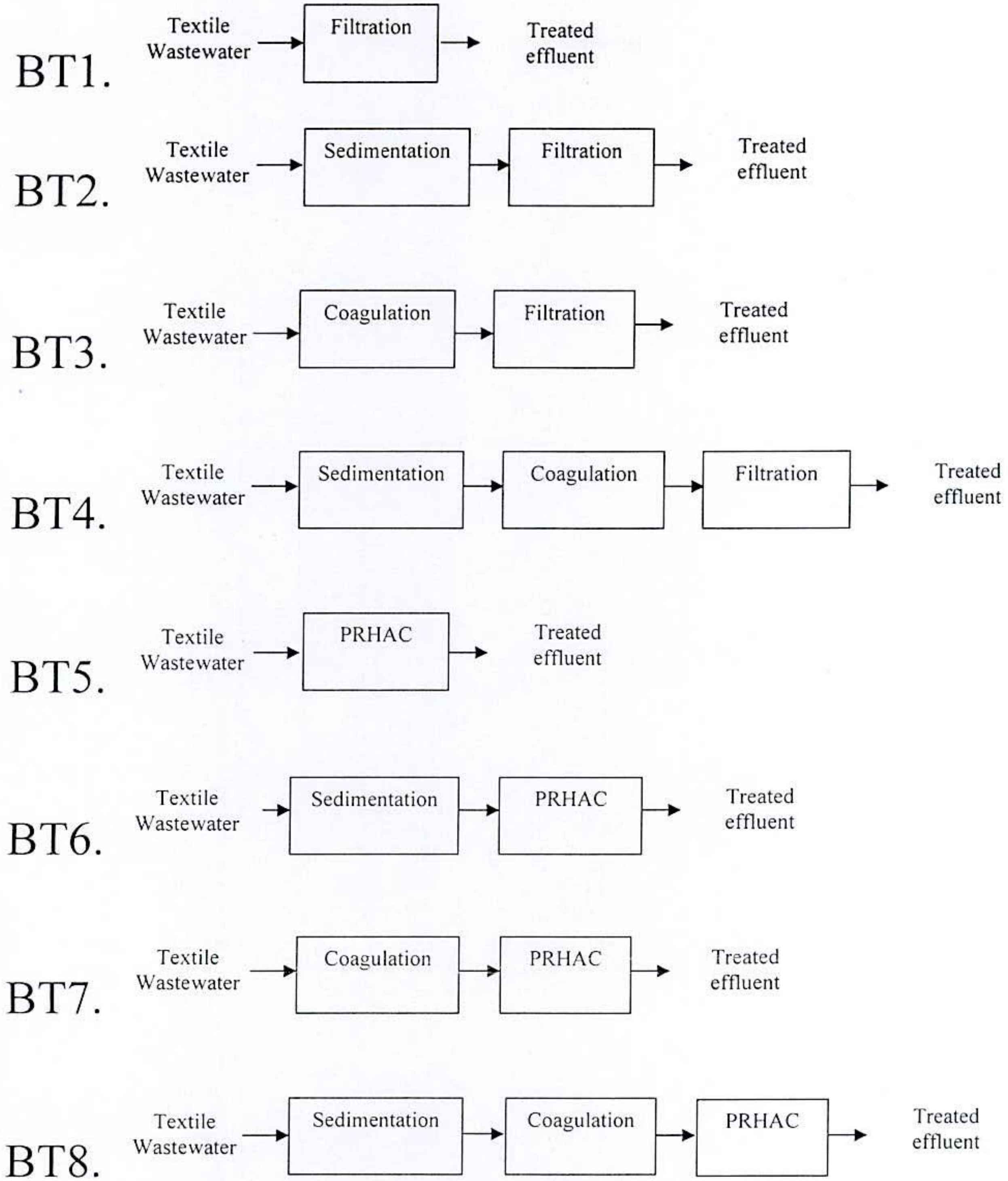


Figure 3.3: Experimental program of batch test combinations

For sedimentation unit the wastewater was retained for 1 hour in a jar. After that the clear effluent from the top of the sedimentation unit was collect for test. For coagulation unit, $FeCl_3$ was used as coagulant. The coagulant dose was used as 4.0 g/L and with 500 mL wastewater. Then the wastewater is subjected to rapid mixing for 1 minute and after that 30 minutes slow mixing. Then the wastewater was retained for 60 minutes. After 60 minutes the clear effluent from sedimentation unit was collected for further test. For filtration unit, course sand filter was used. The wastewater passes through the sand filter was collected in separate beaker. For activated carbon adsorption unit, 8 g activated carbon was mixed in 100 mL wastewater for 60 minutes in 40 °C. Then the mixed wastewater was filtered in Whatman filter paper and collected the effluent.

3.10 Fabrication of Furnace

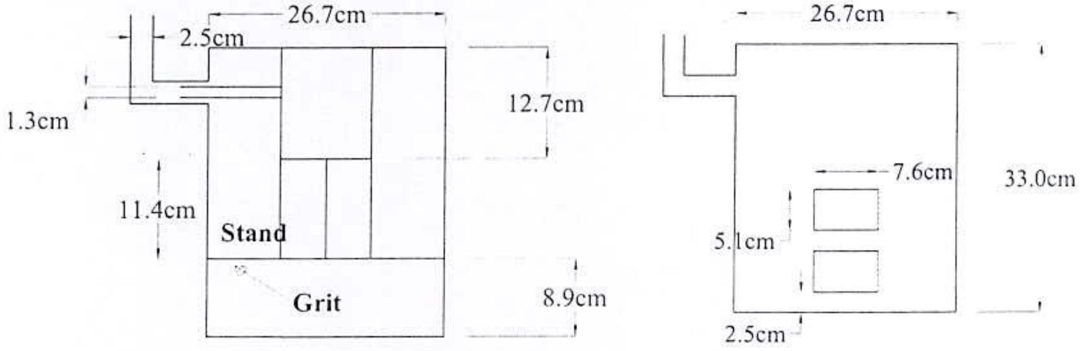
Three selected types were fabricated to compare different aspects of the furnaces to produce AC economically. The types were varied in the capacity of input materials that can be used to prepare activated carbon at a time. They were designated as Type A, Type B and Type C. Different steps of the fabrication of furnace shown in Figure 3.10.

3.10.1 Type A Furnace

The materials needed for producing Type A Furnace are given below:

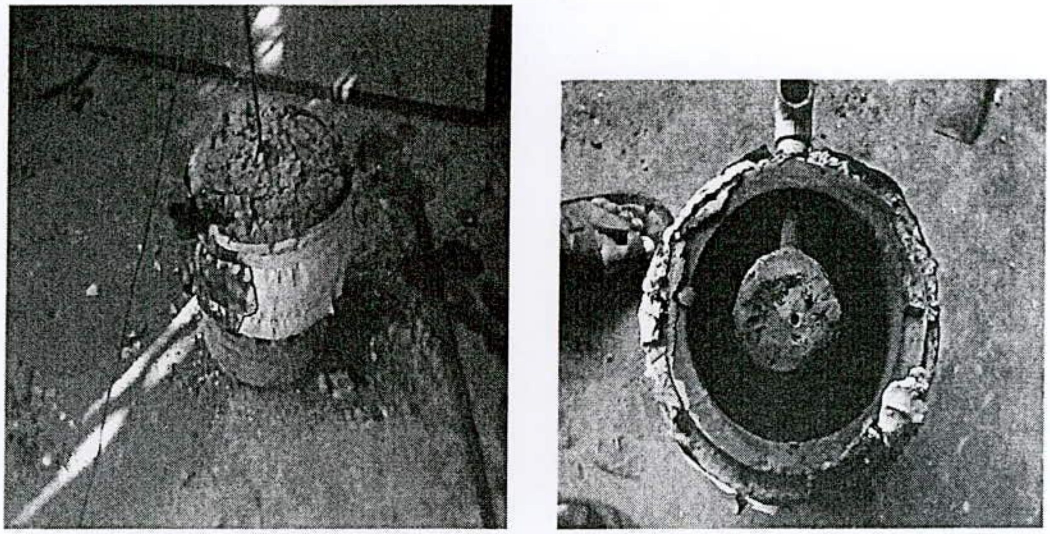
a) 1.25 mm MS steel sheet
b) 1.00 mm MS steel sheet
c) Fire clay
d) 10.16 cm diameter and 12.7 cm height used steel pot
e) Weir
f) Cotton
g) 1.27 cm and 2.54 cm diameter steel pipe
h) Wielding rod

Type A was a small furnace as shown in Figure 3.5. This was made of 1.25 mm MS steel sheet. Two MS steel sheet were bent in a circular form and connected with each other. The void spaces between these sheets were filled with fire clay which worked as an insulator. The furnace had a diameter of 26.67 cm and height of 33.02 cm with two 6.35 cm X 10.16 cm openings at the bottom side. Between these two openings grit was placed. The fuel was placed on the grit through the top opening and through the bottom opening the ash was taken out. There was another small hole of 1.27 cm diameter at the top side of the furnace was used smoke outlet. The top of the furnace was open. This opening was closed in the time of production of AC with a separate cover. A small pot with 10.16 cm in diameter and 12.7 cm in height was placed in the furnace. This pot had two openings, one at the bottom and other at the top. The bottom opening was closed with a wire net. The top opening was joined with the furnace top side opening.



(a) Cross-Section (b) Front View

Figure 3.4: Schematic diagram of Type A Furnace



(a) Front view of Furnace **(b)** Top view of Furnace

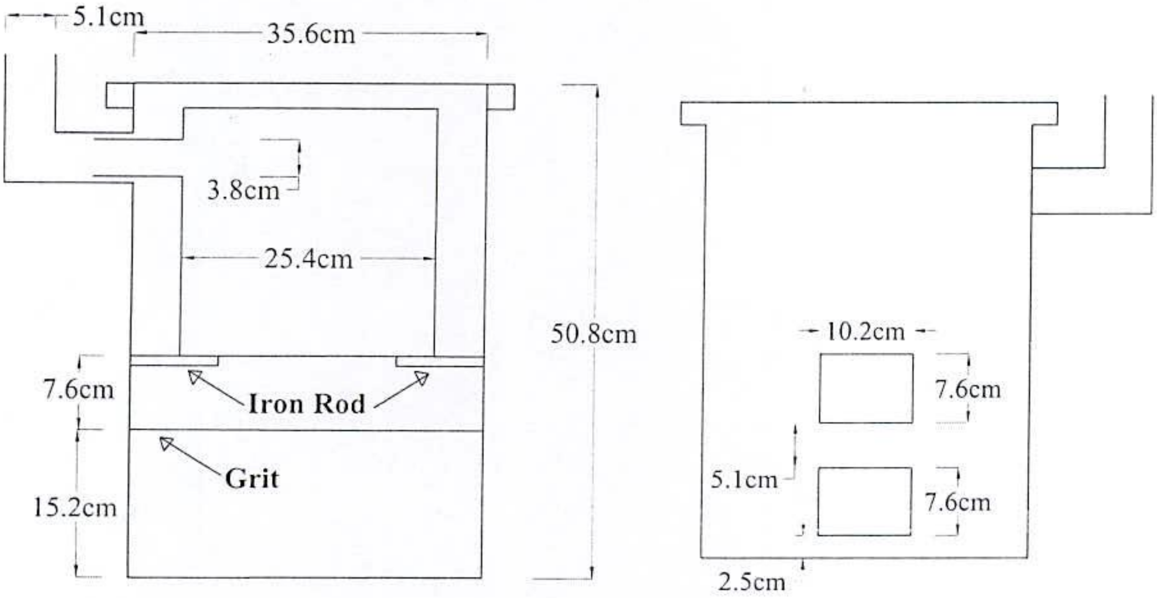
Figure 3.5: Type A furnace

3.10.2 Type B Furnace

The materials needed for producing Type B Furnace are given below:

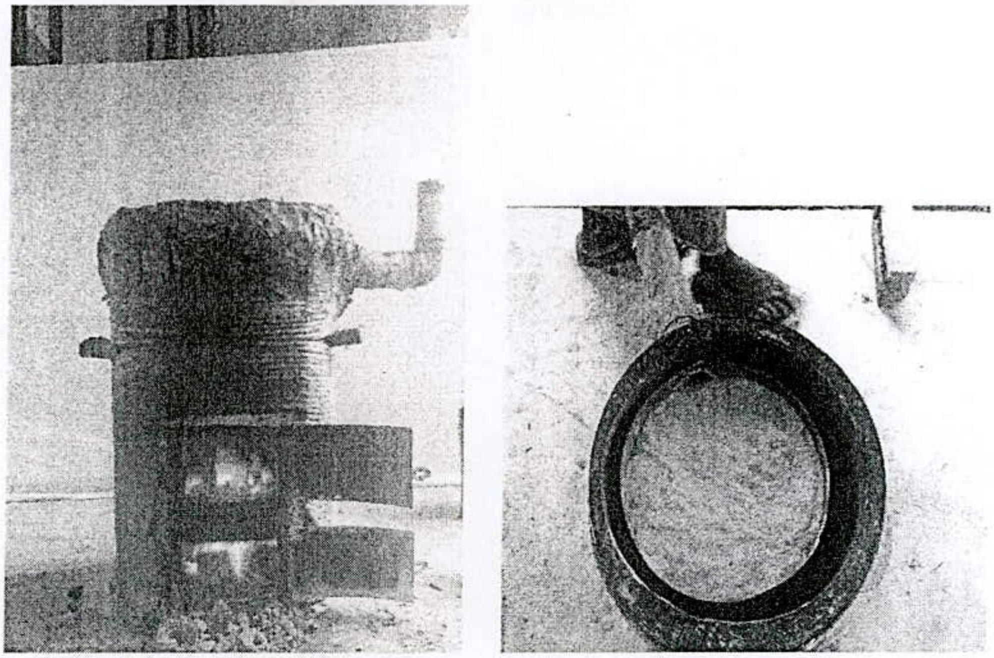
a) 1.00 mm MS steel sheet
b) 25.4 mm wide MS steel bar
c) Clay
d) Chalk powder
e) Asbestos rope
f) Weir
g) Weir net
h) 3.81 cm and 5.08 cm diameter steel pipe
i) Wielding rod

Type B was a medium furnace as shown in Figure 3.7. This was made of 1.00 mm MS steel sheet. Two MS steel sheet were bent in a circular form and connected with each other. The void spaces between these sheets were filled with clay and chalk powder mixture which worked as an insulator. The outer side of the furnace was coiled with asbestos rope. The furnace had a diameter of 35.56 cm and height of 50.8 cm with two 7.62 cm X 15.24 cm openings at the bottom side. Between these two openings grit was placed. The fuel was placed on the grit through the top opening and through the bottom opening the ash was taken out. There was another small hole of 5.08 cm diameter at the top side of the furnace used as smoke outlet. The top of the furnace was open. This opening was closed in the time of operation with a separate cover. A container with 25.4 cm in diameter and 25.4 cm in height was placed in the furnace. This container was produced with 1.00 mm MS steel sheet. This container had two openings, one at the bottom and other at the top. The bottom opening dimension was 5.08 cm X 7.62 cm. This opening was closed with a wire net. The top opening was joined with the furnace top side opening. Inside the container two trays of wire net were placed on which raw material was placed.



(a) Cross-Section (b) Front View

Figure 3.6: Schematic diagram of Type B Furnace



(a) Front view of Furnace **(b)** Top view of Furnace

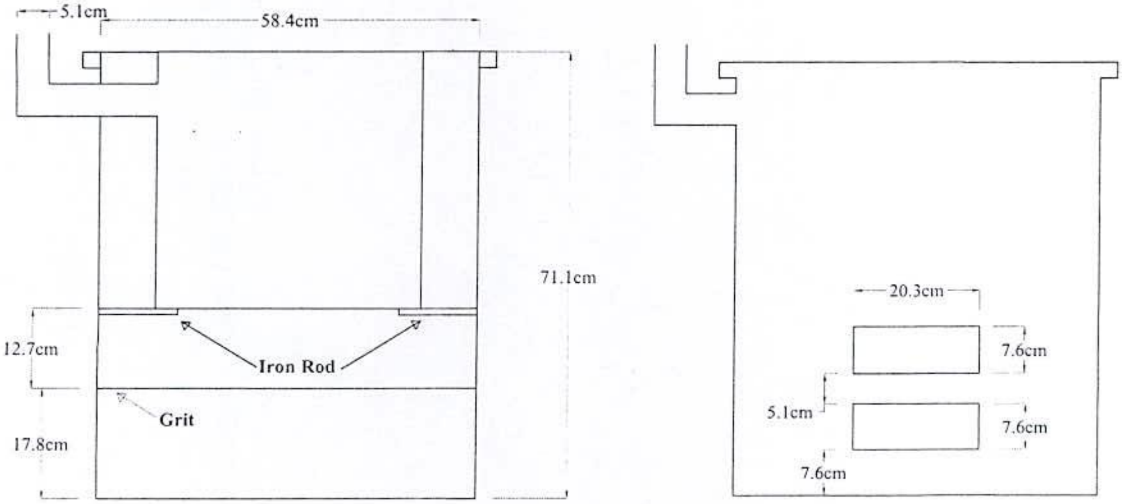
Figure 3.7: Type B furnace

3.10.3 Type C Furnace

The materials needed for producing Type C Furnace are given below:

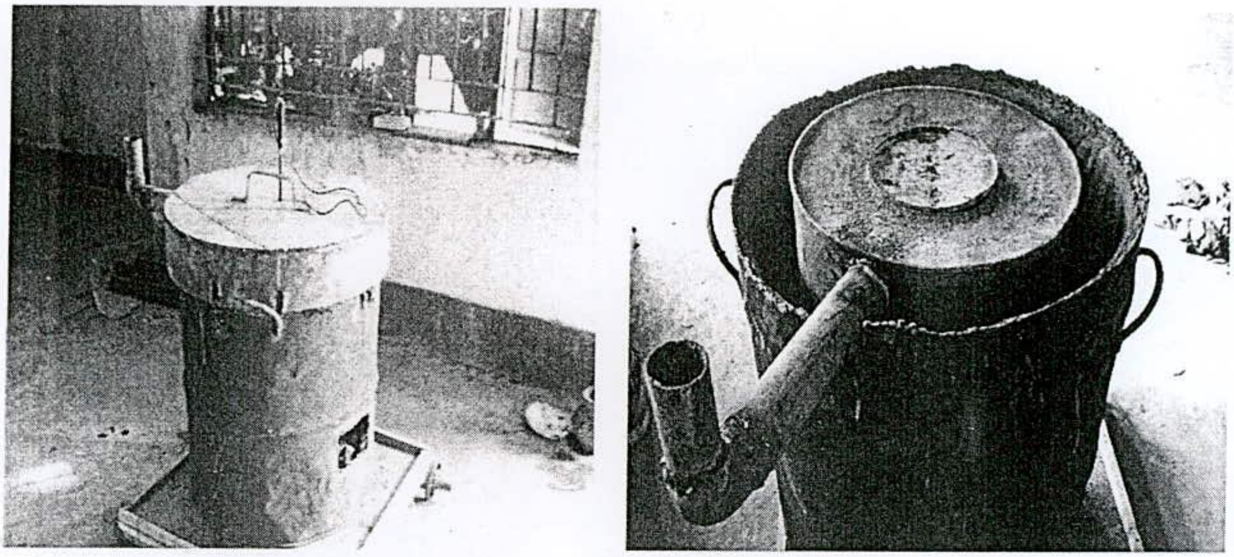
a) Drum
b) 25.4 mm wide MS steel bar
c) 10 mm MS rod
d) Rice husk
e) Clay
f) Wielding rod
g) Weir
h) Weir net
i) 3.81 cm and 5.08 cm diameter steel pipe

Type C was a large furnace as shown in Figure 3.9. This was made of 1.75 mm thick modified drum. A mixture of clay and rice husk was paint on the inner side of the drum. This mixer was used as an insulator. The furnace had a diameter of 58.42 cm and height of 71.12 cm with two 10.16 cm X 15.24 cm openings at the bottom side. Between these two openings grit was placed. The fuel was placed on the grit through the top opening and through the bottom opening the ash was taken out. There was another small hole of 5.08 cm diameter at the top side of the furnace. This was used to take out the smoke from furnace. The top of the furnace was open. This opening was closed in the time of operation with a separate cover made of 1.00 mm MS steel. A small drum with 40.64 cm in diameter and 40.64 cm in height was placed in the furnace. This drum had two openings, one at the bottom and other at the top. The bottom opening was closed with a wire net. The top opening was joined with the furnace top side opening.



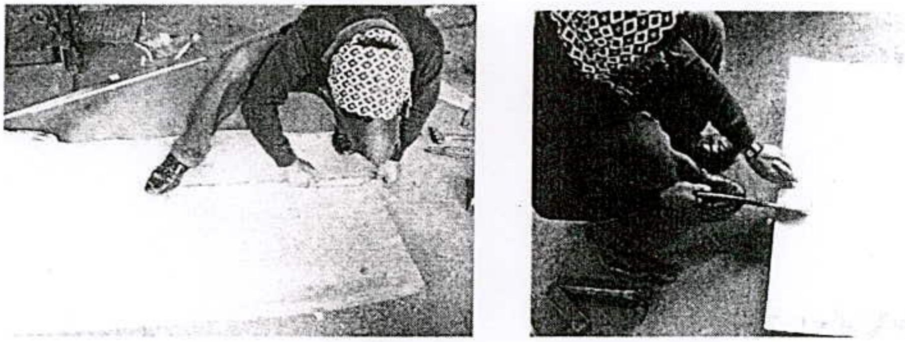
(a) Cross-Section (b) Front View

Figure 3.8: Schematic diagram of Type C Furnace

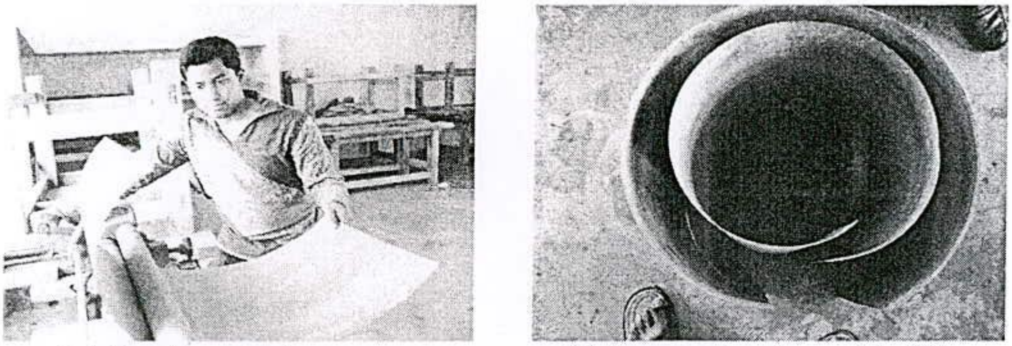


(a) Front view of Furnace **(b)** Top view of Furnace

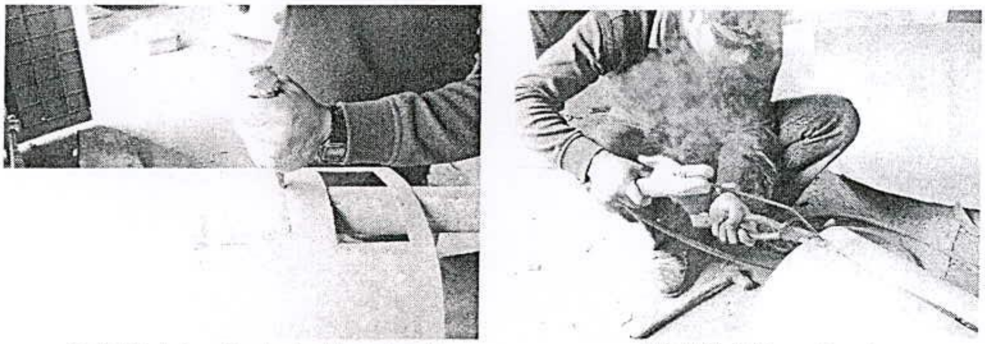
Figure 3.9: Type C furnace



(a) Measuring sheet (b) Cutting sheet



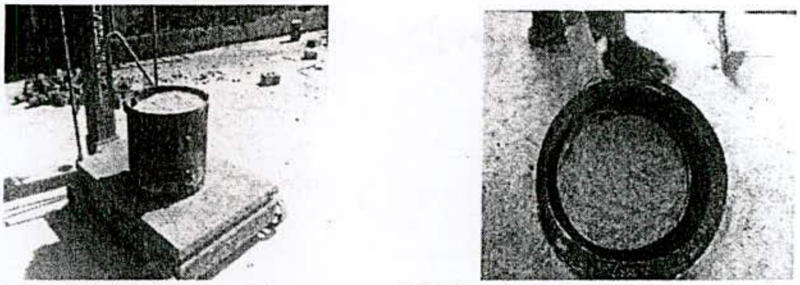
(c) Bending sheet (d) Inner and outer mold of furnace



(e) Making hole in the sheet (f) Wielding sheet

(g) Setting of furnace

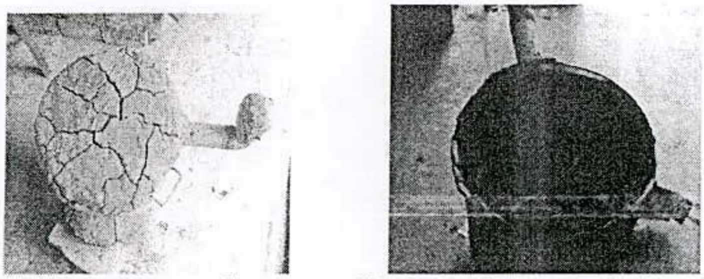
Figure 3.10: Different stage of furnace fabrication



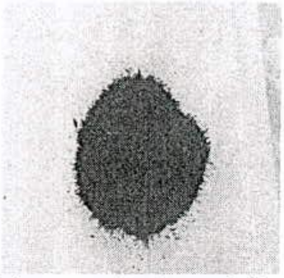
(a) Weight the container (b) Placing the container in furnace

(c) Seal the container (d) Seal the furnace

(e) Heat the furnace (f) Seal the furnace openings

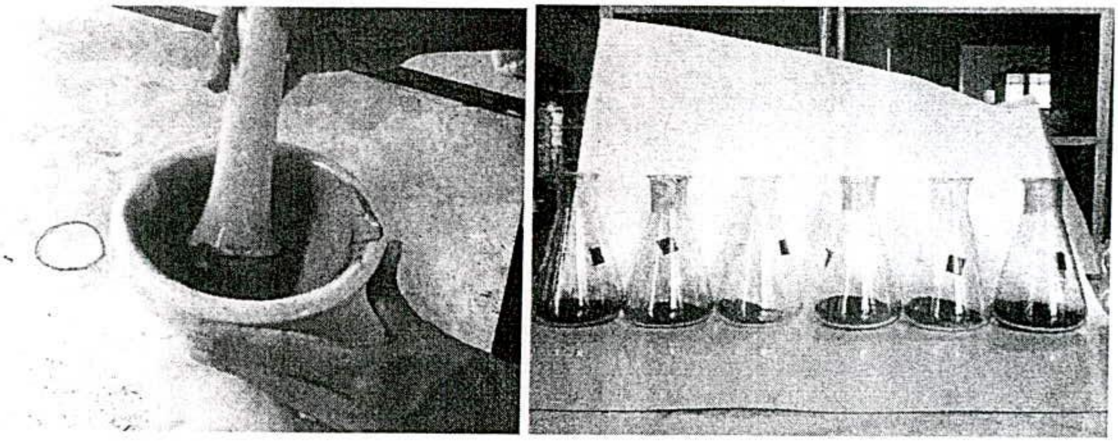


(g) Keep for cooling (h) Open furnace after cooling

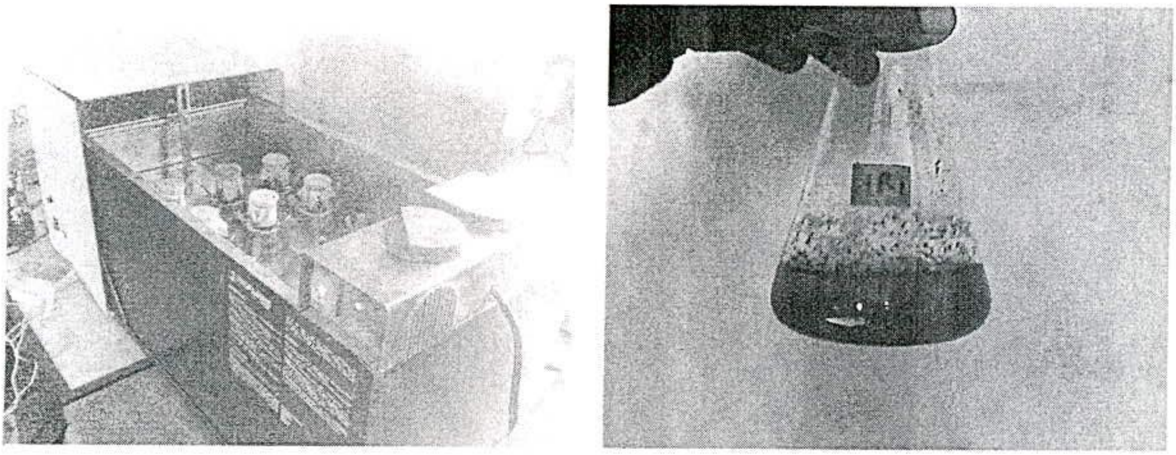


(i) Bring out Activated Carbon

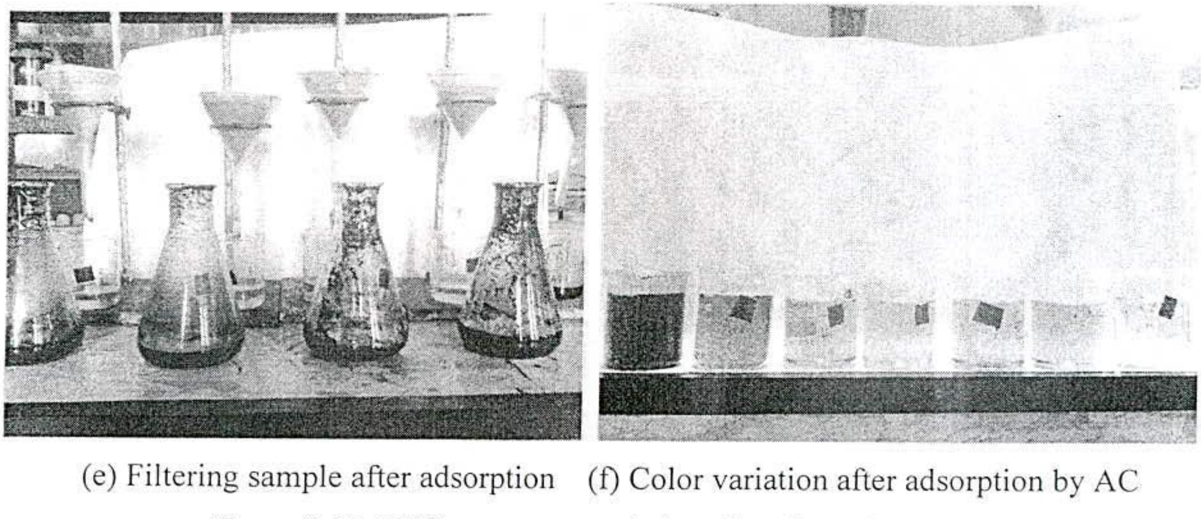
Figure 3.11: Different steps in production of Activated carbon



(a) Crushing of AC (b) Weighted AC in conical flux



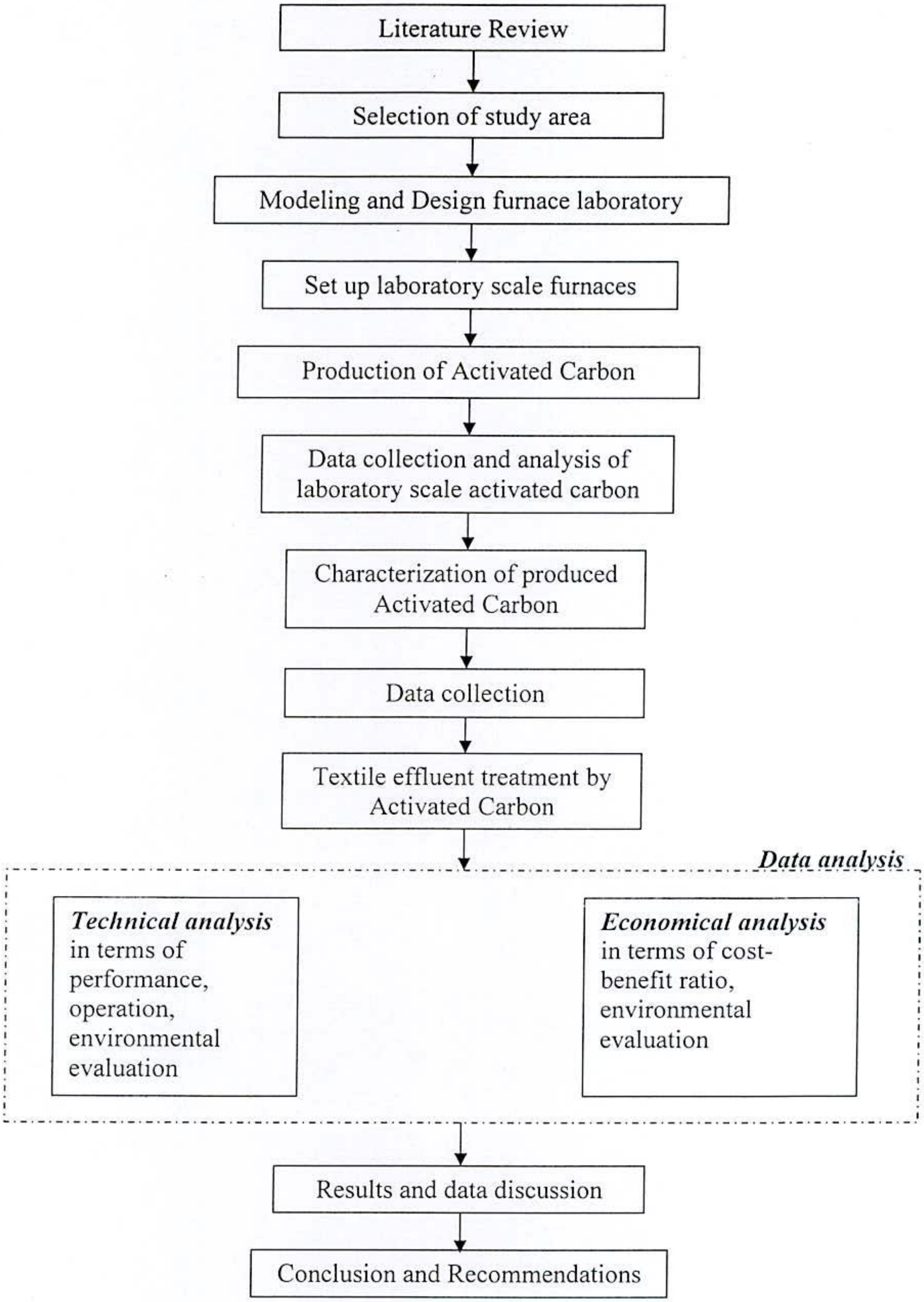
(c) Adsorption study in water bath (d) Sample with AC after adsorption



(e) Filtering sample after adsorption (f) Color variation after adsorption by AC

Figure 3.12: Different steps carried on the adsorption study

3.11 Research framework



CHAPTER FOUR

PRODUCTION OF ACTIVATED CARBON

4.1 General

Muffle furnace and horizontal/vertical tube furnace are usually used to producing activated carbon mostly. These instruments can rise about 1200 °C temperature. Production of activated carbon in these instruments is expensive due to the expensive cost of instrument. Large scale production of activated carbon is not possible by this instrument. Production of activated carbon needs at least 400 °C temperature (Abdullah et al., 2001). For this reason low cost furnaces were fabricated. These furnaces can rise temperature above 400 °C which is favorable to prepare activated carbon and also can produce large amount of activated carbon.

4.2 Production of Activated Carbon

Several batch experiments were carried out in each type of furnace. In each batch different conditions were applied to find out optimum condition of producing activated carbon.

4.2.1 Activated Carbon produced in Type A Furnace

The following are the general steps applied in producing Activated Carbon in Type A Furnace

a) First the small pot was filled with raw material. The capacity of the pot was around 0.250 kg.
b) Then the top of the pot was closed and sealed with clay.
c) Next the pot was placed in the furnace.
d) Then the cover of the furnace was closed and also sealed with clay.
e) The fuel was placed on the grit and burning started. When the process was going on the smoke produced in the furnace entered the pot through the bottom opening and passed

out through the top opening which was connected with smoke outlet. This heated air and the produced heat were used for producing activated carbon.

f) A digital thermometer was placed inside the pot to record the inside temperature. The furnace was fueled until the furnace temperature reached above 500 °C and maintained the furnace temperature above 500 °C for about 2 hours.

g) The smoke came out from the furnace and was also observed. Initially the smoke color was black.

h) When the smoke color turned into white, all the openings were sealed with clay. The outlet temperature was observed as 82 °C when white smoke came out.

i) Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon.

Batch 1of Type A Furnace

This batch was conducted on September 07, 2009. 250 gm rice husk was collected in a 10.16 cm diameter small pot. The rice husk was in compacted condition in the pot. Then the pot was closed, sealed and put in the furnace. Then the cover of the furnace was closed and also sealed with clay. A digital thermometer was placed inside the pot from the top cover of the furnace to measure the temperature. Then the fuel was placed on the grit and started burning. When the Process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passes out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 1.5 hours. The highest temperature was recorded 474 °C. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white, all the openings including the smoke outlet were sealed with clay. Then the sealed furnace was kept for 24 hours and after that it was opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

Only 78.5 gm activated carbon was found from this batch experiment which is 31.4% of the raw material of 250 gm. The rice husk was finely burnt and produced good quality activated carbon. As fuel of 5.3 kg firewood and 100 mL of oil were used. The temperature variation is shown in Figure 4.1. The production cost is found to be 478 BDT per kg. Detailed cost analysis is shown in Appendix A.

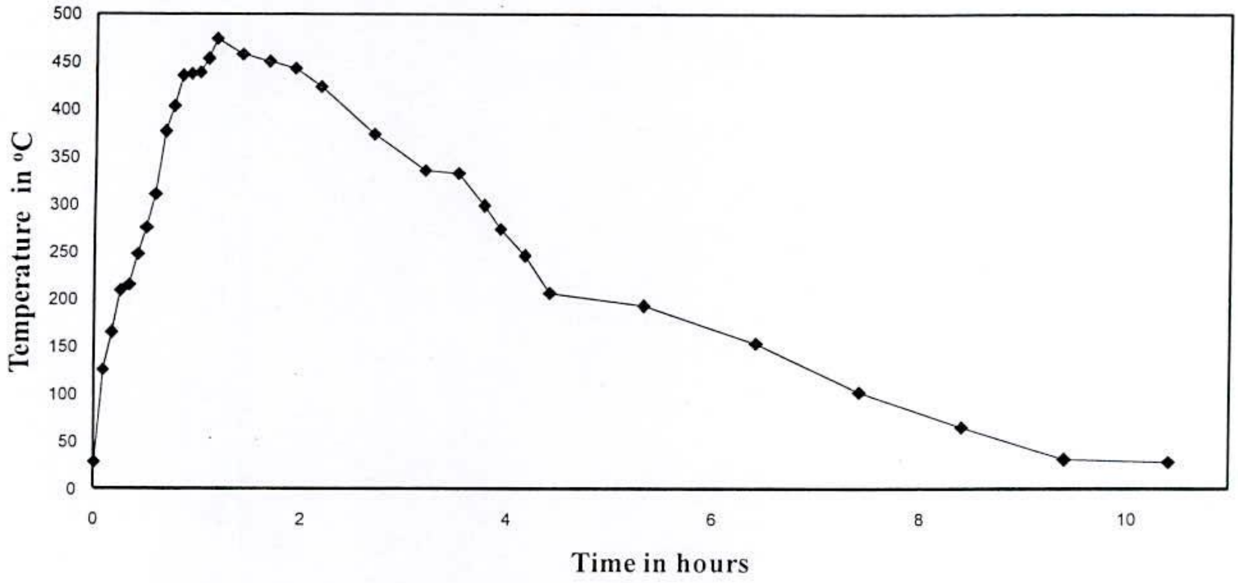


Figure 4.1: Temperature variation with time at the production stage

Batch 2 of Type A Furnace

This batch was conducted on October 19, 2009. 210 gm rice husk was collected in a 10.16 cm diameter small pot. The rice husk was in compacted condition in the pot. Then the pot was closed and put in the furnace. Then the cover of the furnace was closed and also sealed with clay. A digital thermometer was placed inside the pot from the top cover of the furnace to measure the temperature. Then the fuel was placed on the grit and started burning. When the Process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 3 hours. The highest temperature was recorded 553 °C. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white, all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

Only 82.46 gm activated carbon was produced from this batch experiment which is 39.27% of the raw material 210 gm. The rice husk was finely burnt and produced good quality activated carbon. As fuel of 6 kg firewood and 100 mL of oil were used. The temperature variation was shown in Figure 4.5. The production cost is found to be 503 BDT per kg. Detailed cost analysis is shown in Appendix A.

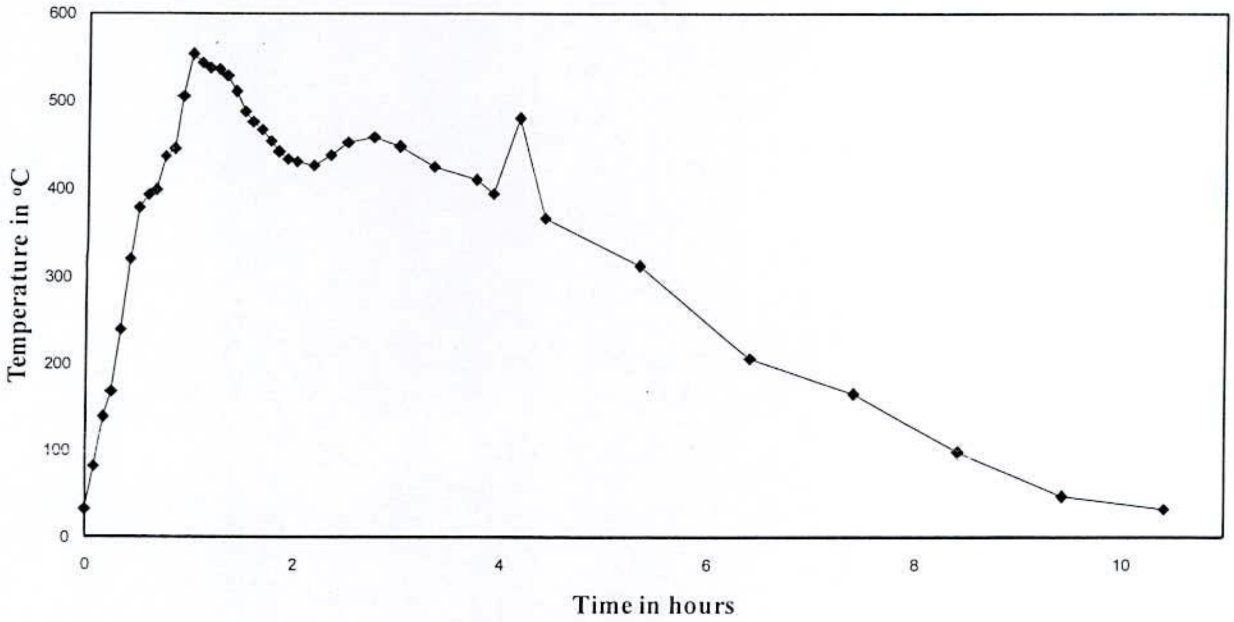


Figure 4.2: Temperature variation with time at the production stage

Batch 3 of Type A Furnace

This batch was conducted on October 20, 2009. In this batch the 240 gm rice husk was mixed with an aqueous solution of ammonium sulphate (activating chemical) made by dissolving 50 g of ammonium sulphate in 300 mL of distilled water. Then the soaked rice husk was put in a 10.16 cm diameter small pot. The rice husk was in compacted condition in the pot. Then the pot was closed, sealed and put in the furnace. Then the cover of the furnace was closed and also sealed with clay. A digital thermometer was placed inside the pot from the top cover of the furnace to measure the temperature. Then the fuel was placed on the grit and burning started. When the process was going on the smoke produced in the furnace entered the pot through the bottom opening and passes out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 3 hours. The highest temperature was recorded 534 °C. The smoke came out from the furnace and was also observed. Initially the smoke color was black. When the smoke color turned into white, all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

Only 128 gm activated carbon was found from this batch experiment which is 53.33% of the raw material of 240 gm. The activated carbon finely burnt. As fuel of 6 kg firewood and 100 mL of oil were used. The temperature variation was shown in Figure 4.6. The production cost is found to be 536 BDT per kg. Detailed cost analysis is shown in Appendix A.

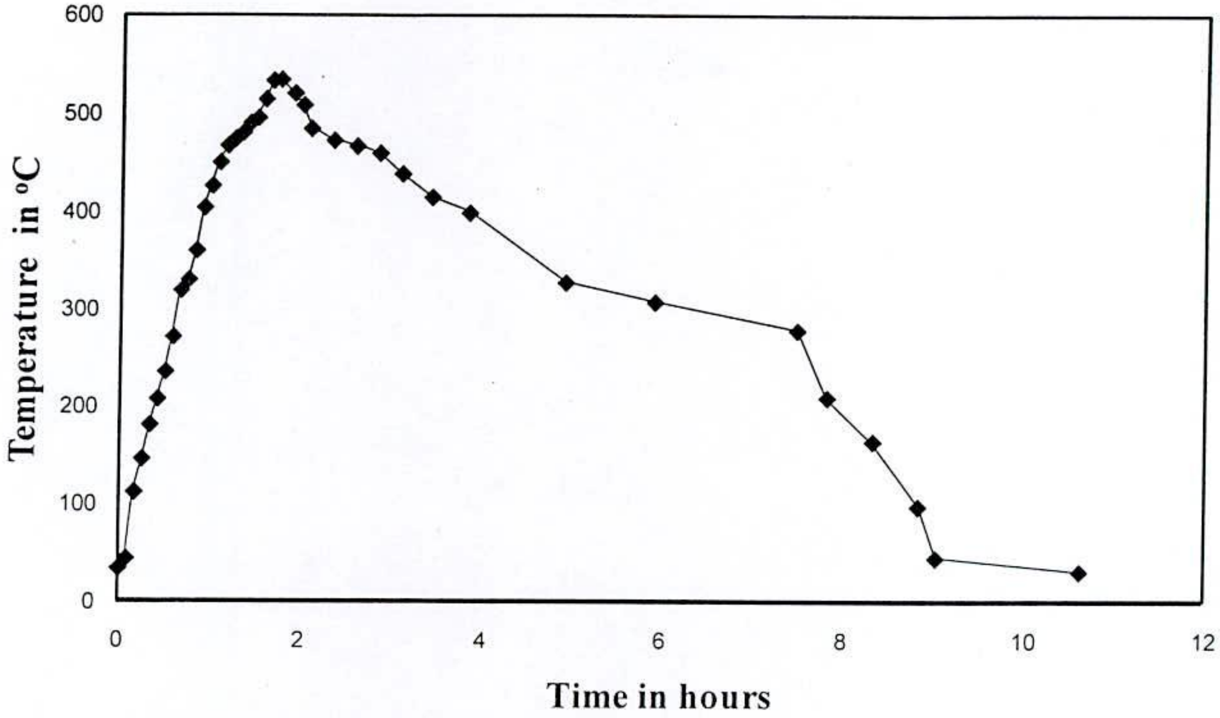


Figure 4.3: Temperature variation with time at the production stage

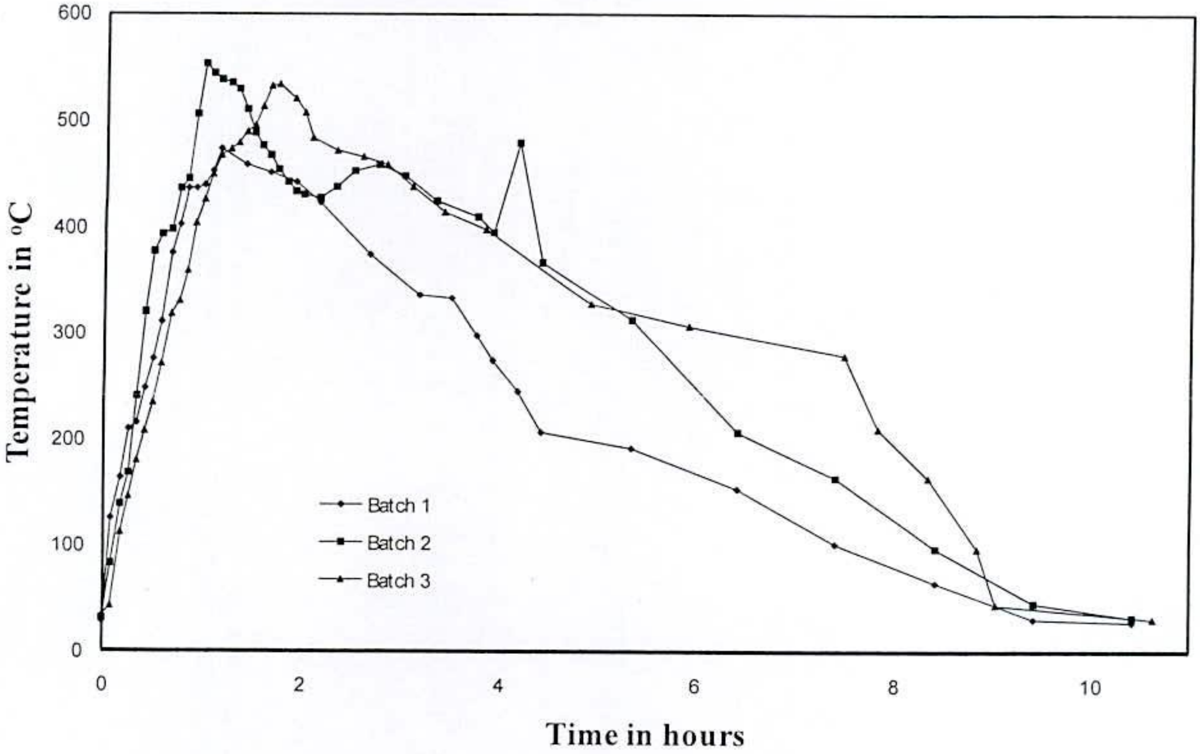


Figure 4.4: Temperature variation with time at the production stage in Type A furnace for different batches

It was seen from Figure 4.4 that, the temperature above 400 °C was maintained for about 2.5 hours for every batch test which is favorable condition for production of activated carbon.

4.2.2 Activated Carbon produced in Type B Furnace

The following are the general steps applied in producing Activated Carbon in Type B Furnace

a) First the container bottom was filled with raw material and than placed one tray.
b) Again raw material was placed on the tray and then other tray was placed. There is a 1 inch gap between bottom layer of the material and the tray.
c) The raw materials in the bottom layer were placed in dense condition and on the tray raw material was placed in loose condition. The capacity of container was around 3.5 kg.
d) After filling the container with raw material, the top of the container was closed and sealed with clay.
e) Next the container was placed in the furnace.
f) Then the cover of the furnace was closed and also sealed with clay.
g) The fuel was placed on the grit and start burning. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passes out through the top opening which was connected with furnace smoke outlet. This heated air and the produced heat was used for producing activated carbon.
h) The smoke came out from the furnace was also observed. Initially the smoke color was black.
i) The furnace was fueled until the black smoke turned into white smoke.
j) When the smoke color turn into white, all the openings were sealed with clay. The outlet temperature was observed as 86 °C when white smoke came out.
k) Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon.

Batch 1 of Type B Furnace

This batch was conducted on February 07, 2010. 3 kg 50 gm rice husk was collected in a 25.4 cm diameter container. Rice husk was laid in the container in three layers. There was 2.54 cm gap between consequent two layers. Rice husk was put in loose condition in every layer. Then the container was closed, sealed and put in the furnace. Then the cover of the furnace was closed and also sealed with clay. Then the fuel was placed on the grit and burning started. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with smoke outlet. This heated air and the produced heat were used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 4.5 hours. The smoke came out from the furnace and was also observed. Initially the smoke color was black. When the smoke color turned into white and outlet temperatures become 82 °C then all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

1 kg 250 gm activated carbon was found from this batch experiment which is 40.98% of the raw material of 3 kg 50 gm. Bottom layer form good quality activated carbon. Most of the rice husk at the bottom layer converted into activated carbon whereas at the top and middle layer's rice husk was partially converted into activated carbon and mixed with ash. In this batch 12 kg firewood and 200 mL oil were used. The production cost is found to be 77 BDT per kg. Detailed cost analysis is shown in Appendix A.

Batch 2 of Type B Furnace

This batch was conducted on February 14, 2010. 3 kg 50 gm rice husk was collected in a 25.4 cm diameter container. Rice husk was laid in the container in three layers. There was 2.54 cm gap between consequent two layers. Rice husk was put in compacted condition in every layer. Then the container was closed and sealed and put in the furnace. Then the cover of the furnace was closed and also sealed with clay. Then the fuel was placed on the grit and burning started. When the Process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with smoke outlet. This heated air and the produced heat were used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 4.5 hours. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white and outlet temperatures become 86 °C then all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

Only 700 gm activated carbon was found from this batch experiment which is 21.43% of the raw material of 3 kg 50 gm. Most of the rice husk at the bottom layer converted into activated carbon whereas at the top and middle layer's rice husk was partially converted into activated carbon and mixed with ash. In this batch 12 kg firewood and 200 mL oil were used. The production cost is found to be 138 BDT per kg. Detailed cost analysis is shown in Appendix A.

Batch 3 of Type B Furnace

This batch was conducted on May 31, 2010. 3 kg 50 gm rice husk was collected in a 25.4 cm diameter container. Rice husk was laid in the container in three layers. There was 2.54 cm gap between consequent two layers. Rice husk was put in compacted condition in bottom layer, loose in middle and top layer. Then the container was closed and sealed and put the container in the furnace. Then the cover of the furnace was closed and also sealed with clay. Then the fuel was placed on the grit and start burning. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passes out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 5 hours. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white and outlet temperature become 84 °C than all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

2 kg 125 gm activated carbon was found in middle and bottom layer from this batch experiment which is 60.71% of the raw material used. Most of the rice husk at the every layer converted into carbon. Small amount of ash was found. In this batch 12 kg firewood and 200 mL oil were used. The production cost is found to be 46 BDT per kg. Detailed cost analysis is shown in Appendix A.

Batch 4 of Type B Furnace

This batch was conducted on August 10, 2010. 3 kg 50 gm rice husk was collected in a 25.4 cm diameter container. Rice husk was laid in the container in three layers. There was 2.54 cm gap between consequent two layers. Rice husk was put in compacted condition in bottom, in loose condition in middle layer and in top layer one part was in compacted and other part was in loose condition. Then the container was closed and sealed and the container was put in the furnace. Then the cover of the furnace was closed and also sealed with clay. Then the fuel was placed on the grit and burning started. When the process was going on the smoke produced in the furnace entered the pot through the bottom opening and passes out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 4.5 hours. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white and outlet temperatures become 92 °C then all the openings were sealed with clay. Then the sealed furnace was kept for 24 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

2 kg 600 gm activated carbon was found from this batch experiment which is 74.29% of the raw material used. Rice husk at the compacted part of the top layer remain same and at the loose part it burnt converted into activated carbon. The smoke passed through the loose portion of the top layer. Rice husk at the middle layer and bottom layer produced good quality activated carbon. In this batch 12 kg firewood and 200 mL oil were used. The production cost is found to be 37 BDT per kg. Detailed cost analysis is shown in Appendix A.

4.2.3 Activated Carbon produced in Type C Furnace

The following are the general steps applied in producing Activated Carbon in Type C Furnace

a) First the small container was filled with raw material. The capacity of the drum was around 14 kg.
b) Then the top of the drum was closed and sealed with clay.
c) Next the drum was placed in the furnace. Then the cover of the furnace was closed and also sealed with clay.
d) The fuel was placed on the grit and burning started. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon.
e) A digital thermometer was placed inside the pot to record the inside temperature.
f) The furnace was fueled until the furnace temperature reached above 500 °C and maintained the furnace temperature above 500 °C.

g) The smoke came out from the furnace was also observed. Initially the smoke color was black.

h) When the smoke color turned into white, all the openings were sealed with clay. The outlet temperature was observed as 94 °C when white smoke came out.

i) Then the sealed furnace was kept for 48 hours and then opened to bring out the produced activated carbon.

Batch 1 of Type C Furnace

This batch was conducted on December 15, 2010. 14 kg 600 gm rice husk was collected in a 40.64 cm diameter small container. The rice husk was in loose condition in the container. Then the container was closed and sealed and put the container in the furnace. Then the cover of the furnace was closed and also sealed with clay. A digital thermometer was placed inside the container from the top cover of the furnace to measure the temperature. Then the fuel was placed on the grit and burning started. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with Smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 13 hours. The highest temperature was recorded 574 °C. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white, all the openings were sealed with clay. Then the sealed furnace was kept for 48 hours and opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

Only 2 kg 900 gm activated carbon was found from this batch experiment which is only 19.86% of the raw material used. Maximum rice husk fully burned and become ash. The activated carbon was mixed with ash. In the top of rice husk layer no activated carbon was traced. The bottom portion of the container produced some activated carbon in which ash content was 52.8%. Some compacted portion of rice husk become good quality of activated carbon in which the ash content was found 30.35%. About 21 kg firewood and 250 mL oil were used. The amount of air entered in the furnace was higher than the amount of smoke produced. The smoke did not pass all through the rice husk constantly. The activated carbon production was not good. The production cost is found to be 73 BDT per kg. Detailed cost analysis is shown in Appendix A.

Batch 2 of Type C Furnace

This batch was conducted on December 30, 2010. 13 kg 700 gm rice husk was collected in a 16" diameter small container. The rice husk was in loose condition in the container. Then the container was closed and sealed and the container was put in the furnace. Then the cover of the furnace was closed and also sealed with clay. A digital thermometer was placed inside the container from the top cover of the furnace to measure the temperature. Then the fuel was placed on the grit and burning started. When the process was going on, the smoke produced in the furnace entered the pot through the bottom opening and passed out through the top opening which was connected with smoke outlet. This heated air and the produced heat was used for producing activated carbon. The furnace was fueled until the furnace temperature reached above 400 °C and maintained the furnace temperature above 400 °C for 13 hours. The highest temperature was recorded 482 °C. The smoke came out from the furnace was also observed. Initially the smoke color was black. When the smoke color turned into white, all the openings were sealed with clay. Then the sealed furnace was kept for 48 hours and then opened to bring out the produced activated carbon. Continuous monitoring of sealing was provided because clay layer was cracked after some hours by propagation of heat.

Result

6 kg 350 gm activated carbon was found from this batch experiment which was only 46.35% of the raw material used. Good amount of activated carbon was found with fair quality. Some portions did not burn properly. The bottom portion formed good quality of activated carbon but the top portion fully burnt and became ash and middle portion of the container did not burnt properly. About 21 kg firewood and 250 mL oil were used. The amount of air entered in the

furnace was higher than the amount of smoke produced. The smoke did not pass all through the rice husk constantly. The activated carbon production was good. The production cost is found to be 33 BDT per kg. Detailed cost analysis is shown in Appendix A.

CHAPTER FIVE

CHARACTERIZATION OF ACTIVATED CARBON

5.1 General

To characterize the produced activated carbon following parameters were determined: moisture content, volatile content, ash content and fixed carbon. These were found by proximate analysis (dry basis). Besides, produced activated carbon, laboratory grade and one commercial grade activated carbon were determined for comparison. The produced activated carbon was classified as Type A activated carbon, Type B activated carbon, Type C activated carbon and chemical activated carbon. SEM photograph of produced activated carbon and raw rice husk also were determined. To study adsorption characteristics adsorption study and column study were carried out. The adsorption study includes kinetic study, effect of temperature on adsorption and effect of adsorbent dose and equilibrium study for Isotherm. All the experiments were triplicate and only the mean values were reported. The maximum deviation is less than 5%. methylene blue were used as experimental sample for the adsorption study.

5.2 Characterization of activated carbon

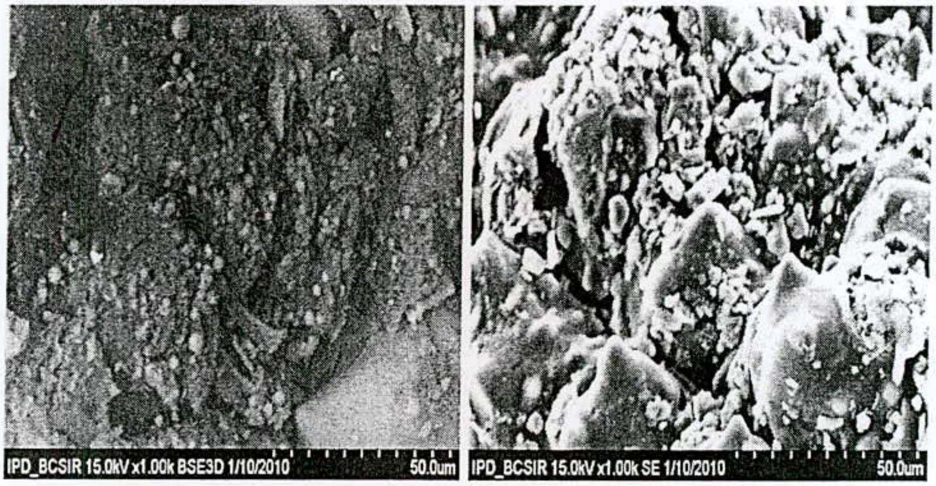
The experiment data and calculation were presented in Appendix A. The result of analysis of Table 5.1 showed that the ash content of activated carbon produced in Type C furnace resulting to higher ash content of 57.43% which is higher than of activated carbon produced by *Aloko, 2007* and produced in Type B furnace resulting lower ash content but higher than commercial and laboratory grade activated carbon. This was an indication of the level of impurity present in it. So it was seen that the activated carbon produced in Type B furnace has less impurity. The volatile content present in the carbon of Type B activated carbon is quite near of the laboratory grade activated carbon but is much higher than activated carbon produced by *Aloko, 2007.* The moisture content of PRHAC is much lower than other. The ash content and fixed carbon content were quite similar for all PRHAC produced in different furnaces. From the fixed carbon content it was seen that the carbon yield was lower than laboratory grade activated carbon but quite similar to activated carbon produced by *Aloko, 2007.* This implies that PRHAC were less carbonized compare to laboratory grade activated carbon but quite similar to activated carbon produced by *Aloko, 2007.* The test data are given in Appendix A.

5.3 SEM Photograph

Well-developed pores of activated carbon made from rice husk are clearly shown in SEM photograph as shown in Figure 5.1(b). The surface of the activated carbon compare with the image of the raw rice husk in figure 5.1(a). This is due to the evolution of CO_2 gases during activation process (Reinoso, 1992). The CO_2 gas was effective in developing pores in the bulk of the precursor, which resulted in high adsorption properties.

Table 5.1: Characterization of different activated carbon

Parameters	Laboratory grade AC	Commercial grade AC	Produced AC of Type A	Produced AC of Type B	Produced AC of Type C	Chemically AC	Activated carbon produced by *Aloko, 2007* (%)
Moisture content	16.83	8.00	1.00	1.96	3.00	6.00	4.5
Volatile content	7.92	3.00	6.00	7.94	4.00	5.88	0.06
Ash content	5.88	0.99	55.34	53.47	57.43	42.57	48.20
Fixed carbon content	69.37	88.01	37.66	36.63	35.57	45.55	-



(a) (b)

Figure 5.1: Cross section images of (a) Raw rice husk, (b) Activated carbon made of rice husk

5.4 Results

5.4.1 Effect of temperature on adsorption

Adsorption of methylene blue i.e., removal of color on activated carbon has been investigated from room temperature to 60°C as shown in Figure 5.2. For all the 10 curves it is seen that adsorption of the methylene blue dye has increased from 30°C to 40°C almost linearly and after the maximum at 40°C it decreased. At 40°C, 99.76% color has been reduced. So for adsorption with PRHAC 40 $^{\circ}$C is the optimum temperature because if temperature was increased more then 40 $^{\circ}$C then the desorption was started. The test data are given in Appendix B.

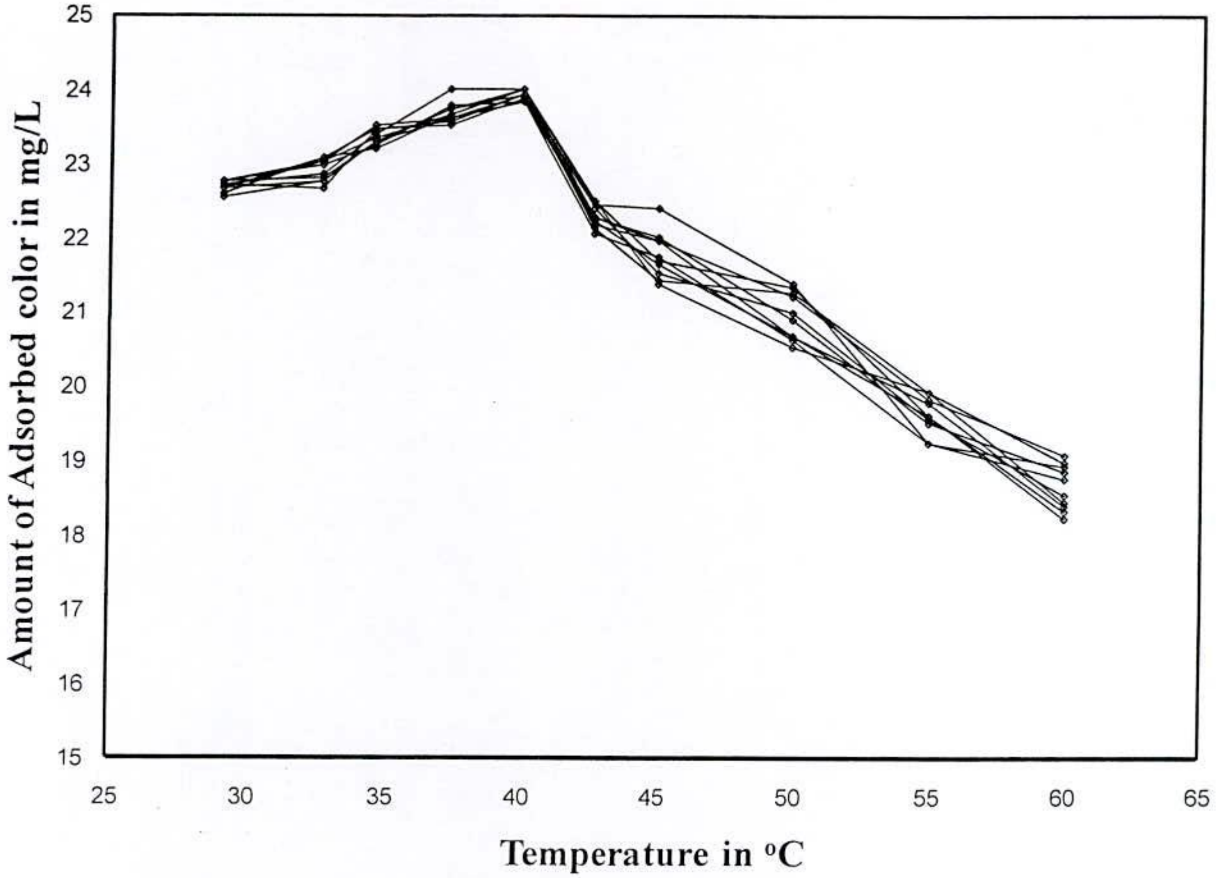


Figure 5.2: Effect of temperature on adsorption

5.4.2. Kinetic study

Agitation time or contact time has pronounced effect on adsorption. The percentage color reduction with respect to time is shown in Figure 5.3. From the results, it can be seen that removal of the color has been increased with time and become maximum at 60 minutes contact time, then decreased. From graph the highest percentage of color removal for 0.05 g to 2.25 g activated carbon at 0.05 g interval were 26.0%, 29.4%, 31.4%, 37.6%, 39.4%, 42.0%, 44.6%, 52.0%, 54.8%, 56.6%, 59.8%, 65.0%, 71.6%, 73.0%, 77.8%, 79.2%, 82.6%, 84.6%, 85.6%, 85.8%, 86.4%, 86.8%, 87.2%, 88.6%, 89.2%, 90.0%, 91.0%, 91.6%, 92.0%, 92.4%, 92.8%, 92.4%, 93.0%, 93.4%, 94.4%, 95.8%, 97.6%, 98.6%, 99.2%, 99.4%, 99.6%, 99.6%, 99.8%, 100%, respectively; except 0.85 g carbon dose. The highest percentage of color removal for 0.85 g was obtained at 65 minutes which was 89.6%. 60 minutes may be the saturation time of adsorption for all the samples and show the maximum removal of color. From Figure 5.3 (a) it was seen that, for the curve 0.05 g PRHAC dose the adsorption of methylene blue color was increased till 60 minutes and the rate of adsorption curve was quite straight line. After 60 minutes time desorption was started and reduced gradually. Also from Figure 5.3 (h) it was seen that, for the curve 2.25 g PRHAC dose the adsorption of methylene blue color was increased till 60 minutes and the rate of adsorption curve was quite straight line. Similarly for all curves of different activated carbon dose shows similar trend of curves such the rate of adsorption was increased till 60 minutes after that desorption was started. So it was seen from all graph that 60 minute is a crucial time for adsorption with PRHAC and after 60 minutes time desorption was started and reduced gradually. Beyond the 60 minutes contact time, some desorption may happen and for detail mechanism further studies are needed. The test data are given in Appendix C.

5.4.3 Effect of adsorbent dose and equilibrium study for Isotherm

The percentage of removal of color with varying doses of PRHAC at optimal temperature and time are shown in Figure 5.4. It is showed that the increase in carbon doses to certain level increase the percentage of color reduction. From Figure 5.4 (a), the graph of 5 min curve shows that from 0.5 g/L to 7.5 g/L PRHAC dose adsorbed methylene blue color rapidly. After that the adsorption was continued but adsorption rate increase slowly. Similar trend also showed by all other curves. Another observation was made from these curves that from 13.5 g/L to 20.0 g/L carbon doses, percentage of color removal was significant. More than 20.0 g/L carbon doses though gave good color removal of above 99.0%. However the higher doses of carbon application are not desirable in terms of economy. Rao, et. al. (2000) carried out adsorption studies using industrial grade Granular activated carbon for treatment of tannery waste water. They observed 48.0 g/L of carbon dose gave maximum color removal of 92.8%. The present study gave a much lower carbon dose for comparable results. The test data are given in Appendix C.

From Figure 5.5 it is seen that the adsorption trend of PRHAC carbon from 0.5 to 7.5 g/L is a straight line with R^2 value of 0.994. Using the equation of $y = 1.672x + 4.111$ any curve within the range of 0.5 to 7.5 g/L PRHAC dose may obtained. The adsorption trend of PRHAC carbon from 8.0 g/L to further more also give a straight line with R^2 value of 0.984. Using the equation

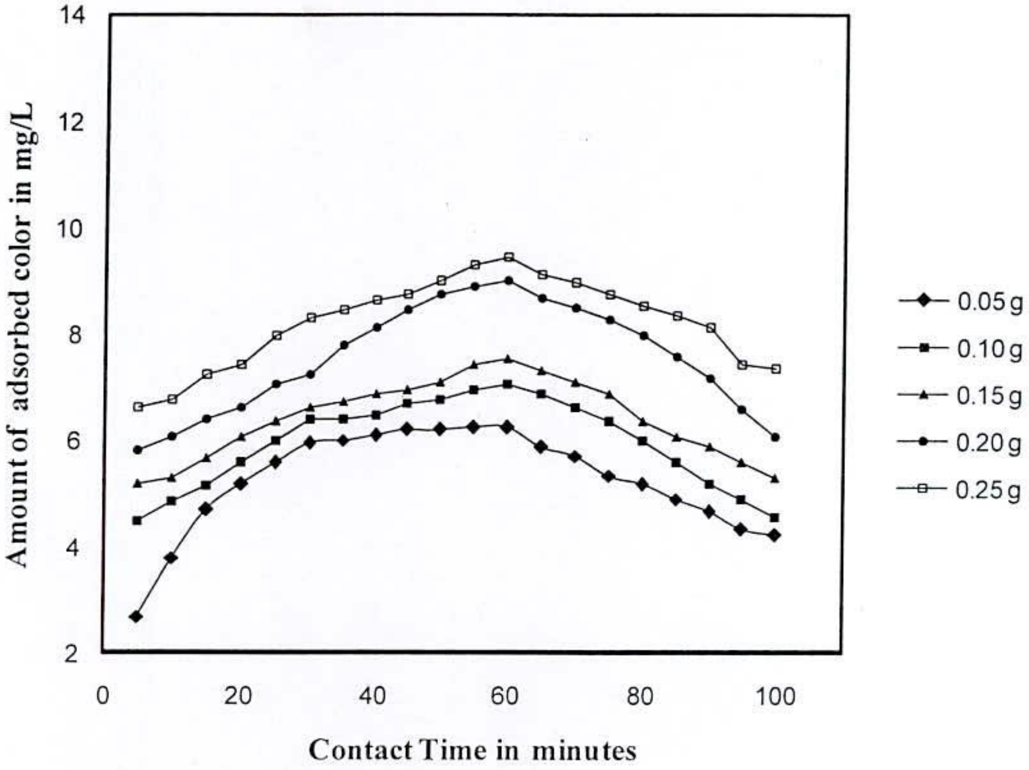


Figure 5.3 (a): Kinetic Study of 0.05, 0.10, 0.15, 0.20 and 0.25 gm PRHAC

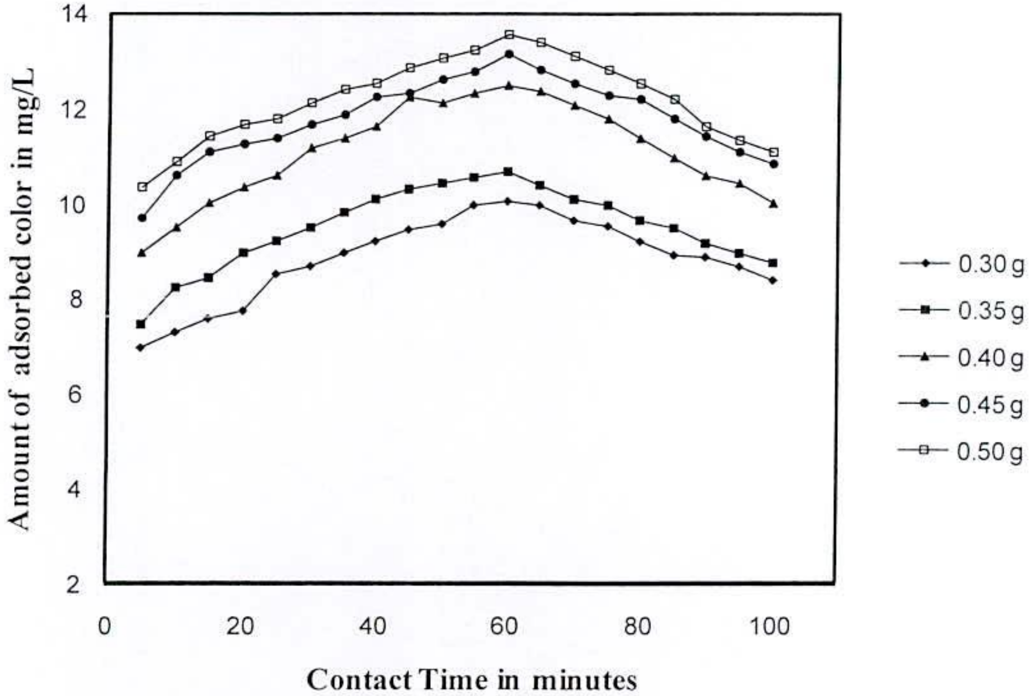


Figure 5.3 (b): Kinetic Study of 0.30, 0.35, 0.40, 0.45 and 0.50 gm PRHAC

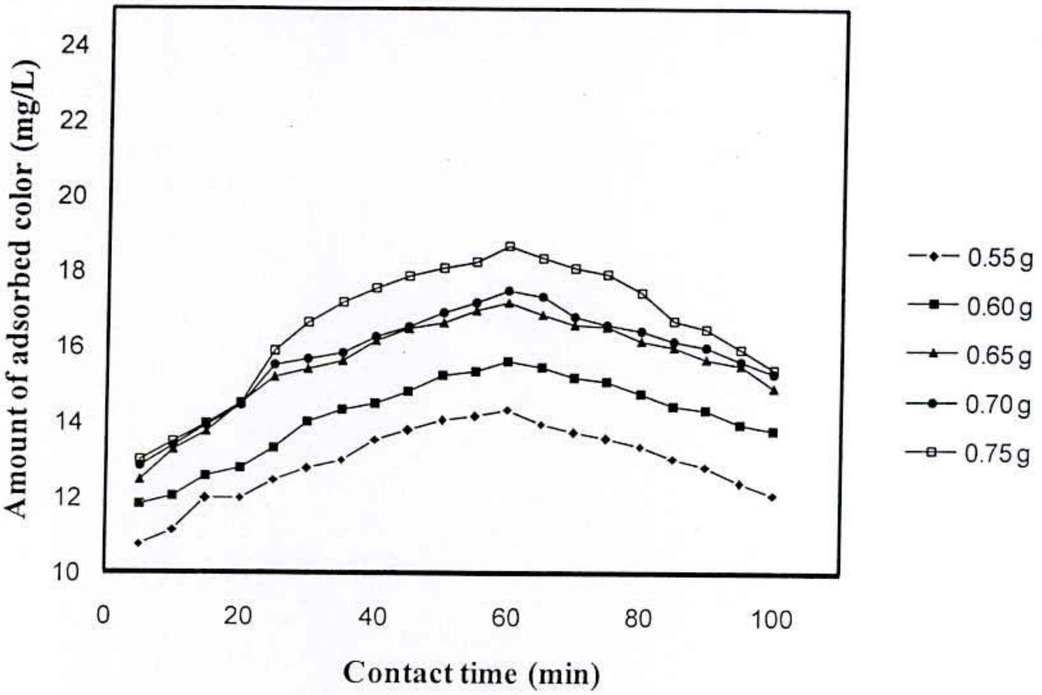


Figure 5.3 (c): Kinetic Study of 0.55, 0.60, 0.65, 0.70 and 0.75 gm PRHAC

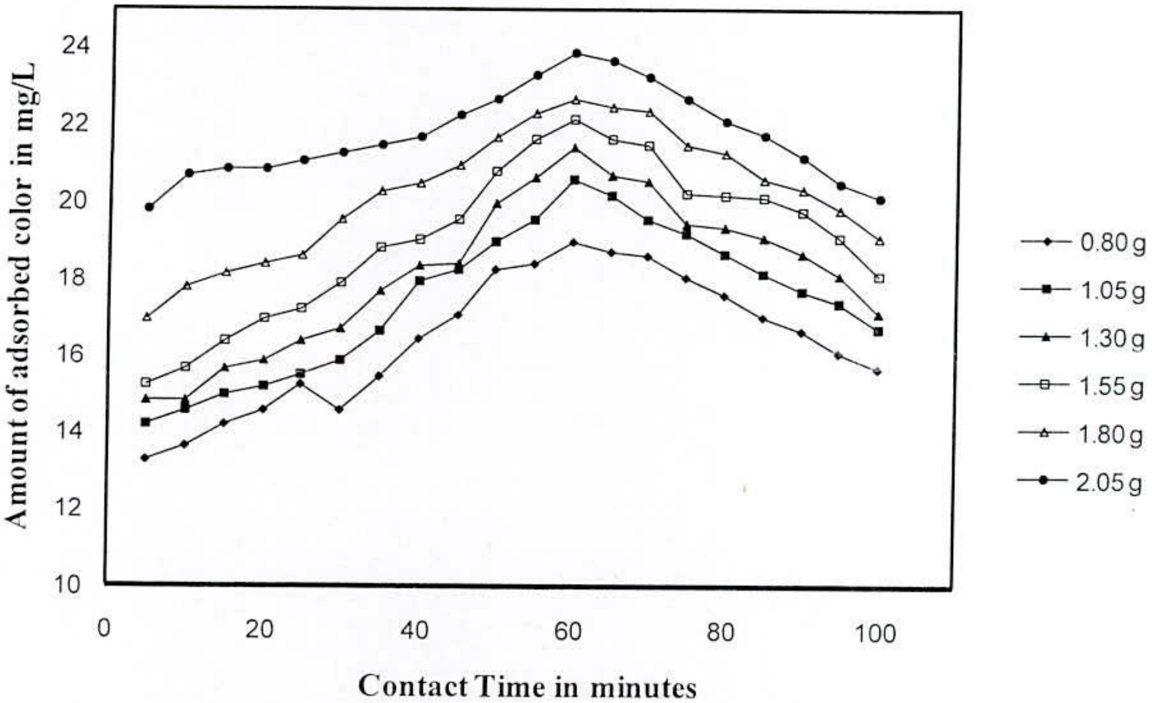


Figure 5.3 (d): Kinetic Study of 0.80, 1.05, 1.30, 1.55, 1.80 and 2.05 gm PRHAC

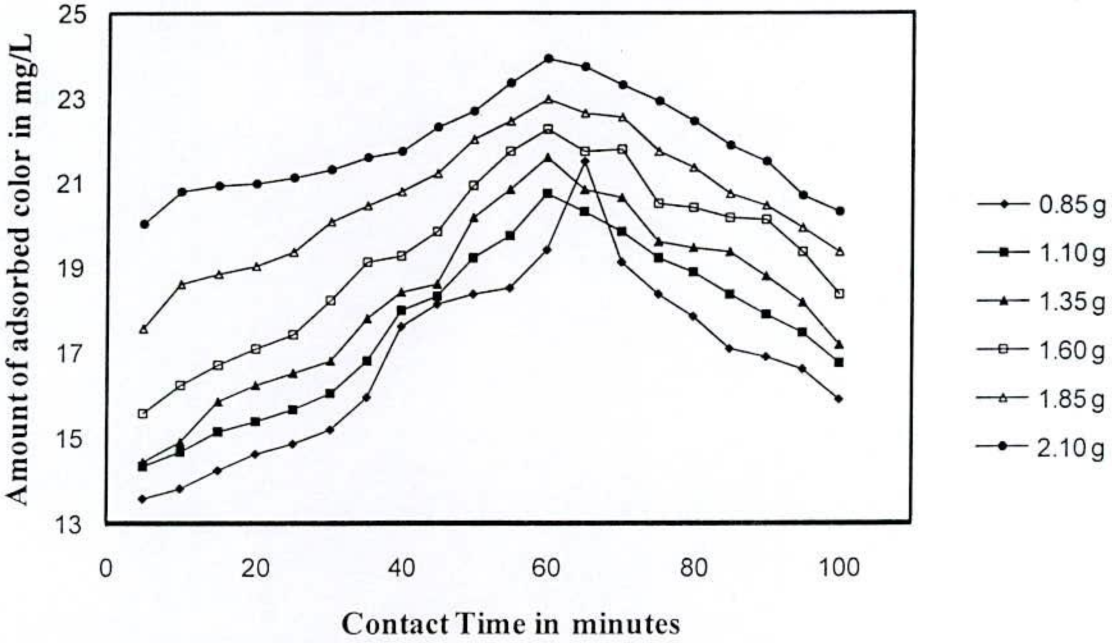


Figure 5.3 (e): Kinetic Study of 0.85, 1.10, 1.35, 1.60, 1.85 and 2.10 gm PRHAC

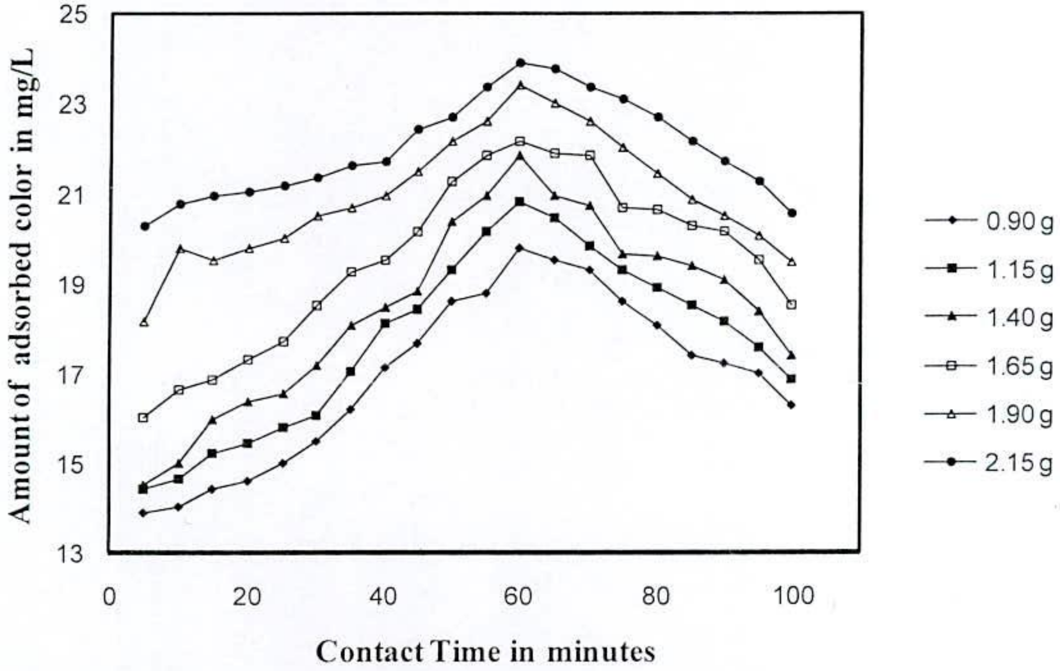


Figure 5.3 (f): Kinetic Study of 0.90, 1.15, 1.40, 1.65, 1.90 and 2.15 gm PRHAC

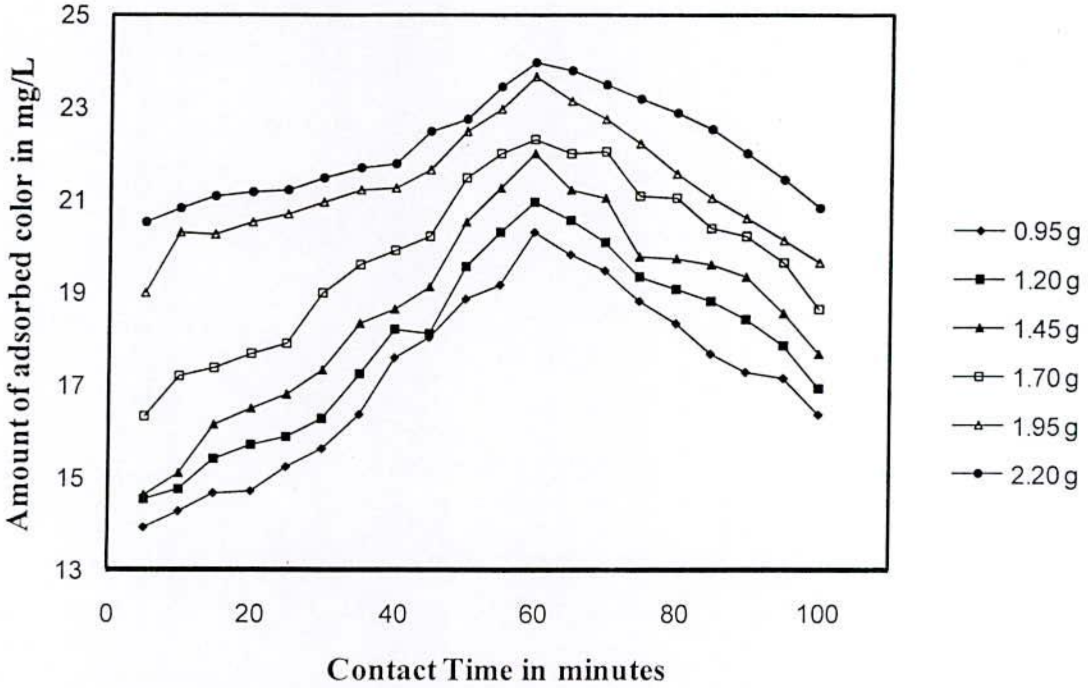


Figure 5.3 (g): Kinetic Study of 0.95, 1.20, 1.45, 1.70, 1.95 and 2.20 gm PRHAC

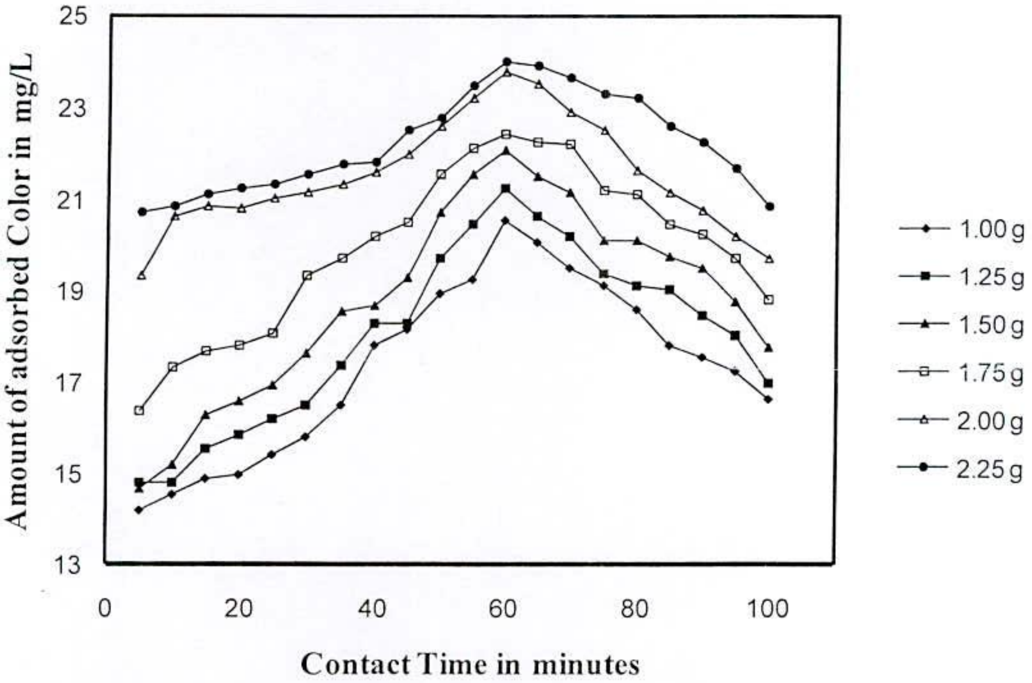


Figure 5.3 (h): Kinetic Study of 1.00, 1.25, 1.50, 1.75, 2.00 and 2.25 gm PRHAC

of $y = 0.408x + 13.04$ any curve within the range of 8.0 g/L to further more PRHAC dose may obtained. These two equations may used for finding the adsorption rate curve with the varying dose of PRHAC. If rapid adsorption needed then adsorption dose from 0.5 g/L to 7.5 g/L may used.

Results of adsorbent dose on adsorption which was obtained under optimum conditions were used for isotherm studies. The experimental data was analyzed using two parameter equilibrium models by both Freundlich and Langmuir adsorption isotherms. The Freundlich isotherms represented by model $x/m = K (Ce^{1/n})$. Freundlich adsorption isotherm represents the relationship between the amount of color adsorbed per unit mass of the adsorbent (x/m) and the concentration of color remaining in the in the solution after adsorption is complete (Ce). K and n are constant representing the adsorption capacity and intensity of adsorption, respectively. The plot of *log x/m* verses *log Ce* was found to be linear shown in Figure 5.6 with R^2 value of 0.956. The adsorption capacity was found 2.951 g color/g and adsorption intensity (n) was found to be 2.33. The values n > 1 represent favorable adsorption condition.

The Langmuir isotherm also represents the relationship between the amount of color adsorbed per unit mass of the adsorbent (x/m) and the concentration of color remaining in the in the solution after adsorption is complete (Ce) by a relation; $(x/m) = (abCe)/(1+aCe)$. Her e 'a' represents the Langmuir constant or bond energy and 'b' represent a practical limiting adsorption capacity with methylene blue molecules and assists in the comparison of adsorption performance. A linear plot of Ce/(x/m) versus Ce is obtained as shown in Figure-5.7. The fit is quite well with R^2 value of 0.95 for the methylene blue. This suggests the applicability of the Langmuir model as shown in the equation of the graph for the investigated system; the results also demonstrate monolayer coverage of methylene blue at the outer surface of the activated carbon. 'a' and 'b' are computed from the slope and intercept. The Langmuir constant i.e., a value is 0.311. This represents the quite strong interaction between adsorbate and adsorbent. Data shows that activated carbon have high adsorption capacity i.e., a value of 526 mg/g compared to the results obtained by Namasivayam et. al. (2002) reported 'b' value of 6.72 mg/g for adsorption of Congo Red (anionic dye) onto activated carbon prepared from coir pith.

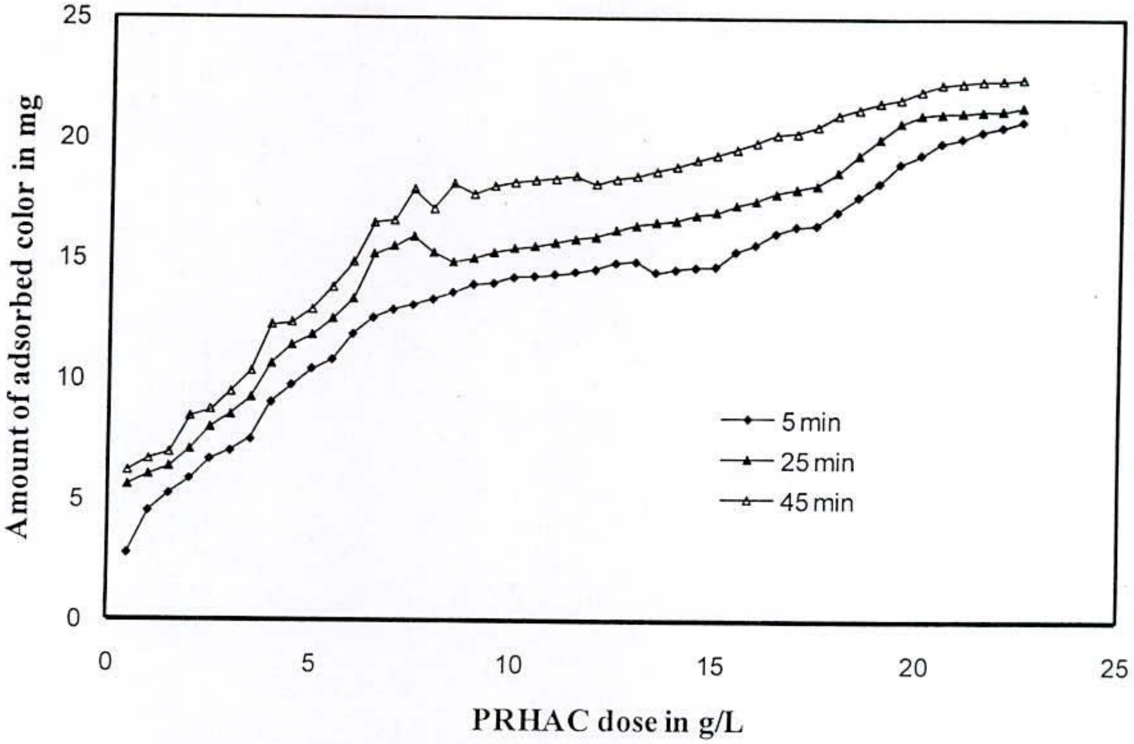


Figure 5.4 (a): Effect of adsorbent dose for 5, 25 and 45 minutes

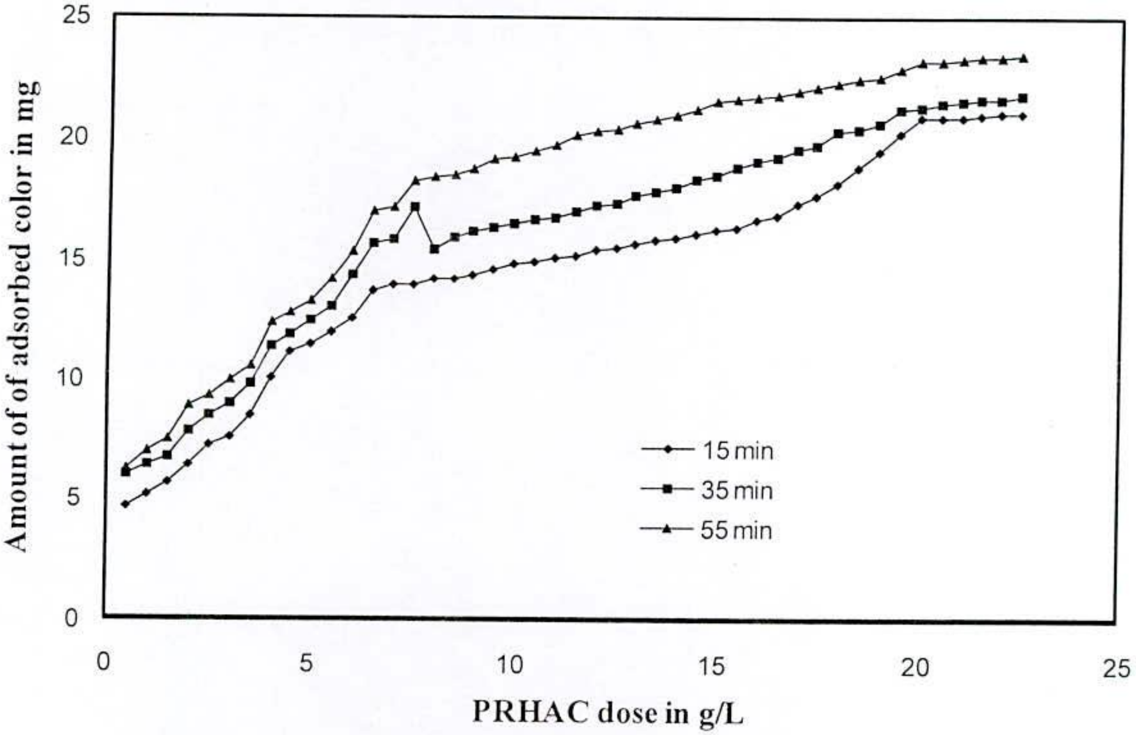


Figure 5.4 (b): Effect of adsorbent dose for 15, 35 and 55 minutes

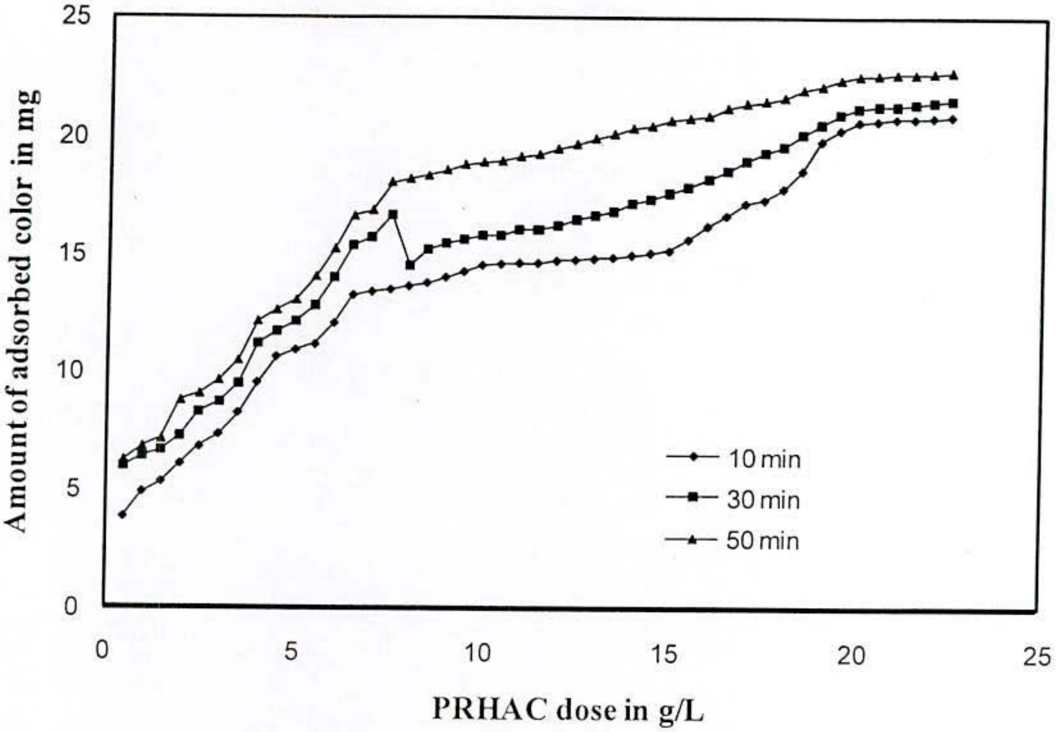


Figure 5.4 (c): Effect of adsorbent dose for 10, 30 and 50 minutes

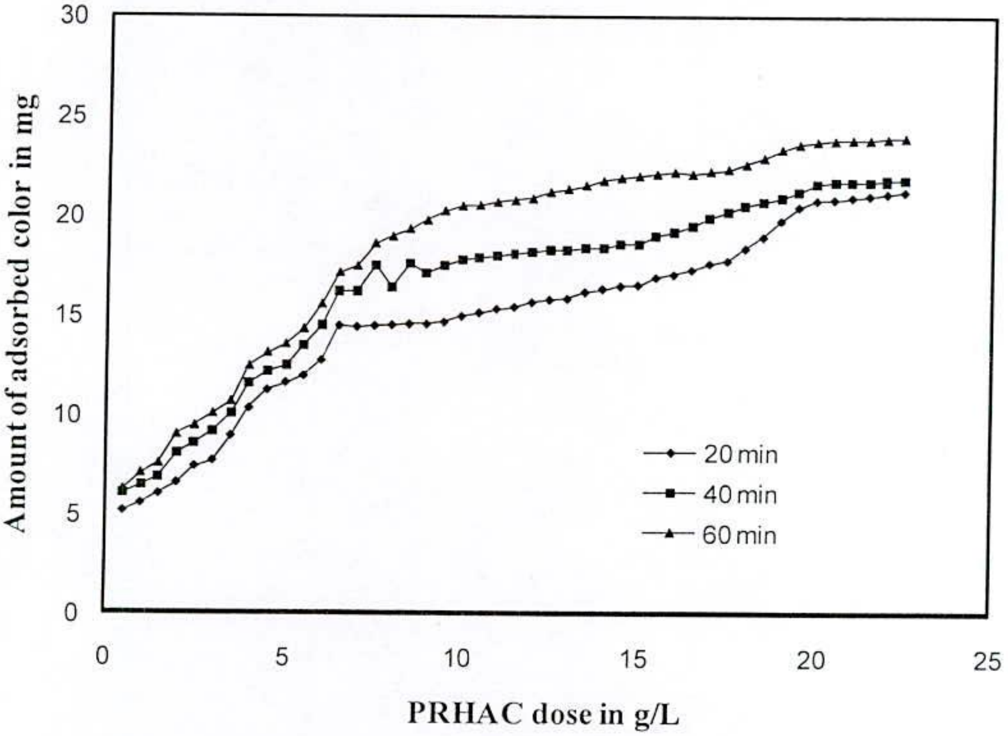


Figure 5.4 (d): Effect of adsorbent dose for 20, 40 and 60 minutes

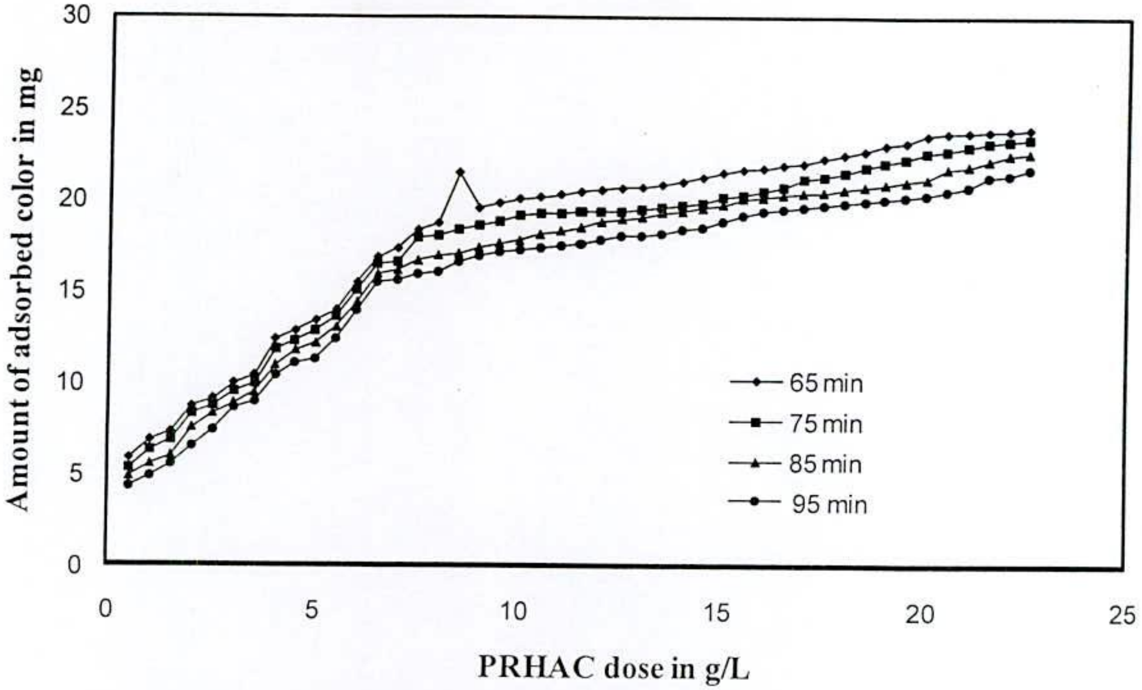


Figure 5.4 (f): Effect of adsorbent dose for 65, 75, 85 and 95 minutes

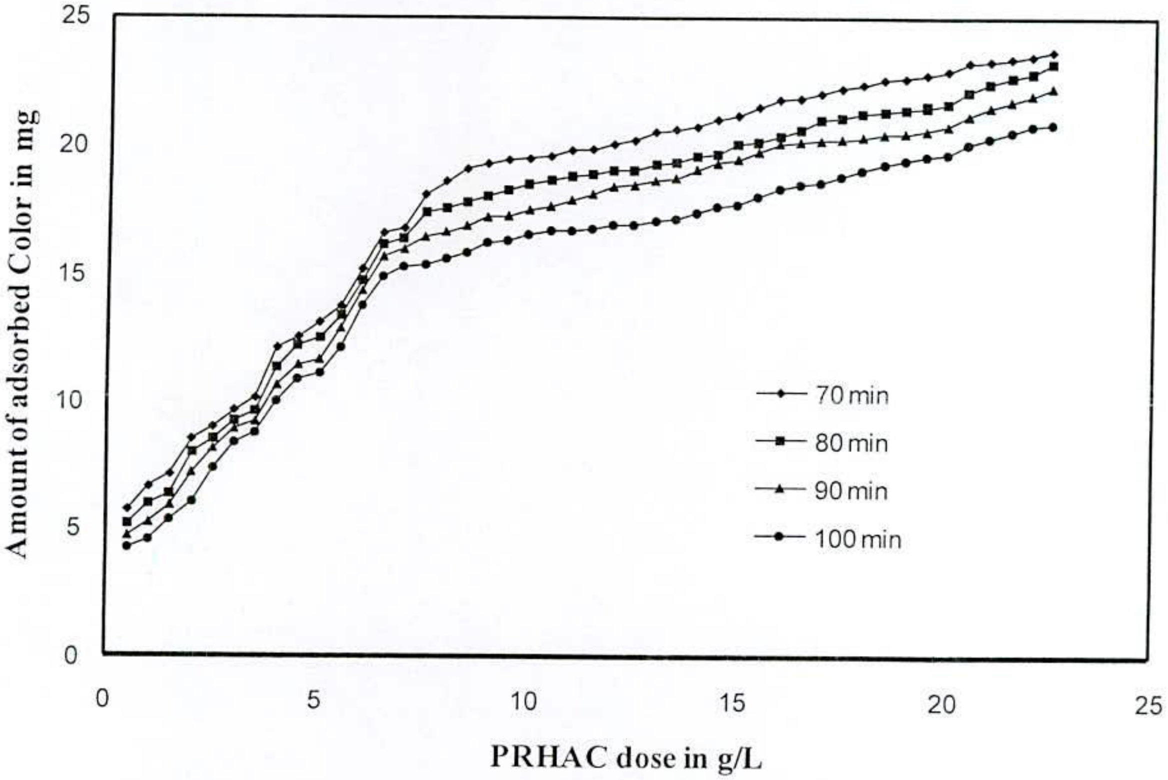


Figure 5.4 (g): Effect of adsorbent dose for 70, 80, 90 and 100 minutes

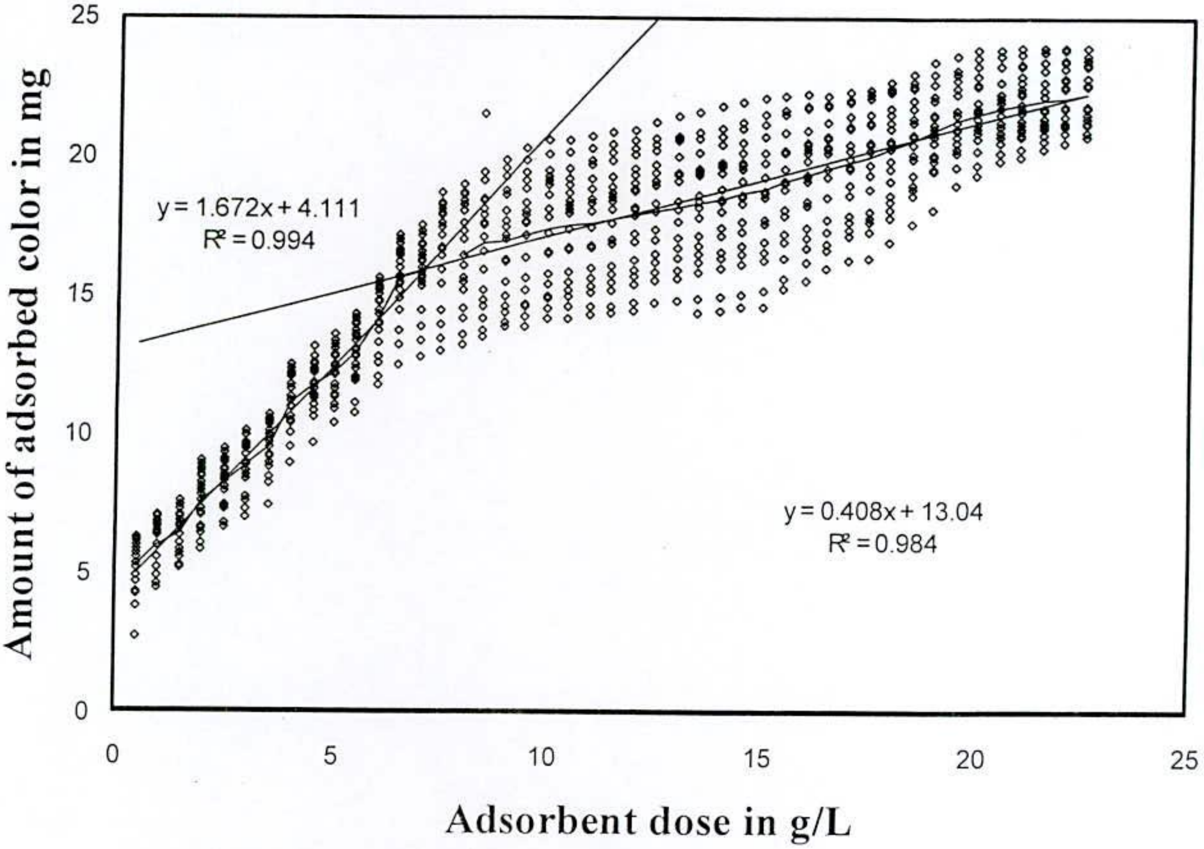


Figure 5.5: Average curve model of kinetic study

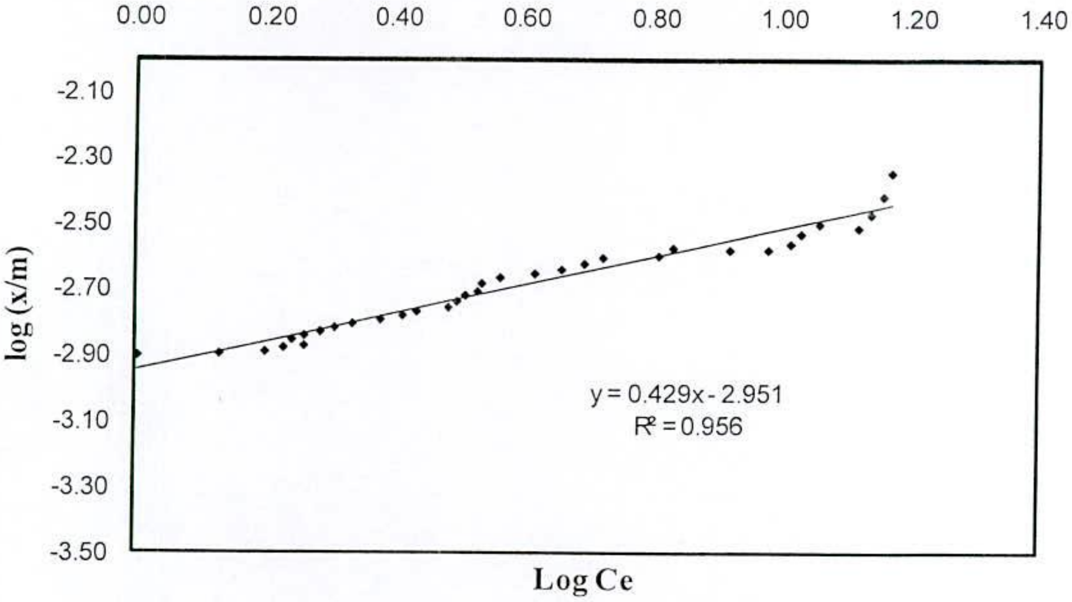


Figure 5.6: Freundlich Isotherm

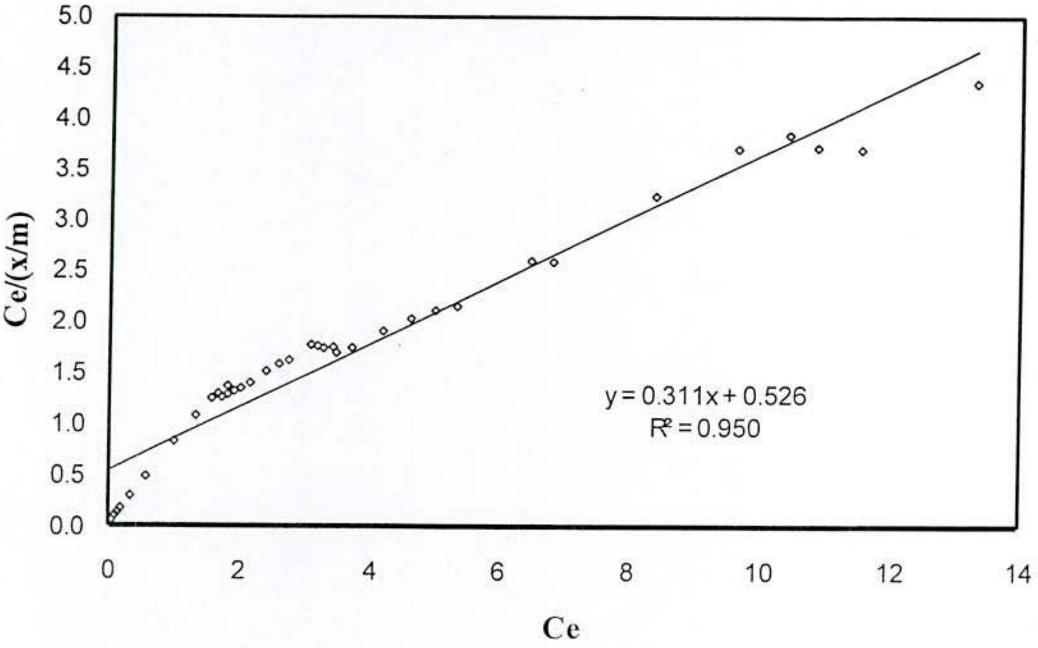


Figure 5.7: Langmuir Isotherm

5.7.4 Column Study

The results of column studies indicated that as the depth of column increase, the time to breakthrough also increases. It was inferred that 30 cm column depth was more effective compared to 20 cm and 10 cm depth. The results of 10 cm, 20 cm and 30 cm depth column operation are shown in Figure 5.8, 5.9 and 5.10, respectively and it was observed that at around 5 minutes, 70 minutes and 140 minutes, respectively, the break through occurred in terms of complete color removal. All the columns exhaust as the discharge of methylene blue through them increasingly. It was observed that at discharged rate of 500 mL, 575 mL and 1000 mL for 10 cm, 20 cm and 30 cm, respectively, all columns were exhaust. In 20 and 30 cm columns up to 128 mL and 260 mL discharge complete removal color was found in 90 minutes and 140 minutes, respectively. In 10 cm column initially 95% color removal was achieved.

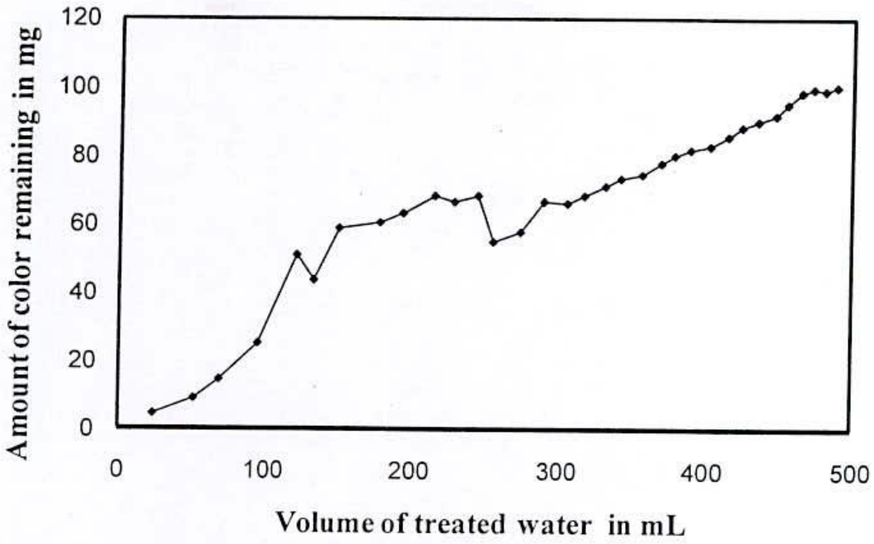


Figure 5.8: Colum study for breakthrough curve development for 10 cm column

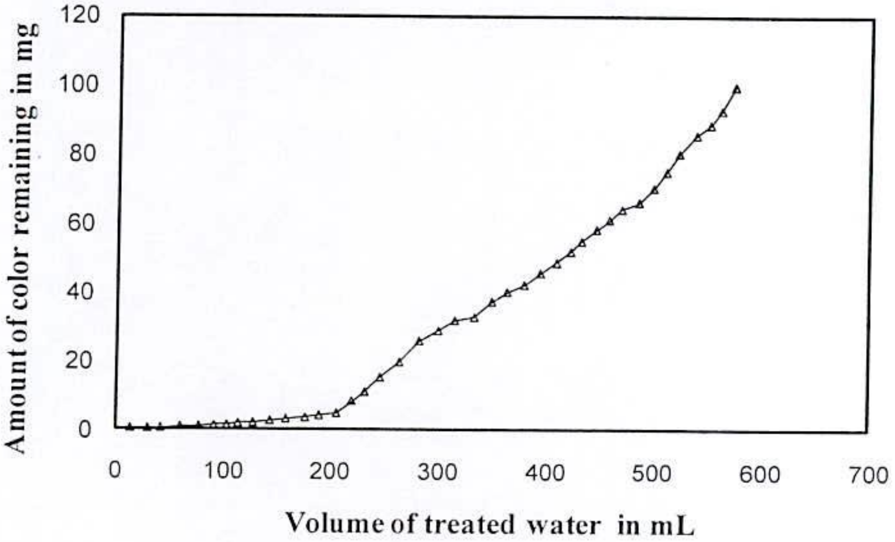


Figure 5.9: Colum study for breakthrough curve development for 20 cm column

However, from the nature of breakthrough curve, it was found that the column capable of continued adsorption when operated in serial mode. As in 20 cm column 5 g PRHAC remove complete color from 128 mL color solution and in 30 cm column 7.5 g PRHAC remove complete color from 260 mL color solution so complete color removal was achieved in column study and decolorization capacity was found to be 26 ~ 35 L/kg of PRHAC. The detailed calculation was given in Appendix E.

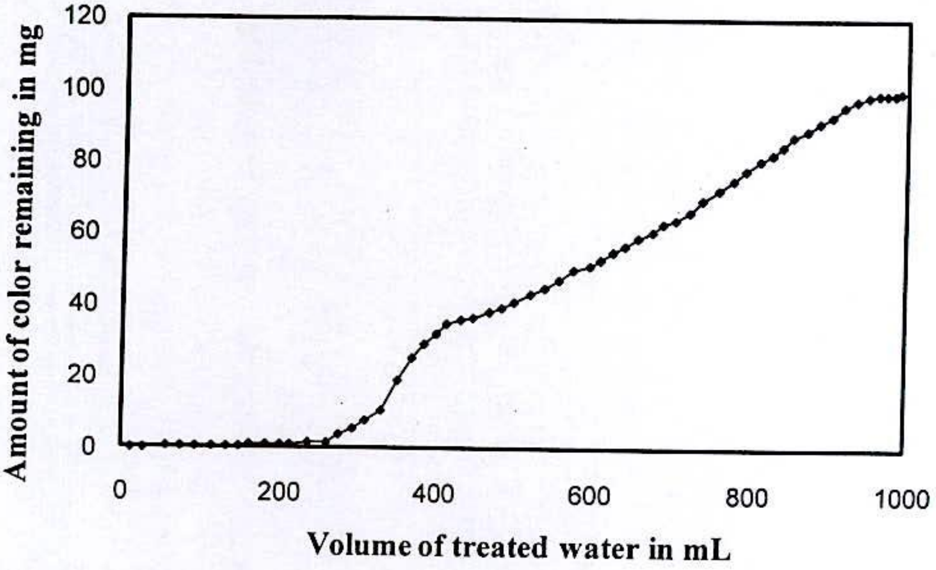


Figure 5.10: Colum study for breakthrough curve development for 30 cm column

CHAPTER SIX

TREATMENT OF TEXTILE WASTEWATER

6.1 General

Textile industry plays an important role in the economy of our country. Out of various activities in textile industry, chemical processing contributes about 70% of pollution. Due to the nature of various chemical processing of textiles, large volumes of wastewater with numerous pollutants are discharged (Das, 2000). There are almost 400 textile industries in and around the Dhaka city and their number is increasing day by day (Karim, 2006). In the dyeing industries, above 30-60 Liters of water are consumed per kg of cloth dyed and large quantities of the wastewaters are released during processing. It amounts to about 16% of the total water consumed in each factory (Habib, 2006). These wastewaters are heavily colored, contain high concentrations of salts, and exhibit high biological oxygen demand (BOD) values. These wastewaters are unfavorable from an ecological point of view if discharged without treatment.

6.2 Characteristics of Textile Wastewaters used in this study

Two types of textile wastewater were used in this study. They are Enzyme wash and Desizing wash wastewater. The characteristics of these two types of wastewaters are shown in Table 6.1. From Table 6.1 it was seen that Desizing wash wastewater was highly colored. It contains high impurities with higher COD value. There were 2570 mg/L of total dissolved solid and 290 mg/L suspended solid present in the Desizing wash wastewater. About 4211 mg O_2/L COD present in Desizing wash wastewater. Significant amount of chemicals such as chloride, manganese, phosphate, nitrate etc. also present in Desizing wash wastewater. On the other hand Enzyme wash wastewater also highly colored wastewater with higher impurities like 1380 mg/L total dissolved solid, 70 mg/L suspended solid and COD values of 1263 mg O_2/L and also contain significant amount of chemicals. Both wastewaters are acidic.

Table 6.1: Characteristics of textile wastewaters after collection from source

Parameter	Unit	Enzyme wash wastewater	Desizing wash wastewater
pH	-	6.17	6.23
Color	Pt-Co	75300000~91500000	201000000~24400000000
BOD	mg/L	56	116
COD	mg O_2/L	1263	4211
Acidity	mg/L	100	200
TS	mg/L	1450	2860
TDS	mg/L	1380	2570
SS	mg/L	70	290
NO_3^-	mg/L	120	40
Mn	mg/L	40	180
PO_4^-	mg/L	8	38
Cl^-	mg Cl^-/L	300	250
Hardness	mg/L	555.6	833.4

Table 6.2: Characteristics of textile wastewaters after storing 9 month

Parameter	Unit	Enzyme wash wastewater	Desizing wash wastewater
pH	-	6.90	7.94
Color	Pt-Co	75300000~91500000	201000000~24400000000
BOD	mg/L	68	50
COD	mg O_2/L	1263.4	1263.4
Acidity	mg/L	120	80
TS	mg/L	480	3460
TDS	mg/L	230	2460
SS	mg/L	250	1000

Table 6.2 shows the characteristics of same wastewaters which were retain in closed container for 9 months. Comprising Table 6.1 and 6.2, it was seen that, the COD value of Desizing wash wastewater was highly reduced but the COD value of Enzyme wash wastewater remain same.

6.3 Characteristics of Textile Wastewaters after treating by Activated Carbon

For batch tests conical fluxes were taken to treat the textile effluents. 100 mL of textile wastewater was taken in each conical flux and 11.0 g of PRHAC were added to every flux. The content of the fluxes were then subjected to mixing in an orbital shaker at 200 rpm. The test was carried out in 40° C temperature and 60 minutes contact time as selected for the study. After the completion of batch tests, effluents filtered were tested for characterization.

Table 6.3: Characteristics of textile wastewaters after treating with activated carbon

Parameter	**Unit**	**Enzyme wash wastewater**	**Desizing wash wastewater**
pH	-	6.5	7.18
Color	Pt-Co	8~16	220~328
BOD	mg/L	4	12
COD	mg O_2/L	421	842
Acidity	mg/L	80	60
Mn	mg/L	20	80
PO_4^-	mg/L	3	5
Cl^-	mg Cl^-/L	150	100

The characteristics of textile wastewaters after batch treated were shown in Table 6.3. Comprise Table 6.1 and 6.3 it was seen that by treating PRHAC reduce about 99 % color from Enzyme wash and Desizing wash wastewater. The COD values, Cl^-, Mn, PO_4^- also reduce at about 65~80 %, 50~60%, 50~55% and 60~85%, respectively.

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6.4 Comparison of adsorption characteristics between different types activated carbon

For this experiment 100 mL of Desizing wash wastewater was taken in each conical flux. Than 1g, 3g, 5g, 8g, 11g and 14g of five different types of activated carbon like laboratory grade activated carbon, PRHAC (crushed), PRHAC (uncrushed) and two commercial grade activated carbons were added to each conical flux. The test was carried out in 40° C temperature and 60 minutes contact time. Fluxes were then subjected to mixing in an orbital shaker at 200 rpm. Percent transmittance of each filtered sample for each conical flux was measured.

Figure 6.1 illustrate the color adsorption of the different types of activated carbon. Sample in beaker at the right of the top of the figure is the untreated textile wastewater. From the top of the Figure 6.1, 1st row represent wastewater treated by laboratory grade activated carbon, 2nd row represent wastewater treated by PRHAC (crushed), 3rd row represent PRHAC (uncrushed), 4th row represent commercial grade activated carbon 1 and 5th row represent commercial grade activated carbon 2. From this it was seen that PRHAC give better adsorption performance than both commercial grade activated carbon.

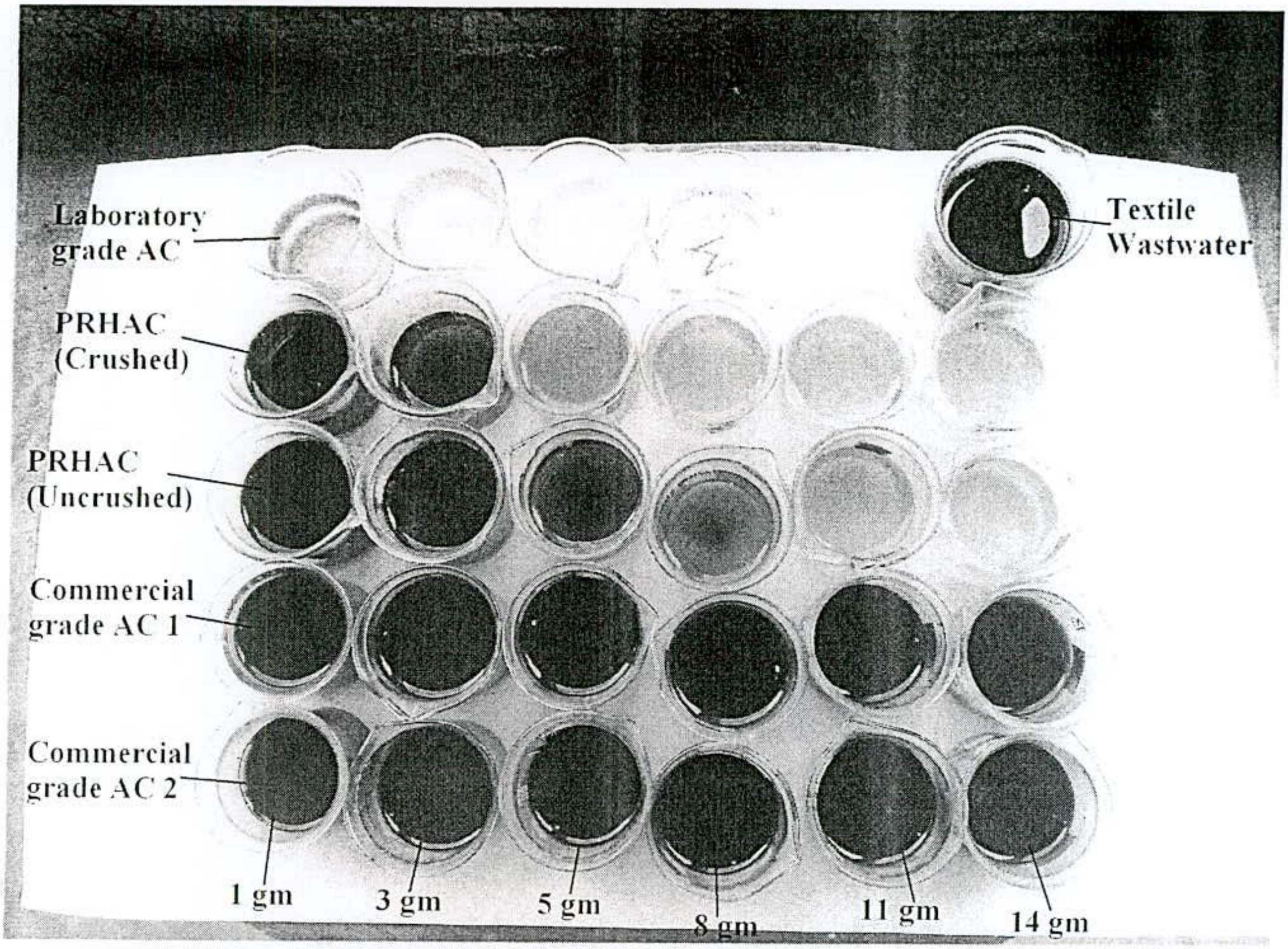


Figure 6.1: Change in color after various treatment of Textile wastewater is clearly shown in different samples

The percentage removals of color with varying doses of different activated carbon at optimal temperature and time are shown in Figure 6.2. At dose 5 g, it can be seen that the color reduction for Laboratory grade, Produced activated carbon (crushed), Produced activated carbon (uncrushed), Commercial grade 1 and commercial grade 2 are 98%, 90%, 75%, 35% and 12%, respectively. Therefore, the PRHAC gives better performance than commercial grade activated carbon. The PRHAC was tested for two conditions. They were tested under crushed and uncrushed state. The activated carbon which was crushed to powder gives better performance than uncrushed prepared activated carbon.

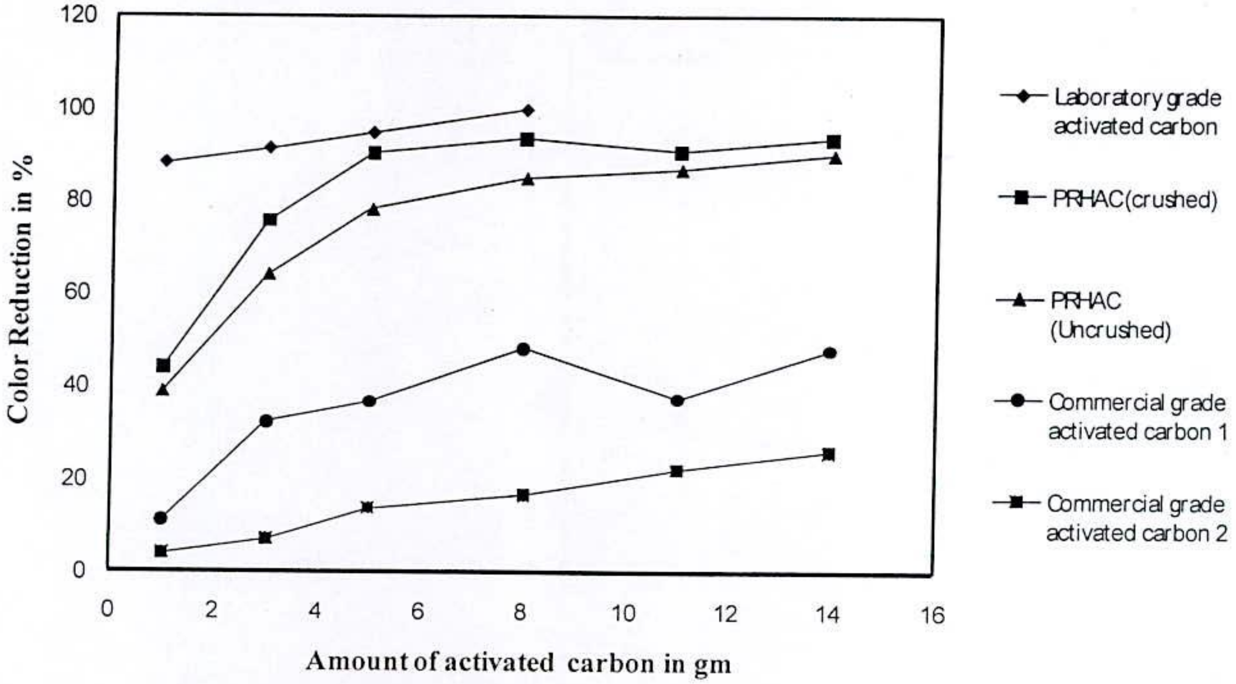
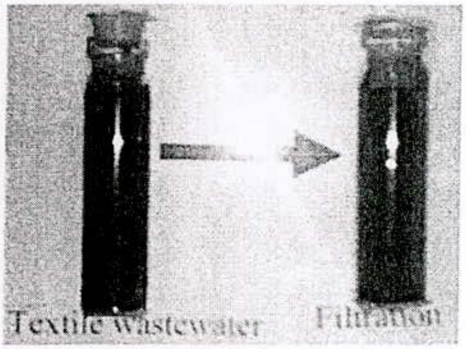


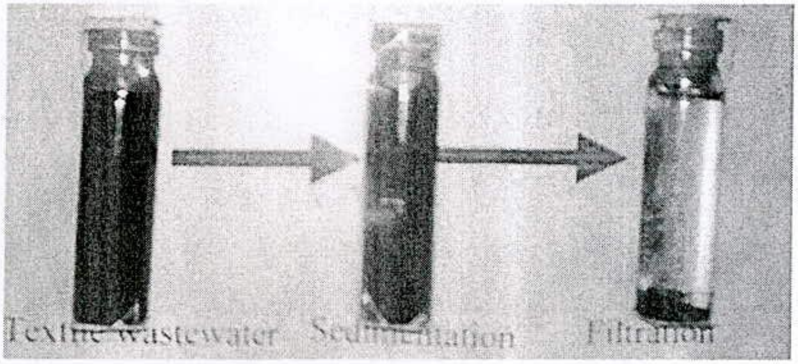
Figure 6.2: Percentage removal of different type's activated carbon

Figure 6.4, 6.5 and 6.6 shows the wastewater color after completing different processes. From these figure it was seen that the effluent from BT 5 is much clear than BT 1. It also seen that the effluent from BT 6 is clear than BT 2, from BT 7 is clear than BT 3 and BT 8 is clear than BT 4.

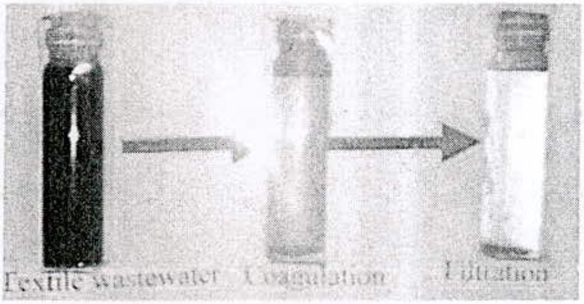
After each process was completed the adsorbed color was measured with spectrophotometer by taking various amount of sample and making them 10 mL with distilled water.



(a) BT 1

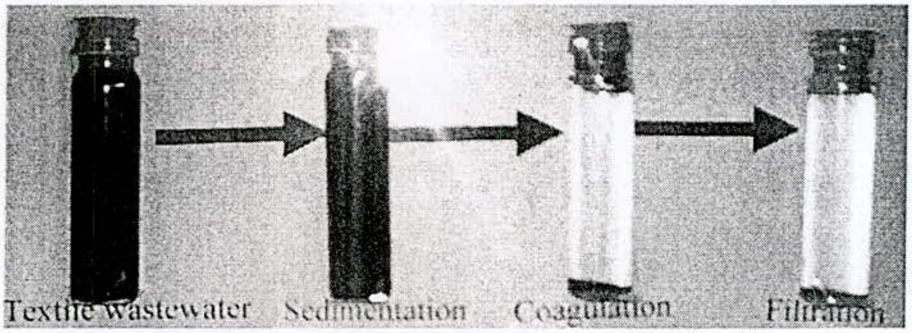


(b) BT 2

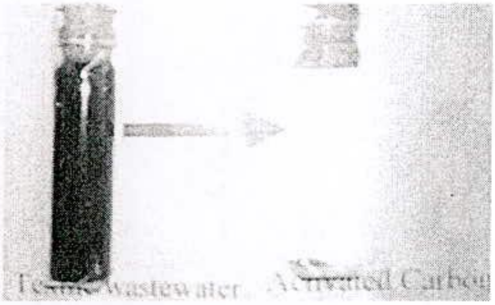


(c) BT 3

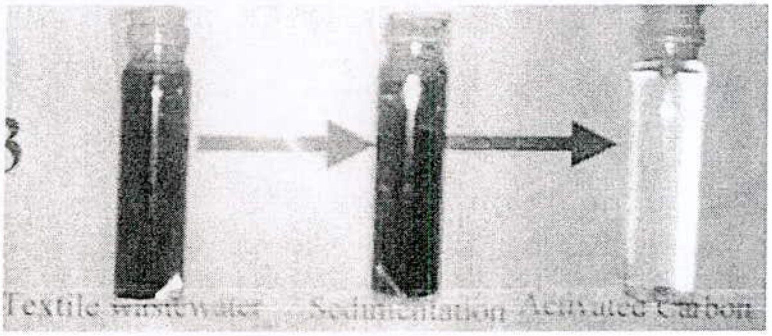
Figure 6.4: Color variation after wastewater passes through different unit process under batch test options (a) BT 1, (b) BT 2 and (c) BT 3



(a) BT 4

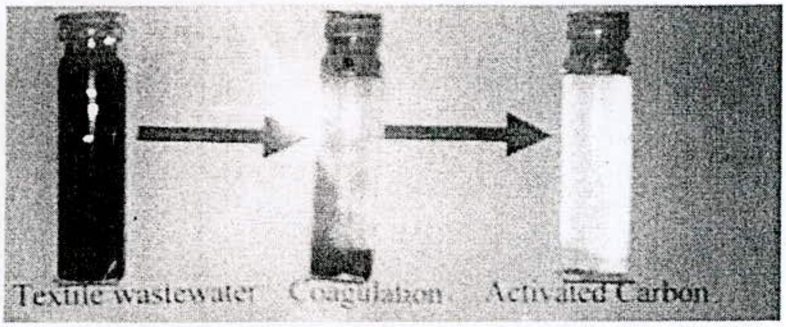


(b) BT 5

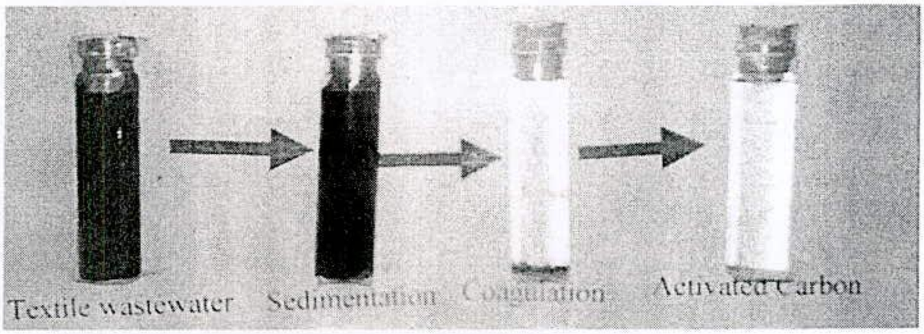


(c) BT 6

Figure 6.5: Color variation after wastewater passes through different unit process under batch test options (a) BT 4, (b) BT 5 and (c) BT 6



(a) BT 7



(b) BT 8

Figure 6.6: Color variation after wastewater passes through different unit process under batch test options (a) BT 7 and (b) BT 8

Table 6.4: Adsorbed color after different process

Batch Test No.	Combination of Batch Test	Amount of sample	Measured color unit in Pt-Co	Dilution Factor	Original color unit in Pt-Co
1	Textile wastewater	0.02 µl	488	500000	244000000
2	Textile wastewater + Sedimentation	0.02 µl	412	500000	206000000
3	Textile wastewater + Sand Filtration	5 µl	422	2000	844000
4	Textile wastewater + Coagulation	0.2 ml	428	50	21400
5	Textile wastewater + Activated Carbon	1 ml	217	10	2170
6	Textile wastewater + Sedimentation + Sand Filtration	1 µl	428	10000	4280000
7	Textile wastewater + Sedimentation + Coagulation	0.2 ml	338	50	16900
8	Textile wastewater + Sedimentation + Activated carbon	1 ml	173	10	1730
9	Textile wastewater + Coagulation + Sand Filtration	5 ml	325	2	650
10	Textile wastewater + Coagulation + Activated Carbon (Direct)	10 ml	239	1	239
11	Textile wastewater + Sedimentation + Coagulation + Sand Filtration	5ml	274	2	548
12	Textile wastewater + Sedimentation + Coagulation + Activated Carbon (Direct)	10 ml	285	1	285

From Table 6.4 shows the color unit of the treated effluent after the end of each process. From this table it is seen that those batch test which have activated carbon unit reduce much color compare to other batch test whose don't have activated carbon unit such as the batch test number 5 reduced higher color than the batch test number 2,3,4; the 10 number batch test reduced highest color from wastewater comprise with batch number 9, the 8 number batch test reduced highest color from wastewater comprise with batch number 6,7,8 and the 12 number batch test reduced highest color from wastewater comprise with batch number 11.

Table 6.5 represents the COD value of different processes wastewater at the end of processes. From this table it was seen that wastewater treated with PRHAC reduced highest COD value than other processes.

Table 6.5: COD value after different process

Serial No.	Combination	COD in mg O_2/L
1	Blank	-
2	Raw	4073
3	Filtration	2037
4	Sedimentation + Filtration	1164
5	Coagulation + Filtration	873
6	Sedimentation + Coagulation + Filtration	3491
7	Activated Carbon	1455
8	Sedimentation + Activated carbon	1746
9	Coagulation + Activated Carbon (Direct)	408
10	Sedimentation + Coagulation + Activated Carbon (Direct)	320
11	Sedimentation	2618
12	Sedimentation + Coagulation (After 30 min)	3491
13	Sedimentation + Coagulation (After 22 hours 30 min)	1455
14	Coagulation (After 30 min)	1455
15	Coagulation (After 22 hours 30 min)	1745

CHAPTER SEVEN

DISCUSSION

7.1 General

The findings revealed from the study have already been stated in the respective sections. In this chapter, the results are discussed successively.

7.2 Fabrication of furnaces and production of activated carbon

Three different types of furnaces were design and fabricated in the laboratory. Locally available materials were used for fabrication. Furnace type A and B were produced sufficient amount of carbon and production rate was good. In the time of operation continuous monitoring on sealing of leak by clays was provided because clay layer was cracked after some hours by propagation of heat. Temperature may slightly rise above 500°C and can be regularly controlled by reducing the fuel namely. A furnace should be sealed properly at time of operation for producing good quality activated carbon. If seal does not work properly, then air will enter in the furnace and may produce higher ash content. The quality of activated carbon produced in Type A furnace is much better than Type B and C furnaces. PRHAC produce from Type B furnace is also good. The production cost of activated carbon using Type B and C furnaces was cheaper than other activated carbon. Because the production cost was found 40.00 BDT and 35.00 BDT per kg for Type B and C furnaces, respectively, whereas the market price of the commercial grade activated carbon varied from 120~250 BDT per kg. PRHAC produced in Type A furnace was costly like 500 BDT per kg because the amount of PRHAC was small for small amount of rice husk input. It was seen that, as the larger amount of activated carbon produced may reduce the production cost of activated carbon.

7.3 Characteristics of Produced Rice Husk Activated Carbon (PRHAC) and Laboratory grade activated carbon

The PRHAC prepared in above 400 °C temperature in absence of air. The bulk density of the PRHAC was 0.38 g/cc and the median pore diameter was 43 Å. The PRHAC absorbed 0.96 g/100g Methylene blue. The adsorption of PRHAC satisfied both Langmuir and Freundlich adsorption isotherm. From the Section 2.5 of the literature review it is seen that the bulk density of the activated carbon is 0.32 g/cc and the mean pore diameter should be greater than 20 Å. It was seen that PRHAC carbon had similar properties like activated carbon as stated in literature review so we can say that the PRHAC is activated carbon.

Different characteristic of different activated carbon are shown in Table 5.1. The ash content of PRHAC was higher than other types of activated carbons. This was because more air entered in the furnaces at operation time and supply oxygen for combustion of rice husk. To reduce this effect complete monitoring of sealing should needed. From the SEM photograph of Figure 5.1, well-developed pore was seen in PRHAC compare to the rice husk.

From Figure 5.2 it was seen that PRHAC adsorb color up to 60 minutes. After that desorption was started. For finding reason of this desorption further study was needed. Figure 5.3 shows the temperature effect on adsorption by produced activated carbon. At 40°C maximum adsorption of color was occurred. After 40°C temperature adsorption rate was decrease. Figure 5.4 shows that the adsorption rate was increased as the adsorbent dose increased. The effect of adsorbent dose satisfied the Freundlich and Langmuir adsorption isotherm. The R^2 value was found 0.956 and 0.95 for Freundlich adsorption isotherm (Figure 5.5) and Langmuir adsorption isotherms (Figure 5.6), respectively.

The adsorption characteristics of laboratory grade activated carbon studied also in this work. The results were shown in Appendix F. Figure F 1.1 shows the adsorbed color removal of laboratory grade activated carbon with varying different time interval. From these figures it was seen that as the time interval increase the adsorption capacity of activated carbon also increase and finally it became almost straight line. Figure F 2.1 represent the color adsorption of activated carbon in different temperature. At about 40°C maximum adsorption was occurred. After that the adsorption rate of activated carbon decreased. Figure F 3.1 and F 3.2 represent the adsorption of color by different amount of activated carbon. From Figure F 3.1 it was seen that, 10 mg laboratory grade activated carbon adsorb about 80 % methylene blue color and about 100% adsorption was achieved for 16 mg activated carbon. From these it also observed that, as the adsorbent dose of activated carbon increase the amount of adsorbed color also increase.

Comparing the graphs of both PRHAC and laboratory grade activated carbon as shown in Figure F 1.1, 2.1 & 3.1 it was seen that, graph trend of both activated carbon were quite similar except the graph for contact time study. The experimental solution should be placed in the conical flux by burette for getting accurate measurement. In the time of placing conical flux in the water bath, the solution in the conical flux should be below the water level. Activated carbon that adsorbs color should be stored in safe place and may used for regeneration activated carbon.

7.4 Treatment of textile effluent

PRHAC adsorbs color better than commercial grade activated carbon. Figure 6.2 shows that PRHAC adsorb 75~90% color from desizing wash effluent; whereas, commercial grade activated carbon adsorb only 12~35% color. Textile wastewater treated with activated carbon reduces BOD, COD, amount of Manganese, Phosphate as shown in Table 6.3. From Table 6.3 it was seen that by treating PRHAC reduce about 99 % color from Enzyme wash and Desizing wash wastewater. The COD values, Cl^-, Mn, PO_4^- also reduce at about 65~80 %, 50~60%, 50~55% and 60~85%, respectively. From Figure 6.4, 6.5 and 6.6 it was seen that the effluent from BT 5 is much clear than BT 1. It also seen that the effluent from BT 6 is clear than BT 2, from BT 7 is clear than BT 3 and BT 8 is clear than BT 4.The textile effluent should be diluted before measuring adsorbed color.

It is seen that PRHAC adsorb 99% color, 90~93% BOD, 67~80% COD, 20~70% acidity, 50~56% Manganese, 63~87% Phosphate and 50~60 % Chloride from enzyme wash and desizing wash wastewater as shown in Table 7.1 and 7.2.

Table 7.1: Characteristics of Enzyme wash wastewater

Parameter	**Unit**	**After collection**	**After treated with PRHAC**	
			Measured value	**%**
pH	-	6.17	6.5	-
Color	Pt-Co	Very deep (7,53,00,000~9,15,00,000)	8~16	99.9
BOD	mg/L	56	4	92.9
COD	mg O_2/L	1263	421	66.7
Acidity	mg/L	100	80	20.0
Mn	mg/L	40	20	50.0
PO_4^-	mg/L	8	3	62.5
Cl^-	mg Cl^-/L	300	150	50.0

Table 7.2: Characteristics of Desizing wash wastewater

Parameter	**Unit**	**After collection**	**After treated with PRHAC**	
			Measured value	**%**
pH	-	6.23	7.18	-
Color	Pt-Co	Very deep (20,10,00,000~24,40,00,00,000)	220~328	99.9
BOD	mg/L	116	12	89.7
COD	mg O_2/L	4211	842	80.0
Acidity	mg/L	200	60	70.0
Mn	mg/L	180	80	55.6
PO_4^-	mg/L	38	5	86.8
Cl^-	mg Cl^-/L	250	100	60.0

CHAPTER EIGHT

CONCLUSION AND RECOMMENDATION

8.1 General

The main objectives of this study are to prepare a low-cost activated carbon for textile effluent treatment. The findings revealed from the study have already been stated in the respective section. In this chapter, the summery of findings are concluded and necessary recommendations are suggested.

8.2 Conclusion

Detailed laboratory analysis and tests were carried out to determine the characteristics and efficiency of color removal of PRHAC. The characteristics of activated carbon were studied with respect to adsorption kinetic study, column study, contact time study, physical properties and textile wastewater treatment efficiency. The main findings from this study are as follows:

1. Low cost furnaces are fabricated which are able to produce activated carbon from rice husk in low cost.
2. PRHAC is justified as activated carbon and have good adsorption capacity compare to commercial grade activated carbon in terms of Methylene blue adsorption.
3. PRHAC is efficient for treating textile wastewater compare to commercial grade activated carbon and other treatment processes like sedimentation, coagulation and sand filtration.
4. The equilibrium study for isotherm was satisfied both Freundlich and Langmuir adsorption isotherms theory. For Freundlich adsorption isotherm, R^2 value was found 0.96. The adsorption capacity and adsorption intensity (n) were found 2.951 g color/g and 2.33, respectively. The values $n > 1$ represent favorable adsorption condition. For Langmuir adsorption isotherm, R^2 value was found 0.95. The adsorption capacity and

bond energy were found 0.526 g color/g and 0.311, respectively. This represents that PRHAC have high adsorption capacity and the quite strong interaction between adsorbate and adsorbent.

5. It is seen that PRHAC adsorb 99% color, 90~93% BOD, 67~80% COD, 20~70% acidity, 50~56% Manganese, 63~87% Phosphate and 50~60 % Chloride from enzyme wash and desizing wash wastewater.

8.3 Recommendation for future work

- The quality of the PRHAC may be improved if furnace fabrication and furnace maintenance improved.
- The PRHAC also may used for treating drinking water as well as reducing heavy metals from industrial wastewater.
- The residue of the PRHAC may have some adsorption power which can be used for treatment of water and wastewater.
- The residue of the used PRHAC may reuse for produced activated carbon.

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Batch 1		Batch 2 (19/10/09)		Batch 3	
Time in min	Temperature in °C	Time in min	Temperature in °C	Time in min	Temperature in °C
		235	395	355	307
		250	480	450	278
		265	367	470	209
		320	312	500	164
		385	206	530	97
		445	164	542	44
		505	97	638	30
		565	46	355	307
		625	32	450	278
				470	209
				500	164
				530	97
				542	44
				638	30

Production cost analysis

For Type A furnace:

Batch 1: (07/09/09)

Rice Husk	250 gm	@ 5 Tk per kg	= 1.25/=
Firewood	5 kg 300 gm	@ 6 Tk per kg	= 31.80/=
Fuel (oil)	100 mL	@ 44 Tk per liter	= 4.40/=
		Total	= 37.45/=

Activated carbon found 78.5 gm

Rate of activated carbon = 37.45/0.0785 = 477.07 ~ 477 Tk per kg

Appendix B

Test results of proximate analysis of different types of activated carbon

Laboratory grade activated carbon

Date: 05/05/10

Table B 1.1: Data for Volatile content (including moisture)

Sample No	Blank (g)	Blank + Sample (Before heat) (g)	Blank + Sample (After heat) (g)	Sample (Before heat) (g)	Sample (After heat) (g)	Volatile Content (Including moisture) (%)
1	29.33	30.34	30.09	1.01	0.76	24.75
2	29.12	30.13	29.88	1.01	0.76	24.75
3	36.67	37.67	37.43	1.00	0.76	24.00

Table B 1.2: Data for Ash content

Sample No	Blank (g)	Blank + Sample (Before heat) (g)	Blank + Sample (After heat) (g)	Sample (Before heat) (g)	Sample (After heat) (g)	Ash content (%)
1	29.33	30.34	29.41	1.01	0.08	7.93
2	29.12	30.13	29.18	1.01	0.06	5.88
3	36.67	37.67	36.72	1.00	0.05	5.00

Table B 1.3: Data for Moisture Content

Sample No	Blank (g)	Blank + Sample (Before heat) (g)	Blank + Sample (After heat) (g)	Sample (Before heat) (g)	Sample (After heat) (g)	Moisture Content (%)
1	18.75	19.78	19.61	1.03	0.86	16.51
2	19.57	20.58	20.41	1.01	0.84	16.83
3	17.91	18.92	18.73	1.01	0.82	18.81

Table B 1.4: Data for Volatile Content (Considering moisture content 16.83%)

Sample No	Volatile Content (Including moisture) (%)	Moisture Content (%)	Volatile Content (%)
1	24.75	16.83	7.92
2	24.75		7.92
3	24.00		7.17

Commercial granular activated carbon

Date: 06/05/10

Table B 2.1: Data for commercial granular activated carbon

Sample No	Moisture Content (%)	Volatile Content (Including moisture) (%)	Ash content (%)	Volatile Content (Considering moisture content of 8%) (%)
1	11.00	28.96	1.98	1.90
2	8.00	29.11	0.99	4.87
3	6.00	36.68	0.00	3.00

Chemically activated carbon

Date: 05/05/10

Table B 3.1: Data for chemically activated carbon

Sample No	Moisture Content (%)	Volatile Content (Including moisture) (%)	Ash content (%)	Volatile Content (Considering moisture content of 6%) (%)
1	6.00	11.88	44.56	5.88
2	6.93	11.00	42.00	5.00
3	5.88	13.86	42.57	7.86

Activated carbon produced in large oven

Date: 06/05/10

Table B 4.1: Data for activated carbon produced in large oven

Sample No	Moisture Content (%)	Volatile Content (Including moisture) (%)	Ash content (%)	Volatile Content (Considering moisture content of 3%) (%)
1	2.00	7.00	58.00	4.00
2	3.00	6.00	56.00	3.00
3	4.00	7.00	57.43	4.00

Activated carbon produced in medium oven

Date: 04/05/10

Table B 5.1: Data for activated carbon produced in medium oven

Sample No	Moisture Content (%)	Volatile Content (Including moisture) (%)	Ash content (%)	Volatile Content (Considering moisture content of 1.96%) (%)
1	-	9.90	50.50	7.94
2	2.97	11.00	46.00	9.04
3	1.96	6.93	53.47	4.97

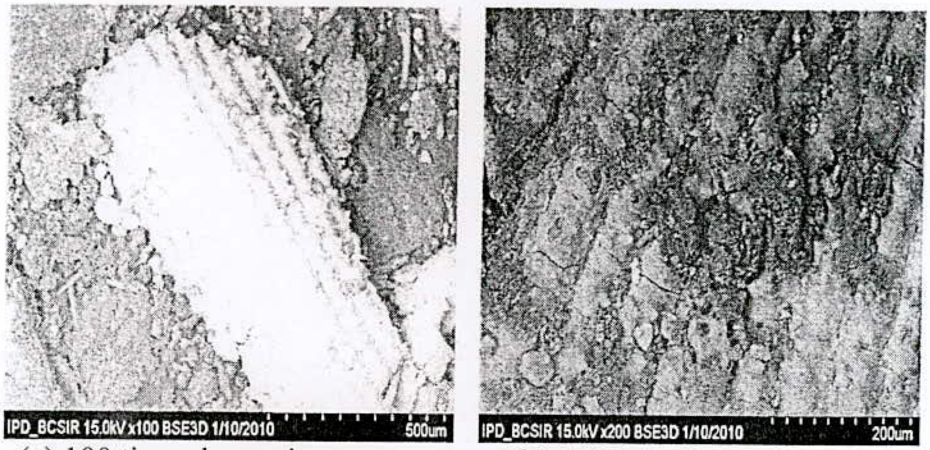
Activated carbon produced in small oven

Date: 04/05/10

Table B 6.1: Data for activated carbon produced in medium oven

Sample No	Moisture Content (%)	Volatile Content (Including moisture) (%)	Ash content (%)	Volatile Content (Considering moisture content of 1%) (%)
1	1.98	1.98	64.36	0.98
2	-	7.77	55.34	6.77
3	1.00	7.00	54.46	6.00

SEM Photograph

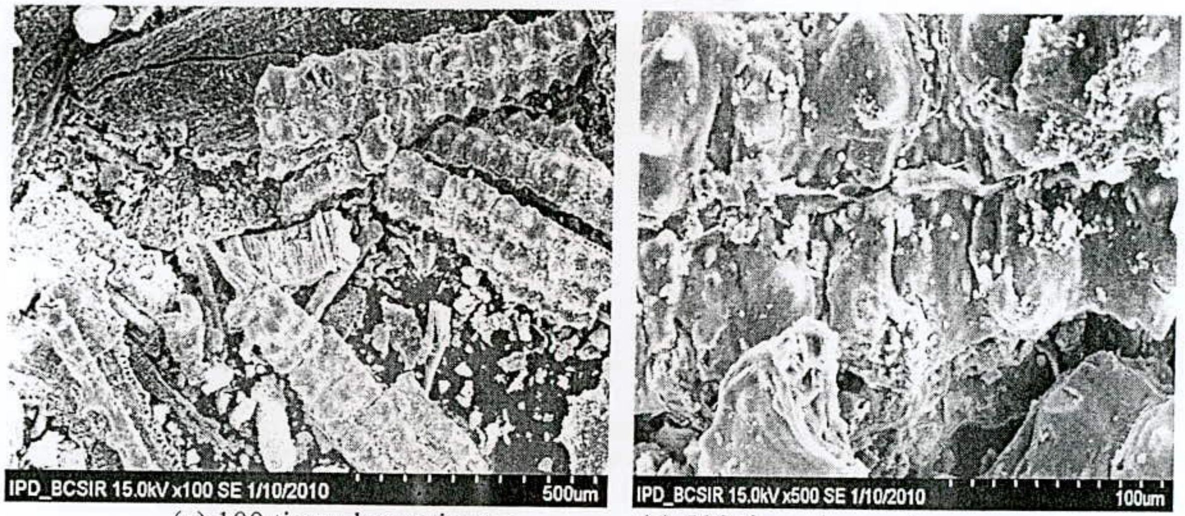


(a) 100 times larger image (b) 200 times larger image

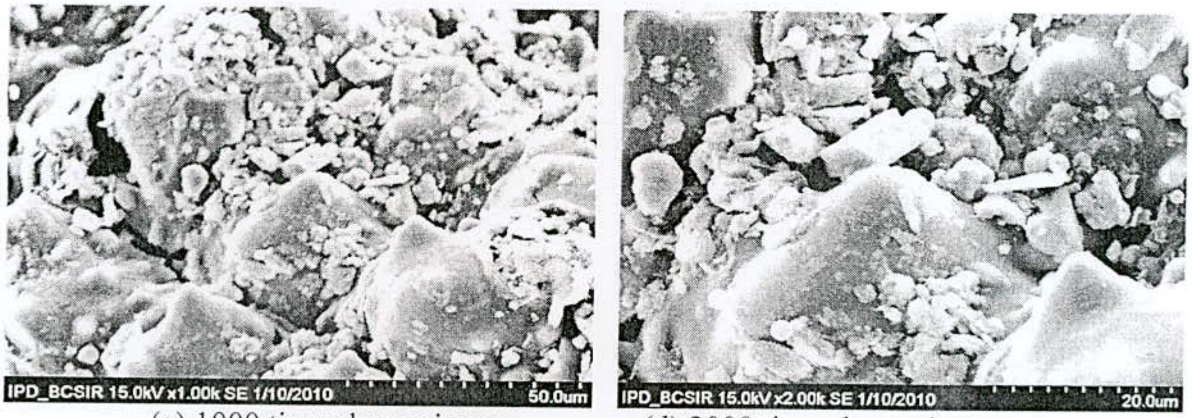
(c) 500 times larger image (d) 1000 times larger image

(e) 5000 times larger image

Figure B 1: SEM Photograph of rice husk



(a) 100 times larger image (e) 500 times larger image



(c) 1000 times larger image (d) 2000 times larger image

Figure B 2: SEM Photograph of produced activated carbon

Appendix C

Test results of temperature effect of PRHAC

Date: 15-06-10

Activated carbon was added in 100 mL experimental sample

Table C 1.1: Adsorption of color for temperature variation in Pt-Co

Temp	Raw*	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Standard Deviation	Average
29.1	449	24	25	23	27	25	23	26	23	25	24	1.35	24.5
32.7	449	21	17	19	23	18	18	17	22	23	25	2.87	20.3
34.6	449	11	15	14	13	9	12	10	13	13	10	1.94	12
37.3	449	0	6	4	5	7	6	9	5	7	8	2.50	5.7
40.0	449	0	0	3	1	3	0	2	0	1	1	1.20	1.1
42.7	449	32	28	36	35	32	29	34	28	30	33	2.87	31.7
45.1	449	38	43	42	48	37	30	38	49	46	44	5.82	41.5
50.0	449	52	50	63	51	58	49	62	65	56	62	6.01	56.8
55.0	449	78	82	89	76	84	89	79	76	83	82	4.71	81.8
60.0	449	92	108	95	104	96	98	105	94	102	106	5.68	100

*Amount of color added was 24 mg/L

Table C 1.2: Adsorption of color for temperature variation in percentage (%)

Temp	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Average	mg/L
29.1	94.65	94.43	94.88	93.99	94.43	94.88	94.21	94.88	94.43	94.65	94.54	22.69
32.7	95.32	96.21	95.77	94.88	95.99	95.99	96.21	95.10	94.88	94.43	95.48	22.91
34.6	97.55	96.66	96.88	97.10	98.00	97.33	97.77	97.10	97.10	97.77	97.33	23.36
37.3	100.00	98.66	99.11	98.89	98.44	98.66	98.00	98.89	98.44	98.22	98.73	23.70
40.0	100.00	100.00	99.33	99.78	99.33	100.00	99.55	100.00	99.78	99.78	99.76	23.94
42.7	92.87	93.76	91.98	92.20	92.87	93.54	92.43	93.76	93.32	92.65	92.94	22.31
45.1	91.54	90.42	90.65	89.31	91.76	93.32	91.54	89.09	89.76	90.20	90.76	21.78
50.0	88.42	88.86	85.97	88.64	87.08	89.09	86.19	85.52	87.53	86.19	87.35	20.96
55.0	82.63	81.74	80.18	83.07	81.29	80.18	82.41	83.07	81.51	81.74	81.78	19.63
60.0	79.51	75.95	78.84	76.84	78.62	78.17	76.61	79.06	77.28	76.39	77.73	18.65

Appendix D

Test results of contact time study

Date: 21/06/10

For all tests the temperature was 40 ± 0.1 °C. Activated carbon was added in 100 mL experimental sample

Table D 1.1: Adsorption of color for contact time variation

SL No	Time (min)	Raw* Pt-Co	Sample 1		Sample 2		Sample 3		Standard Deviation	Average (%)	mg/L
			Pt-Co	%	Pt-Co	%	Pt-Co	%			
1	5	477	92	80.71	94	80.29	91	80.92	1.53	80.64	19.35
2	10	477	65	86.37	68	85.74	68	85.74	1.73	85.95	20.63
3	15	477	58	87.84	64	86.58	65	86.37	3.79	86.93	20.86
4	20	477	63	86.79	61	87.21	64	86.58	1.53	86.86	20.85
5	25	477	60	87.42	59	87.63	59	87.63	0.58	87.56	21.01
6	30	477	56	88.26	56	88.26	56	88.26	0.00	88.26	21.18
7	35	477	54	88.68	52	89.10	51	89.31	1.53	89.03	21.37
8	40	477	49	89.73	46	90.36	49	89.73	1.73	89.94	21.58
9	45	477	38	92.03	40	91.61	43	90.99	2.52	91.54	21.97
10	50	477	25	94.76	28	94.13	30	93.71	2.52	94.20	22.61
11	55	477	16	96.65	12	97.48	18	96.23	3.06	96.79	23.23
12	60	477	0	100.00	1	99.79	0	100.00	0.58	99.93	23.98
13	65	477	8	98.32	12	97.48	10	97.90	2.00	97.90	23.50
14	70	477	22	95.39	25	94.76	20	95.81	2.52	95.32	22.88
15	75	477	32	93.29	29	93.92	28	94.13	2.08	93.78	22.51
16	80	477	44	90.78	49	89.73	47	90.15	2.52	90.22	21.65
17	85	477	58	87.84	54	88.68	57	88.05	2.08	88.19	21.17
18	90	477	63	86.79	66	86.16	62	87.00	2.08	86.65	20.80
19	95	477	72	84.91	75	84.28	78	83.65	3.00	84.28	20.23
20	100	477	83	82.60	86	81.97	85	82.18	1.53	82.25	19.74

*Amount of color added was 24 mg/L

Test result of adsorbent dose study

Date: 14/06/10

For all tests the temperature was 30 ± 0.1 °C. Activated carbon was added in 100 mL experimental sample

Table D 2.1: Adsorption of color for different adsorption dose

SL No	Amount (mg)	Raw* Pt-Co	Sample 1		Sample 2		Sample 3		Standard Deviation	Average	mg/L
			Pt-Co	%	Pt-Co	%	Pt-Co	%			
1	50	483	362	25.05	365	24.43	360	25.47	2.52	24.98	6.00
2	100	483	357	26.09	354	26.71	358	25.88	2.08	26.22	6.29
3	150	483	320	33.75	318	34.16	315	34.78	2.52	34.23	8.22
4	200	483	313	35.20	310	35.82	311	35.61	1.53	35.54	8.53
5	250	483	299	38.10	294	39.13	300	37.89	3.21	38.37	9.21
6	300	460	232	49.57	230	50.00	238	48.26	4.16	49.28	11.83
7	350	460	222	51.74	225	51.09	228	50.43	3.00	51.09	12.26
8	400	460	218	52.61	214	53.48	220	52.17	3.06	52.75	12.66
9	450	460	195	57.61	193	58.04	198	56.96	2.52	57.54	13.81
10	502	460	174	62.17	172	62.61	175	61.96	1.53	62.25	14.94
11	550	460	150	67.39	156	66.09	148	67.83	4.16	67.10	16.10
12	600	460	134	70.87	130	71.74	139	69.78	4.51	70.80	16.99
13	652	460	117	74.57	125	72.83	113	75.43	6.11	74.28	17.83
14	700	460	104	77.39	109	76.30	102	77.83	3.61	77.17	18.52
15	750	460	95	79.35	96	79.13	95	79.35	0.58	79.28	19.03
16	800	469	98	79.10	94	79.96	95	79.74	2.08	79.60	19.10
17	850	469	90	80.81	90	80.81	92	80.38	1.15	80.67	19.36
18	905	469	86	81.66	88	81.24	83	82.30	2.52	81.73	19.62
19	950	469	78	83.37	80	82.94	85	81.88	3.61	82.73	19.86
20	1002	469	73	84.43	68	85.50	75	84.01	3.61	84.65	20.32
21	1050	469	65	86.14	63	86.57	66	85.93	1.53	86.21	20.69
22	1108	469	62	86.78	60	87.21	62	86.78	1.15	86.92	20.86
23	1150	469	59	87.42	58	87.63	56	88.06	1.53	87.70	21.05
24	1208	469	54	88.49	53	88.70	55	88.27	1.00	88.49	21.24
25	1251	469	56	88.06	58	87.63	55	88.27	1.53	87.99	21.12
26	1300	469	52	88.91	50	89.34	53	88.70	1.53	88.98	21.36
27	1350	469	58	87.63	56	88.06	59	87.42	1.53	87.70	21.05
28	1400	469	49	89.55	48	89.77	52	88.91	2.08	89.41	21.46
29	1450	469	50	89.34	49	89.55	47	89.98	1.53	89.62	21.51
30	1518	469	48	89.77	46	90.19	45	90.41	1.53	90.12	21.63
31	1553	469	50	89.34	46	90.19	48	89.77	2.00	89.77	21.54
32	1600	469	52	88.91	50	89.34	50	89.34	1.15	89.20	21.41
33	1650	469	46	90.19	43	90.83	48	89.77	2.52	90.26	21.66
34	1700	469	39	91.68	40	91.47	42	91.04	1.53	91.40	21.94
35	1852	469	42	91.04	40	91.47	40	91.47	1.15	91.33	21.92

SL No	Amount (mg)	Raw* Pt-Co	Sample 1		Sample 2		Sample 3		Standard Deviation	Average	mg/L
			Pt-Co	%	Pt-Co	%	Pt-Co	%			
36	1900	469	45	90.41	43	90.83	41	91.26	2.00	90.83	21.80
37	2005	469	41	91.26	45	90.41	42	91.04	2.08	90.90	21.82
38	2050	469	40	91.47	40	91.47	41	91.26	0.58	91.40	21.94
39	2100	469	43	90.83	42	91.04	43	90.83	0.58	90.90	21.82
40	2150	469	38	91.90	39	91.68	38	91.90	0.58	91.83	22.04
41	2200	469	36	92.32	35	92.54	38	91.90	1.53	92.25	22.14
42	2250	469	37	92.11	36	92.32	36	92.32	0.58	92.25	22.14
43	2300	469	34	92.75	33	92.96	30	93.60	2.08	93.11	22.35
44	2358	469	32	93.18	29	93.82	31	93.39	1.53	93.46	22.43
45	2400	469	35	92.54	32	93.18	28	94.03	3.51	93.25	22.38
46	2450	469	30	93.60	30	93.60	29	93.82	0.58	93.67	22.48
47	2500	469	32	93.18	31	93.39	31	93.39	0.58	93.32	22.40
48	2550	469	28	94.03	29	93.82	27	94.24	1.00	94.03	22.57
49	2600	469	26	94.46	23	95.10	21	95.52	2.52	95.02	22.80
50	2650	469	22	95.31	15	96.80	18	96.16	3.51	96.09	23.06
51	2700	469	25	94.67	22	95.31	26	94.46	2.08	94.81	22.75
52	2750	469	19	95.95	17	96.38	20	95.74	1.53	96.02	23.04
53	2800	469	14	97.01	13	97.23	13	97.23	0.58	97.16	23.32
54	2850	469	18	96.16	20	95.74	22	95.31	2.00	95.74	22.98
55	2900	469	20	95.74	21	95.52	18	96.16	1.53	95.81	22.99
56	2950	469	16	96.59	15	96.80	17	96.38	1.00	96.59	23.18
57	3011	469	12	97.44	11	97.65	12	97.44	0.58	97.51	23.40
58	3050	469	13	97.23	14	97.01	13	97.23	0.58	97.16	23.32
59	3100	469	10	97.87	12	97.44	10	97.87	1.15	97.73	23.46
60	3150	469	5	98.93	6	98.72	4	99.15	1.00	98.93	23.74
61	3200	469	8	98.29	8	98.29	11	97.65	1.73	98.08	23.54
62	3250	469	8	98.29	10	97.87	9	98.08	1.00	98.08	23.54
63	3300	469	3	99.36	5	98.93	6	98.72	1.53	99.00	23.76
64	3350	469	4	99.15	7	98.51	5	98.93	1.53	98.86	23.73
65	3400	469	4	99.15	4	99.15	4	99.15	0.00	99.15	23.80
66	3450	469	3	99.36	2	99.57	2	99.57	0.58	99.50	23.88
67	3500	469	2	99.57	1	99.79	0	100.00	1.00	99.79	23.95

*Amount of color added was 24 mg/L

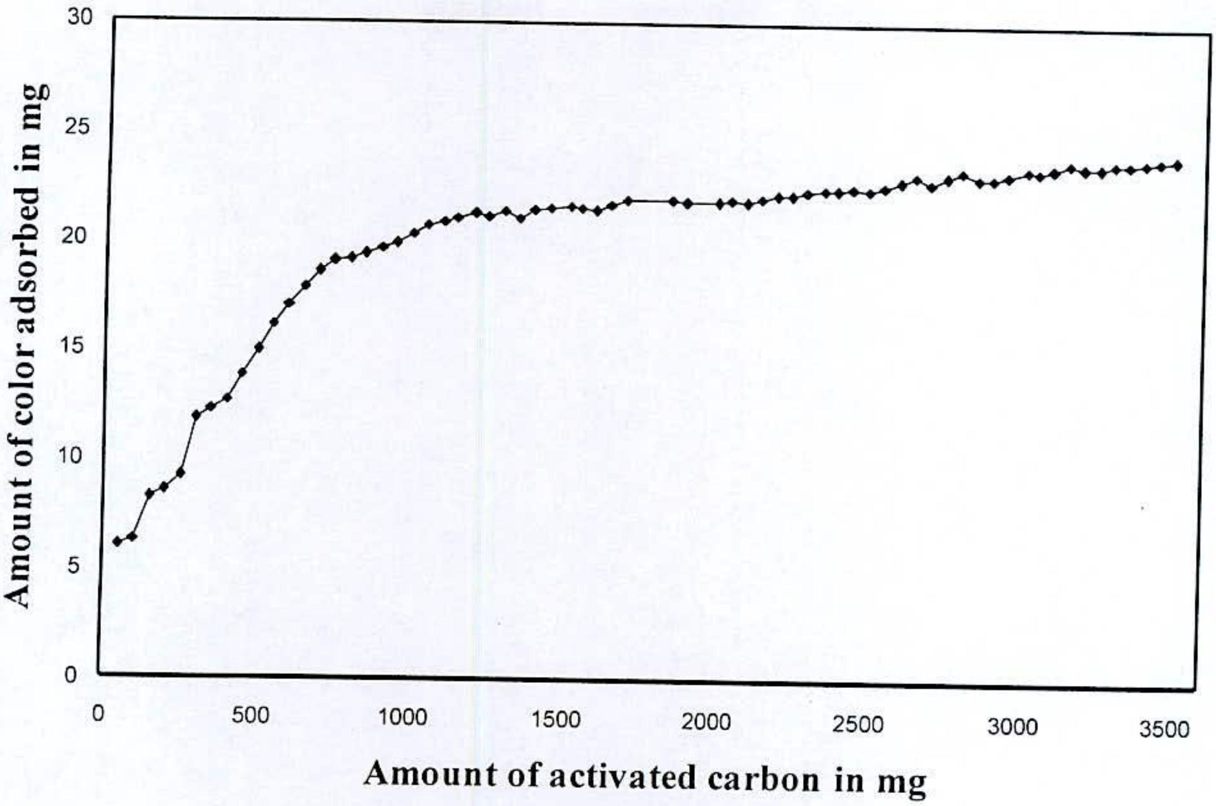


Figure D 1: Effect of adsorbent dose

Test results of contact time and adsorption dose study

Date: 09-07-10 ~ 11-07-10

Sample is prepared by mixing 24 mg methalyene blue in 1000 mL DW. A sample of 100 mL was taken. The study was conducted at 40^{0}C temperature. The raw was found 500 Pt-Co.

Table D 3.1: Adsorption of color for different adsorption dose and contact time variation

Amount(gm)/ Time(min)	50 mg			100 mg			150 mg			200 mg			250 mg		
	Pt-Co	%	mg	Pt-Co	%	mg	Pt-Co	%	mg	Pt-Co	%	mg	Pt-Co	%	mg
5	444	11.20	2.69	407	18.60	4.46	392	21.60	5.18	379	24.20	5.81	362	27.60	6.62
10	421	15.80	3.79	399	20.20	4.85	390	22.00	5.28	374	25.20	6.05	359	28.20	6.77
15	402	19.60	4.70	393	21.40	5.14	382	23.60	5.66	367	26.60	6.38	349	30.20	7.25
20	392	21.60	5.18	384	23.20	5.57	374	25.20	6.05	362	27.60	6.62	345	31.00	7.44
25	384	23.20	5.57	375	25.00	6.00	368	26.40	6.34	353	29.40	7.06	334	33.20	7.97
30	376	24.80	5.95	367	26.60	6.38	362	27.60	6.62	349	30.20	7.25	327	34.60	8.30
35	375	25.00	6.00	367	26.60	6.38	360	28.00	6.72	338	32.40	7.78	324	35.20	8.45
40	373	25.40	6.10	365	27.00	6.48	357	28.60	6.86	331	33.80	8.11	320	36.00	8.64
45	371	25.80	6.19	361	27.80	6.67	355	29.00	6.96	324	35.20	8.45	318	36.40	8.74
50	371	25.80	6.19	359	28.20	6.77	352	29.60	7.10	318	36.40	8.74	312	37.60	9.02
55	370	26.00	6.24	355	29.00	6.96	345	31.00	7.44	315	37.00	8.88	306	38.80	9.31
60	370	26.00	6.24	353	29.40	7.06	343	31.40	7.54	312	37.60	9.02	303	39.40	9.46
65	378	24.40	5.86	357	28.60	6.86	348	30.40	7.30	319	36.20	8.69	310	38.00	9.12
70	381	23.80	5.71	362	27.60	6.62	352	29.60	7.10	323	35.40	8.50	313	37.40	8.98
75	389	22.20	5.33	368	26.40	6.34	357	28.60	6.86	328	34.40	8.26	318	36.40	8.74
80	392	21.60	5.18	375	25.00	6.00	368	26.40	6.34	334	33.20	7.97	322	35.60	8.54
85	398	20.40	4.90	384	23.20	5.57	374	25.20	6.05	342	31.60	7.58	326	34.80	8.35
90	403	19.40	4.66	392	21.60	5.18	378	24.40	5.86	351	29.80	7.15	331	33.80	8.11
95	410	18.00	4.32	398	20.40	4.90	384	23.20	5.57	363	27.40	6.58	345	31.00	7.44
100	412	17.60	4.22	405	19.00	4.56	390	22.00	5.28	374	25.20	6.05	347	30.60	7.34

Adsorption Isotherms Data for analysis

Table D 4.1: Data for adsorption isotherm analysis

Initial adsorbed Co (mg)	Final adsorbed Ce (mg)	Amount of adsorbed x (mg)	Amount of adsorbent m (g)	x/m (mg/mg)	Ce/(x/m)	log (x/m)	log Ce
24	24	0	0	-	-	-	-
24	14.98	9.02	2.0	0.00451	3321.51	-2.34582	1.175512
24	14.54	9.46	2.5	0.00378	3842.49	-2.42205	1.162564
24	13.92	10.08	3.0	0.00336	4142.86	-2.47366	1.143639
24	13.3	10.7	3.5	0.00306	4350.47	-2.51468	1.123852
24	11.52	12.48	4.0	0.00312	3692.31	-2.50585	1.061452
24	10.85	13.15	4.5	0.00292	3712.93	-2.53429	1.03543
24	10.42	13.58	5.0	0.00272	3836.52	-2.56607	1.017868
24	9.65	14.35	5.5	0.00261	3698.61	-2.58351	0.984527
24	8.4	15.6	6.0	0.00260	3230.77	-2.58503	0.924279
24	6.82	17.18	6.5	0.00264	2580.33	-2.57789	0.833784
24	6.48	17.52	7.0	0.00250	2589.04	-2.60156	0.811575
24	5.33	18.67	7.5	0.00249	2141.14	-2.60392	0.726727
24	4.99	19.01	8.0	0.00238	2099.95	-2.62411	0.698101
24	4.61	19.39	8.5	0.00228	2020.89	-2.64184	0.663701
24	4.18	19.82	9.0	0.00220	1898.08	-2.65714	0.621176
24	3.7	20.3	9.5	0.00214	1731.53	-2.67023	0.568202
24	3.46	20.54	10.0	0.00205	1684.52	-2.68740	0.539076
24	3.41	20.59	10.5	0.00196	1738.95	-2.70753	0.532754
24	3.26	20.74	11.0	0.00189	1729.03	-2.72458	0.513218
24	3.17	20.83	11.5	0.00181	1750.12	-2.74201	0.501059
24	3.07	20.93	12.0	0.00174	1760.15	-2.75841	0.487138
24	2.74	21.26	12.5	0.00170	1611.01	-2.76935	0.437751
24	2.59	21.41	13.0	0.00165	1572.63	-2.78333	0.4133
24	2.4	21.6	13.5	0.00160	1500.00	-2.79588	0.380211
24	2.16	21.84	14.0	0.00156	1384.62	-2.80688	0.334454
24	2.02	21.98	14.5	0.00152	1332.58	-2.81934	0.305351
24	1.92	22.08	15.0	0.00147	1304.35	-2.83209	0.283301
24	1.82	22.18	15.5	0.00143	1271.87	-2.84437	0.260071
24	1.73	22.27	16.0	0.00139	1242.93	-2.85640	0.238046
24	1.82	22.18	16.5	0.00134	1353.92	-2.87152	0.260071
24	1.68	22.32	17.0	0.00131	1279.57	-2.88175	0.225309
24	1.58	22.42	17.5	0.00128	1233.27	-2.89240	0.198657
24	1.34	22.66	18.0	0.00126	1064.43	-2.90001	0.127105
24	1.01	22.99	18.5	0.00124	812.74	-2.90563	0.004321
24	0.58	23.42	19.0	0.00123	470.54	-2.90917	-0.23657
24	0.34	23.66	19.5	0.00121	280.22	-2.91602	-0.46852
24	0.19	23.81	20.0	0.00119	159.60	-2.92427	-0.72125
24	0.14	23.86	20.5	0.00116	120.28	-2.93408	-0.85387
24	0.1	23.9	21.0	0.00114	87.87	-2.94382	-1
24	0.1	23.9	21.5	0.00111	89.96	-2.95404	-1
24	0.05	23.95	22.0	0.00109	45.93	-2.96312	-1.30103
24	0	24	22.5	0.00107	0.00	-2.97197	-

Appendix E

Results for column Study

Sample is prepared by mixing 100 mg methalyene blue in 1000 mL DW. The study was conducted in room temperature. The raw color was found 433 Pt-Co for dilution ratio 1:5.

Date: 25/08/10

Table E 1.1: Data for 10 cm column

Time (min)	Pt-Co	Volume of Treated water (mL)	Cumulative Volume (mL)	Color Remaining (%)	Color Remaining (mg)	Dilution ratio
0	433	-	-	100.00	100.00	1:5
5	97	23.0	23.00	4.48	4.48	DM*
10	196	29.0	52.00	9.05	9.05	DM*
15	315	16.0	68.00	14.55	14.55	DM*
20	108	27.0	95.00	24.94	24.94	1:5
25	220	27.0	122.00	50.81	50.81	1:5
30	189	11.0	133.00	43.65	43.65	1:5
35	255	17.5	150.50	58.89	58.89	1:5
40	261	28.0	178.50	60.28	60.28	1:5
45	273	16.0	194.50	63.05	63.05	1:5
50	295	21.0	215.50	68.13	68.13	1:5
55	287	13.5	229.00	66.28	66.28	1:5
60	295	15.5	244.50	68.13	68.13	1:5
65	236	11.0	255.50	54.50	54.50	1:5
70	249	18.0	273.50	57.51	57.51	1:5
75	288	16.5	290.00	66.51	66.51	1:5
80	286	16.0	306.00	66.05	66.05	1:5
85	295	12.0	318.00	68.13	68.13	1:5
90	308	14.0	332.00	71.13	71.13	1:5
95	316	11.0	343.00	72.98	72.98	1:5
100	321	15.0	358.00	74.13	74.13	1:5
105	337	12.0	370.00	77.83	77.83	1:5
110	346	10.0	380.00	79.91	79.91	1:5
115	352	11.0	391.00	81.29	81.29	1:5
120	358	13.0	404.00	82.68	82.68	1:5
125	370	12.0	416.00	85.45	85.45	1:5
130	382	9.0	425.00	88.22	88.22	1:5
135	389	10.0	435.00	89.84	89.84	1:5
140	396	13.0	448.00	91.45	91.45	1:5
145	411	8.0	456.00	94.92	94.92	1:5

Time (min)	Pt-Co	Volume of Treated water (mL)	Cumulative Volume (mL)	Color Remaining (%)	Color Remaining (mg)	Comment
150	425	9.0	465.00	98.15	98.15	1.5
155	430	7.0	472.00	99.31	99.31	1.5
160	428	8.0	480.00	98.85	98.85	1.5
165	432	8.0	488.00	99.77	99.77	1.5

*DM = Direct measurement

Calculation:

Considering 20 cm column

0.005 kg PRHAC completely removes color from 0.128 L color solution
So 1 kg PRHAC completely removes color from = (0.128/0.005) = 25.6 L ~ $\boxed{\text{26 L}}$ color solution

Considering 30 cm column

0.0075 kg PRHAC completely removes color from 0.260 L color solution
So 1 kg PRHAC completely removes color from = (0.260/0.0075) = 34.67 L ~ $\boxed{\text{35 L}}$ color solution

Appendix F

Test results of Laboratory grade Activated carbon

Contact Time Study

The raw solution was made by dissolving 24 mg methelyne blue in 1000 ml DW.

Date: 09/06/10

Table F 1.1: Data for adsorbed color varying with time

Serial No	Time (min)	Raw	Pt-Co	% color reduction	Amount of adsorbed color (mg)
1	5	445	139	68.76	16.50
2	10	445	117	73.71	17.69
3	15	445	97	78.20	18.77
4	20	445	93	79.10	18.98
5	25	445	70	84.27	20.22
6	30	445	62	86.07	20.66
7	35	445	44	90.11	21.63
8	40	382	22	94.24	22.62
9	45	382	18	95.29	22.87
10	50	382	12	96.86	23.25
11	55	382	7	98.17	23.56
12	60	382	3	99.21	23.81
13	65	382	3	99.21	23.81

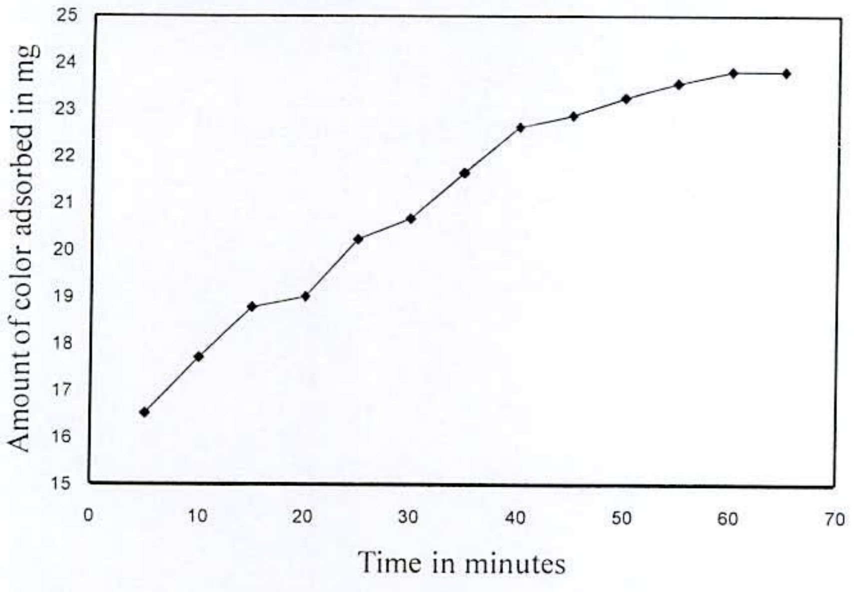


Figure F 1.1: Amount of color removal in different time of laboratory grade activated carbon

Temperature Effect Study

Date: 07/06/10

Raw = 432 Pt-Co, each conical flask is filled with 90 ml color sample and 12 mg activated carbon

Table F 2.1: Data for adsorbed color varying with different temperature

Sample Number	Temperature	Color unit (pt-co)	% color reduction	Amount of adsorbed color (mg)
1	29.7	80	81.48	19.56
2	30.1	74	82.87	19.89
3	32.6	66	84.72	20.33
4	35.1	49	88.66	21.28
5	37.5	41	90.51	21.72
6	40.0	30	93.06	22.33
7	44.6	58	86.57	20.78
8	50	72	83.33	20.00

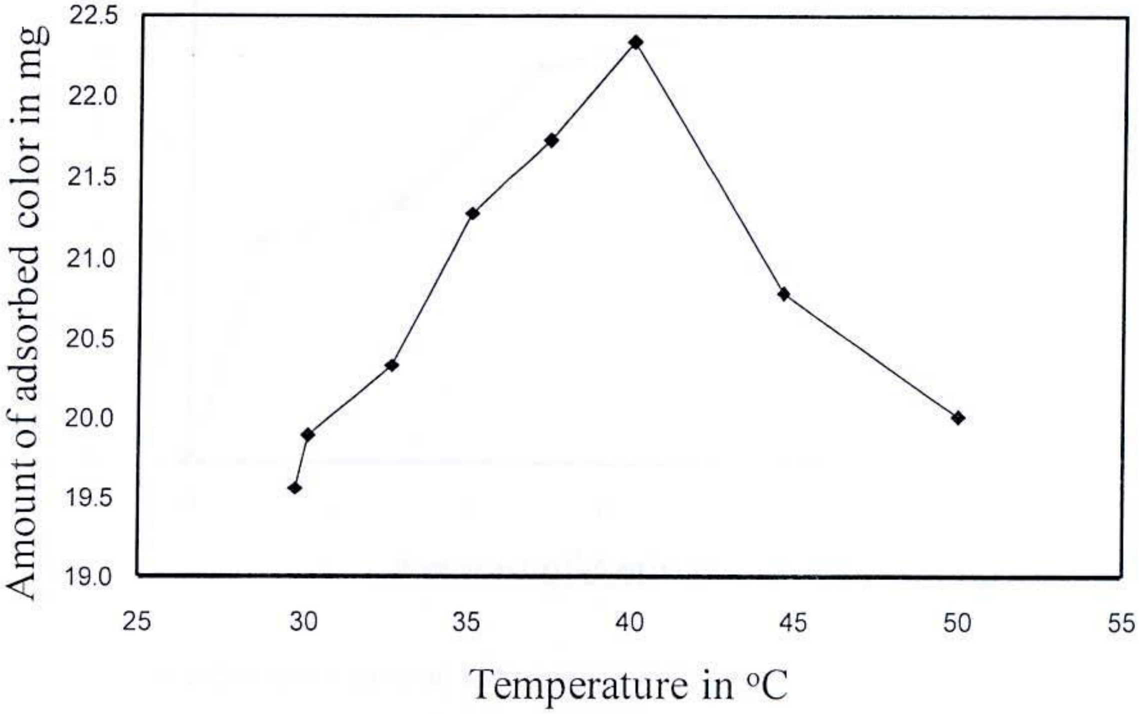


Figure F 2.1: Amount of color removal in different temperature of laboratory grade activated carbon

Appendix F

Test results of Laboratory grade Activated carbon

Contact Time Study

The raw solution was made by dissolving 24 mg methelyne blue in 1000 ml DW.

Date: 09/06/10

Table F 1.1: Data for adsorbed color varying with time

Serial No	Time (min)	Raw	Pt-Co	% color reduction	Amount of adsorbed color (mg)
1	5	445	139	68.76	16.50
2	10	445	117	73.71	17.69
3	15	445	97	78.20	18.77
4	20	445	93	79.10	18.98
5	25	445	70	84.27	20.22
6	30	445	62	86.07	20.66
7	35	445	44	90.11	21.63
8	40	382	22	94.24	22.62
9	45	382	18	95.29	22.87
10	50	382	12	96.86	23.25
11	55	382	7	98.17	23.56
12	60	382	3	99.21	23.81
13	65	382	3	99.21	23.81

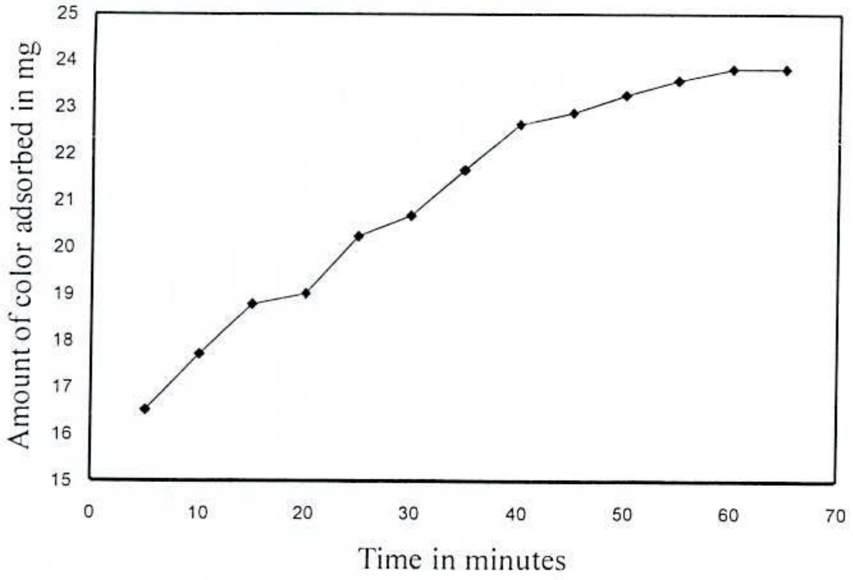


Figure F 1.1: Amount of color removal in different time of laboratory grade activated carbon

Temperature Effect Study

Date: 07/06/10

Raw = 432 Pt-Co, each conical flask is filled with 90 ml color sample and 12 mg activated carbon

Table F 2.1: Data for adsorbed color varying with different temperature

Sample Number	Temperature	Color unit (pt-co)	% color reduction	Amount of adsorbed color (mg)
1	29.7	80	81.48	19.56
2	30.1	74	82.87	19.89
3	32.6	66	84.72	20.33
4	35.1	49	88.66	21.28
5	37.5	41	90.51	21.72
6	40.0	30	93.06	22.33
7	44.6	58	86.57	20.78
8	50	72	83.33	20.00

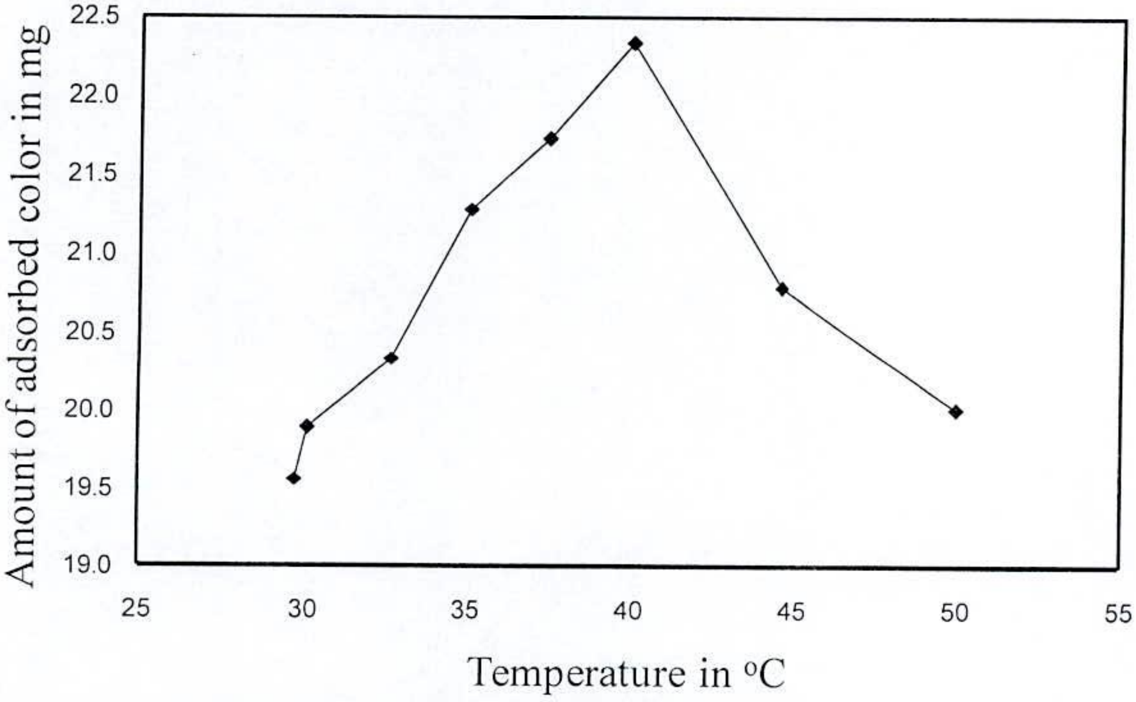


Figure F 2.1: Amount of color removal in different temperature of laboratory grade activated carbon

Activated carbon dose study

The carbon was put on each conical flask and than add 90 ml raw solution in each conical flask.

Date: 04/06/06

Table F 3.1: Data for adsorbed color varying with different amount of activated carbon

Amount of Carbon	Color Unit	%	Amount of adsorbed color (mg)
0	310	0.00	0
1	180	41.94	10.06
3	156	49.68	11.92
5	77	75.16	18.04
9	38	87.74	21.06
10	30	90.32	21.68

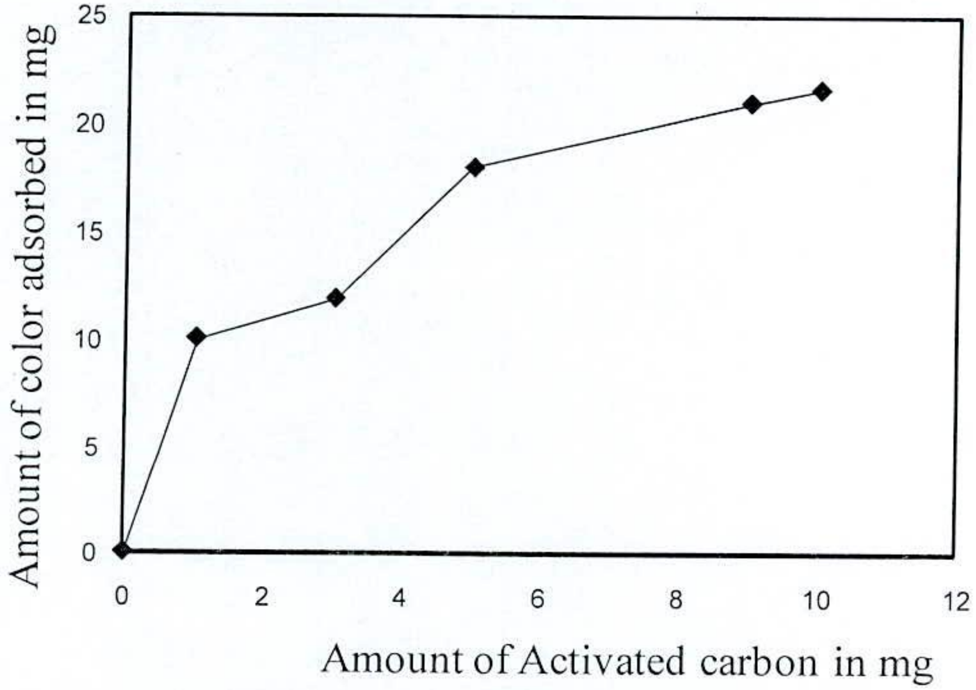


Figure F 3.1: Amount of color removal with varying dose of laboratory grade activated carbon

Temperature: 30^0C and 60 minutes contact time

Table F 3.4: Data for adsorbed color varying with different amount of activated carbon

Serial No	Amount (mg)	Raw	Sample 1		Sample 2		Sample 3		Standard Deviation	Average	Amount of adsorbed color (mg)
			Pt-Co	%	Pt-Co	%	Pt-Co	%			
1	50	483	362	25.05	365	24.43	360	25.47	2.52	24.98	6.00
2	100	483	357	26.09	354	26.71	358	25.88	2.08	26.22	6.29
3	150	483	320	33.75	318	34.16	315	34.78	2.52	34.23	8.22
4	200	483	313	35.20	310	35.82	311	35.61	1.53	35.54	8.53
5	250	483	299	38.10	294	39.13	300	37.89	3.21	38.37	9.21
6	300	460	232	49.57	230	50.00	238	48.26	4.16	49.28	11.83
7	350	460	222	51.74	225	51.09	228	50.43	3.00	51.09	12.26
8	400	460	218	52.61	214	53.48	220	52.17	3.06	52.75	12.66
9	450	460	195	57.61	193	58.04	198	56.96	2.52	57.54	13.81
10	502	460	174	62.17	172	62.61	175	61.96	1.53	62.25	14.94
11	550	460	150	67.39	156	66.09	148	67.83	4.16	67.10	16.10
12	600	460	134	70.87	130	71.74	139	69.78	4.51	70.80	16.99
13	652	460	117	74.57	125	72.83	113	75.43	6.11	74.28	17.83
14	700	460	104	77.39	109	76.30	102	77.83	3.61	77.17	18.52
15	750	460	95	79.35	96	79.13	95	79.35	0.58	79.28	19.03
16	800	469	98	79.10	94	79.96	95	79.74	2.08	79.60	19.10
17	850	469	90	80.81	90	80.81	92	80.38	1.15	80.67	19.36
18	905	469	86	81.66	88	81.24	83	82.30	2.52	81.73	19.62
19	950	469	78	83.37	80	82.94	85	81.88	3.61	82.73	19.86
20	1002	469	73	84.43	68	85.50	75	84.01	3.61	84.65	20.32
21	1050	469	65	86.14	63	86.57	66	85.93	1.53	86.21	20.69
22	1108	469	62	86.78	60	87.21	62	86.78	1.15	86.92	20.86
23	1150	469	59	87.42	58	87.63	56	88.06	1.53	87.70	21.05
24	1208	469	54	88.49	53	88.70	55	88.27	1.00	88.49	21.24
25	1251	469	56	88.06	58	87.63	55	88.27	1.53	87.99	21.12
26	1300	469	52	88.91	50	89.34	53	88.70	1.53	88.98	21.36
27	1350	469	58	87.63	56	88.06	59	87.42	1.53	87.70	21.05
28	1400	469	49	89.55	48	89.77	52	88.91	2.08	89.41	21.46
29	1450	469	50	89.34	49	89.55	47	89.98	1.53	89.62	21.51
30	1518	469	48	89.77	46	90.19	45	90.41	1.53	90.12	21.63
31	1553	469	50	89.34	46	90.19	48	89.77	2.00	89.77	21.54
32	1600	469	52	88.91	50	89.34	50	89.34	1.15	89.20	21.41
33	1650	469	46	90.19	43	90.83	48	89.77	2.52	90.26	21.66
34	1700	469	39	91.68	40	91.47	42	91.04	1.53	91.40	21.94
35	1852	469	42	91.04	40	91.47	40	91.47	1.15	91.33	21.92
36	1900	469	45	90.41	43	90.83	41	91.26	2.00	90.83	21.80
37	2005	469	41	91.26	45	90.41	42	91.04	2.08	90.90	21.82
38	2050	469	40	91.47	40	91.47	41	91.26	0.58	91.40	21.94
39	2100	469	43	90.83	42	91.04	43	90.83	0.58	90.90	21.82

Serial No	Amount (mg)	Raw	Sample 1		Sample 2		Sample 3		Standard Deviation	Average	Amount of adsorbed color (mg)
			Pt-Co	%	Pt-Co	%	Pt-Co	%			
40	2150	469	38	91.90	39	91.68	38	91.90	0.58	91.83	22.04
41	2200	469	36	92.32	35	92.54	38	91.90	1.53	92.25	22.14
42	2250	469	37	92.11	36	92.32	36	92.32	0.58	92.25	22.14
43	2300	469	34	92.75	33	92.96	30	93.60	2.08	93.11	22.35
44	2358	469	32	93.18	29	93.82	31	93.39	1.53	93.46	22.43
45	2400	469	35	92.54	32	93.18	28	94.03	3.51	93.25	22.38
46	2450	469	30	93.60	30	93.60	29	93.82	0.58	93.67	22.48
47	2500	469	32	93.18	31	93.39	31	93.39	0.58	93.32	22.40
48	2550	469	28	94.03	29	93.82	27	94.24	1.00	94.03	22.57
49	2600	469	26	94.46	23	95.10	21	95.52	2.52	95.02	22.80
50	2650	469	22	95.31	15	96.80	18	96.16	3.51	96.09	23.06
51	2700	469	25	94.67	22	95.31	26	94.46	2.08	94.81	22.75
52	2750	469	19	95.95	17	96.38	20	95.74	1.53	96.02	23.04
53	2800	469	14	97.01	13	97.23	13	97.23	0.58	97.16	23.32
54	2850	469	18	96.16	20	95.74	22	95.31	2.00	95.74	22.98
55	2900	469	20	95.74	21	95.52	18	96.16	1.53	95.81	22.99
56	2950	469	16	96.59	15	96.80	17	96.38	1.00	96.59	23.18
57	3011	469	12	97.44	11	97.65	12	97.44	0.58	97.51	23.40
58	3050	469	13	97.23	14	97.01	13	97.23	0.58	97.16	23.32
59	3100	469	10	97.87	12	97.44	10	97.87	1.15	97.73	23.46
60	3150	469	5	98.93	6	98.72	4	99.15	1.00	98.93	23.74
61	3200	469	8	98.29	8	98.29	11	97.65	1.73	98.08	23.54
62	3250	469	8	98.29	10	97.87	9	98.08	1.00	98.08	23.54
63	3300	469	3	99.36	5	98.93	6	98.72	1.53	99.00	23.76
64	3350	469	4	99.15	7	98.51	5	98.93	1.53	98.86	23.73
65	3400	469	4	99.15	4	99.15	4	99.15	0.00	99.15	23.80
66	3450	469	3	99.36	2	99.57	2	99.57	0.58	99.50	23.88
67	3500	469	2	99.57	1	99.79	0	100.00	1.00	99.79	23.95

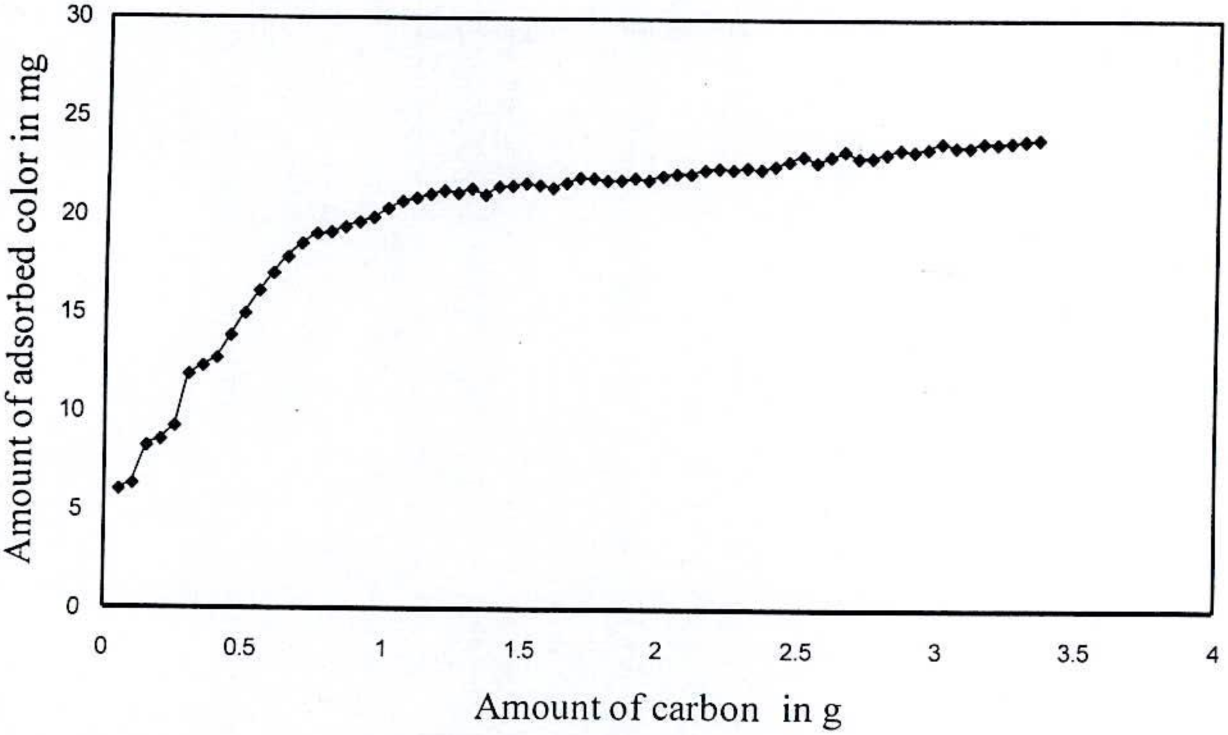


Figure F 3.2: Amount of color removal with varying dose of laboratory grade activated carbon

Appendix G

Test results for the characteristics of textile effluents

Table G 1.1: Labeling of textile effluents

Sample No	Name of the area
S1	Engyme wash effluent
S2	Desizing wash effluent

Characteristics of fresh effluent

Sample collected on 01/10/09

Date: 28/06/10

Measurement of pH

Table G 1.2: Data for pH measurement using multi-meter

Sample No	pH
S1	6.90
S2	7.94

Measurement of BOD

Sample was prepared as 5 ml sample + 295 ml DW

So decimal fraction of sample used (P) = 5/100 = 0.05

Table G 1.3: Results of BOD

Sample No	DO_1	DO_5	P	BOD_5 (mg/L)
S1	5.9	2.5	0.05	68
S2	5.6	3.1	0.05	50

$BOD_5 = (DO_1 - DO_5)/P$

Measurement of Acidity

Titration Methods

Table G 1.4: Data for measurement of acidity

Sample No	Acidity (mg/L)
S1	120
S2	80

Calculation:

mg/L = x ml of NaOH*1000/ml Sample

Measurement of TDS

100ml sample was taken

Table G 1.5.1: Results of TDS, SS & TS

Sample No	TS (g)	TDS (g)	SS (g)
S1	0.048	0.023	0.025
S2	0.346	0.246	0.100

Table G 1.5.2: Result of TDS, SS & TS in mg/L

Sample No	TS	TDS	SS
S1	480	230	250
S2	3460	2460	1000

Measurement of COD

FAS Molarity:

Initial Reading = 10.4 ml
Final Reading = 14.2 ml
Difference = (14.2-10.4) = 3.8 ml
Sample Volume = 5ml

Molarity of FAS = (5*0.1)/3.8 = 0.1316 M

Table G 1.6: Data of COD Calculation

SL No	Sample No	COD (mg O_2/L)
1	Blank	-
2	Blank	-
3	Blank	-
4	S1	1474
5	S1	1474
6	S1	1474
7	S2	1474
8	S2	421
9	S2	421

COD as mg O_2/L = (A-B)*M*8000/mL sample

Where:

A = mL FAS used for blank
B = mL FAS used for sample
M = molarity of FAS = 0.1316 M
8000 = miliequivalent weight of oxygen * 1000 mL/L

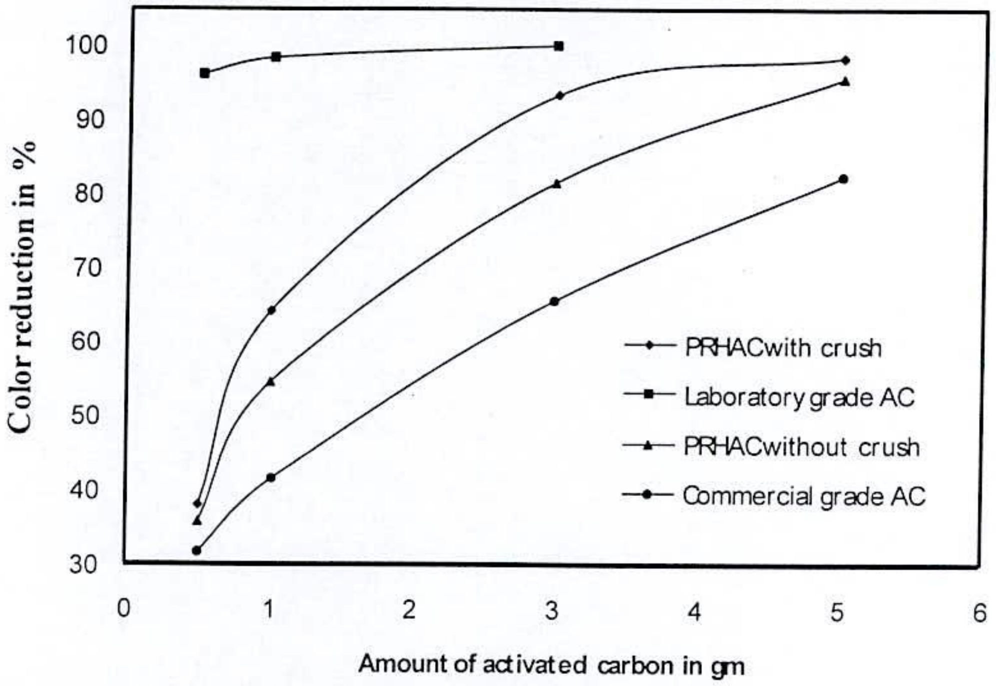


Figure H 1: Percentage removal of color using different types of activated carbon

Date: 26/07/10

Table H 2.1: Labeling of different activated carbon

Sample No	Name of Activated Carbon
S1	Laboratory grade AC
S2	PRHAC (crushed)
S3	PRHAC (uncrushed)
S4	Commercial grade AC 1
S5	Commercial grade AC 2

Using desizing wastewater

Raw = 413, Dilution Factor = 50,

Table H 2.2: Data for adsorbed color by different activated carbon desizing wash effluent

Serial No	Sample No	Amount (gm)	Pt-Co	%
1	S1	1.005	48	88.38
2	S1	3.000	35	91.53
3	S1	5.021	21	94.92
3	S1	8.020	1	99.99
4	S2	1.009	232	43.83
5	S2	3.020	100	75.78
6	S2	5.022	39	90.56
7	S2	8.002	26	93.70
8	S2	11.003	38	90.80
9	S2	14.001	26	93.70
10	S3	1.003	253	38.74
11	S3	3.009	148	64.16
12	S3	5.007	90	78.21
13	S3	8.015	62	84.99
14	S3	11.006	54	86.92
15	S3	14.010	41	90.07
16	S4	1.002	368	10.90
17	S4	3.000	280	32.22
18	S4	5.001	261	36.80
19	S4	8.009	213	48.43
20	S4	11.001	258	37.53
21	S4	14.002	214	48.18
22	S5	1.032	397	3.87
23	S5	3.033	384	7.02
24	S5	5.005	356	13.80
25	S5	8.052	344	16.70
26	S5	11.004	321	22.28
27	S5	14.004	305	26.15

Test results of COD experiment

Date: 12/08/10

FAS Molarity:

Initial Reading = 0.0 ml
Final Reading = 5.5 ml
Difference = (5.5 - 0.0) = 5.5 ml
Sample Volume = 5ml

Molarity of FAS = (5*0.1)/5.5 = 0.091 M

Table H 3.1: Data for COD Calculation

Sample No	COD (mg O_2/L)
1	-
2	4073
3	2618
4	3491
5	320
6	1746
7	3491
8	1164
9	1455
10	408
11	873
12	2037
13	1455
14	1455
15	1745

COD as mg O_2/L = (A-B)*M*8000/mL sample

Where:

A = mL FAS used for blank
B = mL FAS used for sample
M = molarity of FAS = 0.091M
8000 = miliequivalent weight of oxygen * 1000 mL/L

Table H 3.2: Measurement of COD for different batch experiments

Serial No.	Combination	COD (mg O_2/L)
1	Blank	-
2	Raw	4073
3	Filtration	2037
4	Sedimentation + Filtration	1164
5	Coagulation + Filtration	873
6	Sedimentation + Coagulation + Filtration	3491
7	Activated Carbon	1455
8	Sedimentation + Activated carbon	1746
9	Coagulation + Activated Carbon (Direct)	408
10	Sedimentation + Coagulation + Activated Carbon (Direct)	320
11	Sedimentation	2618
12	Sedimentation + Coagulation (After 30 min)	3491
13	Sedimentation + Coagulation (After 22 hours 30 min)	1455
14	Coagulation (After 30 min)	1455
15	Coagulation (After 22 hours 30 min)	1745