LITERATURE SURVEY
Jatropha curcas is a non-edible oil crop predominately used to produce biodiesel and its seeds contain 27-40% oil (Achten et al., 2007). Due to successful use of J. curcas oil in biodiesel production, cultivation of this plant is taken up in many countries. J. curcas grows almost anywhere, even on marginal/saline/acidic/alkaline soils and slopy lands. Nearly, eighty percent of its pods contain dried vegetable and remaining 20% are seeds only used for the biodiesel production in industries. One hectare of Jatropha plantation can produce around 500 gallons of biodiesel per year from its physic nuts along with more than 3500 kg of waste biomass. It is not suitable for agriculture fertilizer due to the low nutrient value and high level of cellulose, hemicelluloses and lignin resulting in difficult to digest or degrade. From this point of view, J. curcas waste may lead to the disposable problem in environment. Adsorption process has been proven as one of the best wastewater treatment technologies around the world. Currently, activated carbon is considered as a universal adsorbent for the removal of pollutants such as dyes and heavy metals from the wastewater due to its high surface areas, large adsorption capacities, fast adsorption kinetics and relative ease of regeneration. The most precursors used for the production of activated carbons are organic materials that are rich in carbon. Agro and natural-wastes are considered being a very important feed stock for the activated carbon preparation, since they are renewable sources and low-cost materials. The agrowastes such as bagasse pith (Gad and El-Sayed 2009), banana pith, coconut tree sawdust, maize cob, sago waste and silkcotton hull (Kadirvelu et al., 2003), Canola hull, coconut shell, coconut coir (Kadirvelu and Namasivayam 2003; Sharma and Uma 2009), Corn grain (Balathanigaimani et al., 2009), oil palm shell (Tan et al., 2008), peach stones (Attia et al., 2008), rambutan peel (Ahmad and Alrozi 2011), rice bran (Suzuki et al., 2007), shell carbon (Ahmad and Kumar 2010), sorghum grain (Diao et al.,
2002) and wheat bran (Hasan et al., 2010) have been found to be suitable precursors owing to their high carbon and low ash contents.

Dyes and heavy metals are hazardous pollutants often found together in wastewaters of several industries. These pollutants have a significant ecological impact on ecosystem and can modify the physical and chemical properties of water affecting the aquatic flora and fauna. For example, the dyes contained in wastewaters reduce the light penetration and may prevent the photosynthesis (Namasivayam and Sangeetha 2006). In addition, some dyes may degrade to generate carcinogens and toxic compounds for human beings and other living organisms. On the other hand, the presence of heavy metal ions in industrial effluents and drinking water resources is also relevant due to its toxicological profile and potential impacts on the human health and environment. Therefore, the removal of both pollutants from wastewaters is currently one of the most important environmental tasks for research and technology development on water management. The treatment of wastewaters polluted by dyes and heavy metals can be performed via chemical precipitation, ion exchange, electrolysis, membrane separation and adsorption. However, the management of these pollutants in multi-component mixtures (i.e., dyes–heavy metals) is difficult and ineffective using some traditional purification processes (Korbahi et al., 2011). Adsorption process is considered as an economical and robust method for improving water quality and can be used to remove a great variety of pollutants. Until now, various adsorbents have been used to remove dyes and heavy metals in mono-component solutions, and they include activated carbons, natural and synthetic polymers, clays, zeolites, biomasses, agricultural and industrial by-products. In particular, the adsorption on activated carbon appears to be the most competitive technology, in terms of costs and removal performance, to reduce the concentrations of these pollutants in wastewaters.
In the majority of adsorption studies performed for the removal of heavy metals and water decolorization, mono-component systems have been analyzed and a limited emphasis has been given to the study of multi-component systems. However, multi-component adsorption studies are useful to identify the competitive effects of several pollutants on adsorbent performance and play an important role for the proper design and operation of water purification processes (Al-Degs et al., 2007). When two or more pollutants are present in solution, they may increase or decrease or may not change the adsorption capacity of the adsorbent. Under these conditions, the adsorbent performance may depend on the number of pollutants present in solution and its concentration. To date, the amount of literature on adsorption processes for simultaneous dye and heavy metal removal from water in multi component systems is rather limited (Shukla and Pai 2005; Visa et al., 2010) reported the adsorption of copper, nickel and zinc on dye loaded groundnut shells and sawdust from aqueous solutions. These authors showed that application of the dye to these materials resulted in an enhancement of adsorption capacities for heavy metals. However, further studies are necessary to improve the knowledge of adsorption process for the simultaneous removal of these hazardous pollutants (i.e., dye and heavy metals) from wastewaters using activated carbons and other adsorbents. This type of studies is useful and fundamental for designing effective and low-cost wastewater treatment methods.

Food and pharmaceutical industries worldwide use synthetic dyes as additives in their products. In the food industry, dyes are used to make products more attractive to consumers. However, dyes have no nutritional value and may have toxic effects, causing from a simple allergy to intolerance to cancer. Dyes that have N-N bonds and sulfonic groups in their structures are considered acid and belong to the azo-dye class (Jain et al., 2003b). The use of these dyes as food additives is prohibited in some countries due to their mutagenic and/or carcinogenic actions. While in others, they are used indiscriminately. Among the synthetic
dyes allowed in Brazil, the dyes, Acid Yellow (AY-6), Acid Yellow 23 (AY-23), and Acid Red 18 (AR-18), are important due to their use in artificially yellow-, orange-, or redbodied confectionery, soft drinks, flavored corn chips, cereals, cake mixes, sports drinks, ice cream, candies, gelatins, pickled products, icings, fermented foods, prescription medicines and pills, and other products (Jain et al., 2003a; Prado and Godoy 2003; Pan et al., 2011; Shokoohi et al., 2010). The improper disposal of these synthetic dyes in industrial wastewater into the environment poses a risk to the aquatic life and contaminates water for human consumption.

The most efficient method of removal of dyes from aqueous effluents is the adsorption process. Few studies in the literature report on the adsorption of food dyes AY-6, AY-23, and AR-18 (Shokoohi et al., 2010; Dotto and Pinto 2011) therefore, further studies are needed.

Previous work by our study group reported on the preparation and characterization of activated carbon with high surface area from flamboyant pods (Delonix regia) (Vargas et al., 2011; Vargas et al., 2010) and its application to the adsorption of methylene blue.

Conscientious effort has been made by researchers to develop a cheaper, more effective and environmental friendly activated carbon that are comparable with commercially available ones. This has taken various dimensions which includes using various precursors such as agricultural waste based materials, clays, polyethenes and so on; devising various methods of preparations; and, use of various chemicals for activation. Activated carbons have been useful in adsorption processes for decades with outstanding excellent records (Al-Degs et al., 2007). Adsorption processes have been used in various fields which include medicine, environment, oil and gas and so on for removal of metals, dyes, pesticides, storage, and oil spillage control (Amin 2009). Chemical activation, a method other than physical activation which is one of the two main processes for the preparation of activated carbon has found immense applications. This is because the method is energy and time saving and, yields good results of product. The process requires impregnation of precursor or charred carbon with
activating agent and pyrolysed; this help in developing the surface area as well as the pores. Various activating agents like H$_2$SO$_4$, HCl, H$_3$PO$_4$, KOH, NaOH, ZnCl$_2$, and K$_2$CO$_3$ have been used (Hayashi et al., 2002; Auta and Hameed 2011). The choice and manner of usage depends on nature of precursor and the performance of the activating agent. Potassium hydroxide is one of the best activating agents that enhances development of good surface area and pore of precursors in the cause of production of activated carbon. The reaction of potassium hydroxide and carbon has numerous stages of developing pores of chars. Its contribution during activation brought about the discovery of CH$_3$CO$_2$K which is also a good activating agent (Auta and Hameed 2011).

Dyes as highly toxic compound can cause permanent injury to the eyes and skin of humans and animals. Dyes and pigments are widely used in various industries to color the final product. They are applied in chemical laboratories for analytical purposes and also in many biomedical and biological laboratories as biological stain. Brilliant green (BG) is one of the most important dyes within the category of dyestuffs, which has been extensively used for dying silk, wool, leather, jute, cotton, biological stain, dermatological agent, veterinary medicine, green ink manufacture, intestinal parasites, fungus textile dying and paper printing, therefore waste water of these industries is highly colored and causes water pollution and needs to be treated before its disposal. Cationic dyes make the brightest class of the known dyes and are water-soluble. Several methods like flocculation, coagulation, and membrane separation have been regularly reported for the treatment of dye stuff waste waters, but most of these methods are either expensive or pose the problem of sludge disposal. The adsorption process provides an attractive alternative for the treatment of dyestuff wastewaters. This process is easy to handle, requires less maintenance and produces smaller amounts of sludge. In this regard preparation and identification of cost effective ease of availability and efficient adsorbent are the major focus in the current state of art in the field of separation and
purification technologies. (Venkat et al., 2007; Fatma et al., 2007; Yunus 2006; Mall et al., 2006). Activated carbons have shown great potential for dye removal due to properties such as large surface area, microporous structure, and high adsorption capacity. The high cost of activated carbon promotes the search for cheap materials mainly derived from biological origin. It has been proved that lignocellulosic agro-waste that arbitrarily either discarded or set on fire is attractive resources for the preparation of carbonaceous materials implemented in adsorption processes. Lignocellulosic materials with unique advantages such as eco-friendly nature, their availability and low cost are suitable precursor for preparation of activated carbon. Current state of art focused on the application of low-cost, reusable, locally available and biodegradable adsorbent made from natural sources like rice husk (Venkat et al., 2007), wheat bran (Fatma et al., 2007), waste apricot (Yunus 2006), bagasse fly ash (Mall et al., 2006) and powdered peanut hull (Gong et al., 2005). Natural and modified clays like sepiolite (Mahir et al., 2005), zeolite (Armagan et al., 2004), perlite (Dogan and Alkan 2003) and bentonite (Ozcan 2005), sugar industry mud (Magdy and Daifullah 1998), palm-fruit bunch (Nassar 1997), Jack fruit peel (Inbaraj and Sulochana 2002), peat (Ho and McKay 1998), orange peel (Namasivayam et al., 1996), sugar cane dust (Khatttri and Singh 1999), peat (Ho and McKay 1999) and neem leaf powder (Bhattacharyya and Sharma 2005), acorns and olive sheds (Lafi 2001) and chemically treated guava leaf powder (Singh and Srivastava 1999) also have been applied to reduce the pollution of wastewaters at a reasonable cost. Hence, there is a scope for the identification and preparation of more economical and effective agrowaste based adsorbents. Acorn (a tree naturally and commercially available in Yasouj, Iran generally is dark brown with complex material containing lignin and cellulose as major constituents.

Many water sources in small and rural communities are contaminated with multiple contaminants, some of which have completely different chemistries that require complex
treatment trains for adequate removal from water. However, such technologies cannot be implemented in small and poor rural communities because of absence of technical knowledge among the residents and unsustainable costs of construction, operation and management of multiple treatment train units. Nevertheless, a need for providing potable water for residents of these communities via simple and inexpensive water treatment systems still exists. Arsenic is one of the most common water contaminants that can be found in drinking water sources of many small and rural communities throughout the world with concentrations often exceeding 500 g/L (Nickson et al., 1998; Nickson et al., 2007). The maximum mandated, or recommended, contaminant levels for arsenic, however, can be as much as 10–50 times lower depending on a country’s regulations (Kovski 2009; Cotton and Wilkinson 1972). Recent risk assessment studies suggest that allowable levels of arsenic in water should be lowered further to 0.1 -g/L because of arsenic’s toxicity and carcinogenicity (Greenwood and Earnshaw 1997; Randall and Sherman 2003). Arsenic has a unique chemistry which allows it to exist as an oxo-anion in natural waters regardless of whether it exists in arsenite (+3) or arsenate (+5) form, the two most dominant forms of arsenic in water. The oxo-anion configuration allows arsenic to interact with metal (hydr) oxide surfaces by forming monodentate and bidentate inner-sphere complexes. This interaction makes many of the metal (hydr) oxide materials suitable media for removal of arsenic from water by adsorption (Cooper et al., 2010). Many water sources in small and rural communities contain natural organic matter or organic contaminants in higher concentrations than arsenic as a result of natural or anthropogenic impacts. In many cases, these organic contaminants can be removed from water by adsorption using granulated activated carbon (GAC). Unlike metal hydroxides, granulated activated carbon has been proven to be a poor adsorbent for treating arsenic (Hristovski et al., 2009). However, recent studies have shown that arsenic and organic co-contaminants can be simultaneously removed from water by hybrid GAC sorbents impregnated with iron
hydroxide nanoparticles. This, in turn, allows for design of small and inexpensive point-of-use water treatment systems capable of removing arsenic and co-contaminants from water sources used by small and rural communities. In addition to iron (hydroxide nanomaterials, many other metals) hydroxide nanomaterials have shown promising arsenic removal properties. Some of them, such as zirconium dioxide nanoparticles, can be used to create hybrid metal hydroxide GAC media capable of simultaneously removing arsenic and organic co-contaminants. Zirconium dioxide nanoparticles can be synthesized inside the pores of GAC media using in situ techniques similar to those used in fabrication of hybrid iron hydroxide GAC media. The synthesis process changes the properties of the media, which may affect the arsenic and organic co-contaminant removal abilities of the media. However, although only a handful of attempts have been made to fabricate hybrid zirconium dioxide GAC media for arsenic removal, almost nothing is known about impact of the in situ ZrO₂ nanoparticle formation on the properties of the sorbent GAC media and the consequent arsenic and organic co-contaminant removal.

Dyes are one of the most hazardous chemical compound classes found in industrial effluents and need to be treated since their presence in water bodies reduces light penetration, precluding the photosynthesis of aqueous flora (Lima et al., 2008; Royer et al., 2009). They are also aesthetically objectionable for drinking and other purposes (Royer et al., 2010). Dyes can cause allergy, dermatitis, skin irritation and also provoke cancer and mutation in humans (Carneiro et al., 2010). The most efficient method for the removal of synthetic dyes from aqueous effluents is the adsorption procedure (Orfao et al., 2006; Calvete et al., 2010). This process transfers the dyes from the water effluent to a solid phase, thereby keeping the effluent volume to a minimum (Calvete et al., 2009; Cuerda-Correa et al., 2010; Malarvizhi and Ho 2010). Subsequently, the adsorbent can be regenerated or stored in a dry place without direct contact with the environment (Calvete et al., 2010). Different adsorbents have
been proposed for the removal of dyes from aqueous solutions (Rosa et al., 2008; Afkhami et al., 2010; Royer et al., 2009; Gay et al., 2010; Zermane et al., 2010; Greluk and Hubicki, 2010). Among these, carbon nanotube (CNT) materials have been proposed for the successful removal of dyes from aqueous effluent (Zhu et al., 2010; Zhu et al., 2007; Kuo et al., 2008; Gong et al., 2009; Mishra, et al., 2010). CNTs have attracted increasing research interest as a new adsorbent. They are an attractive alternative for the removal of dye contaminants from aqueous effluents because they have a large specific surface area, small size as well as hollow and layered structures. CNTs have been found to be efficient adsorbents with a capacity that exceeds that of activated carbon. However, up to the best of our knowledge, there are only six papers in the literature, reporting the use of CNTs for dye removal from aqueous effluents. Therefore, the use of CNT for dye adsorption requires new studies.

In textile dyeing processes, a large volume of dye-contaminated effluent is discharged, and it was estimated that 10-15% of the dye is lost in the dye effluent. The effluents of these industries are highly colored and the disposal of these wastes into receiving waters causes damage to the environment as they may significantly affect photosynthetic activity in aquatic life due to reduced light penetration and may also be toxic to some aquatic life due to the presence of metals, chlorides, etc., in them (Zollinger 1987). Reactive dyes are typically azo-based chromophores combined with different types of reactive groups. They differ from all other classes of dyes in that they bind to the textile fibers such as cotton to form covalent bonds. They have the favorable characteristics of bright color, simple application techniques and low energy consumption and are used extensively in textile industries. Hence their removal is also of great importance (Clarke and Anliker 1980). There are a number of methods for dye removals which include chemical coagulation, flocculation, chemical oxidation, photochemical degradation, membrane filtration, including aerobic and anaerobic biological degradation but all of these methods suffer from one or other limitations,
and none of them were successful in completely removing the color from wastewater. Dyes can be effectively removed by adsorption process; in which dissolved dye compounds attach themselves to the surface of adsorbents (Slokar and Le Marechal 1997; Neill et al., 1999). Adsorption has been extensively used in industrial processes for either separation or purification. Most conventional adsorption plants use activated carbon, which is an expensive material. Besides, there is growing interest in searching for cheaper sources as low-cost adsorbent materials for the adsorption of dyes such as coir pith, sugar cane dust, sawdust, activated carbon fibers (Ramakrishna and Viraraghavan 1997; Namasivayam et al., 2001; Khattri and Singh 1999; Malik 2004; Kadirvelu, et al., 2000), industrial solid wastes: fly ash, shale oil ash, and so on (Kumar, et al., 2005; Janos et al., 2003; Viraraghavan and Ramakrishna 1999; Mohan et al., 2002; Al-Qodah, 2000). During coal-fired electric power generation, two main types of coal combustion byproducts are obtained, fly ash (FA) and bottom ash. The current annual worldwide production of coal ash is estimated about 700 million tones of which at least 70% is FA (Hall and Livingston 2002).

Dyes are widely used in industries such as textiles, pulp mills, leather, dye synthesis, printing, food, and plastics, etc. Since many organic dyestuffs are harmful to human being and toxic to microorganisms, removal of dyestuffs from wastewater has received considerable attention over the past decades. Various treatment methods have been developed for decontamination purposes including coagulation, chemical oxidation, membrane separation, electrochemical process, and adsorption techniques. Of the above mentioned techniques, adsorption was recognized to be a promising and a cost-effective process to remove colors from aqueous solution. Many kinds of adsorbents have been developed for various applications. Due to its effectiveness and versatility, activated carbon is widely employed in water and wastewater treatment. However, the operating cost of activated carbon adsorption is high. Problems of regeneration and difficulty in separation from the wastewater
after use are the two major concerns of using this material. This has led to searches for unconventional adsorbents as alternative adsorbents. The use of unconventional adsorbent has the following features: (Wang and Lee 2005) it can be obtained abundant locally and cheaply. Most of them are readily to be utilized; (Bhattacharyya and Sharma 2005) regeneration of these low-cost substitutes is not necessary whereas regeneration of activated carbon is essential. Such regeneration may result in additional effluent and the adsorbent may suffer a considerable loss; (Hamdaoui 2006) less operation cost in terms of maintenance and supervision are required for the unconventional adsorption systems; (Weng and Pan 2006) utilization of industrial solid waste for the treatment of industrial wastewater is helpful not only to the environment, but also to reduce the disposal cost.

Dye compounds are widely used for textiles, printing, and dyeing, as well as in the food and paper-making industries. Consequently, the effluents of these industries are highly colored. Color is aesthetically objectionable and it also reduces light penetration into water decreasing the efficiency of photosynthesis in aquatic plants, thereby, having adverse impact on their growth (Tao and Tang 2004; Khattri and Singh 2000). Because of higher organic concentration, particular toxicity, complex composition and poor degradability, dyes are the most noticeable contaminant even at very low concentrations, and they need to be removed or decolorized before the wastewater can be discharged (Ozacar and Sengil 2003; Chu 2001). Due to the low biodegradability of dyes, the wastewater with dye is usually treated by physical or chemical treatment processes (Banat et al., 1996). Currently the sorption technique is proven to be effective and attractive processes for the treatment of these wastewaters. Also this method will become inexpensive if the adsorbent material used is of cheaper cost and does not require any expensive additional pretreatment step (Vadivelan and Kumar 2005). Various low cost adsorbents such as dried activated sludge (Al-Qodah, 2000), shale oil ash (Aksu 2001), orange peel (Sivaraj et al., 2001), waste red mud (Namasivayam
and Arasi 1997) fly ash (El-Geundi 1991) have been used as low cost alternatives in color removal processes.

The effluents of wastewater in some industries such as dyestuff, textiles, leather, paper, printing, plastic and food, etc. contain various types of synthetic dyestuffs. The treatment of textile wastewater comprising dyestuffs and other non-biodegradable organics and inorganics poses considerable problems in the wastewater treatment industry. Most studies have focused on the development of a technique and a method for the treatment of dye wastewater. In general, there are several methods of reducing color in textile effluent streams: coagulation–flocculation, biological treatment, oxidation–ozonation, adsorption and membrane processes. The advantages and disadvantages of each technique have been extensively reviewed. Of these methods, adsorption has been found to be an efficient and economic process to remove dyes, pigments and other colorants (Walker et al., 2003; Dogan and Alkan 2003; Kannan and Sundaram 2001). The most widely used adsorbent for industrial applications is activated carbon. However, it is an expensive material unless regeneration is relatively easy, but this adds to the operational costs (Ho and McKay 1999). The use of activated carbon dose effectively removes color although it is ineffective against disperse and vat dyes (Walker et al., 2003). However, the disperse dye group is one of the most important groups of dyes used in the textile dyeing industries (Neamtu et al., 2004). In recent years, many cheap and widely available materials have been identified as suitable adsorbents for the removal of color from wastewaters. Organoclays are the adsorbent materials that have been generally considered by many investigators to have the potential of meeting this requirement (Ye-and Liu 2004). Among the various organoclays, organobentonites are the most widely investigated by many researchers. Organobentonites are produced by replacing exchangeable inorganic cations with organic cations on the internal mineral surfaces of bentonite and also the external surfaces. When the organic cations added to the bentonite is in excess of cation
exchange capacity (CEC) of bentonite. Naturally occurring bentonite is not efficient as an adsorbent for the uptake of hydrophobic organic pollutants from aqueous solution due primarily to the electrically charged and hydrophilic characteristics of its surface. With this exchange treatment, bentonite surfaces are drastically altered. As a result, organobentonites have enhanced sorption capacities for non-ionic organic pollutants. Quaternary ammonium salts have been used most often to render bentonites hydrophobic (Weng et al., 2001). However, the main requirement for compounds to effect this change is that they comprise organic cations containing non-polar groups. Hence, it is worthwhile to broaden the range of compounds suitable for this purpose to enable alternative materials to be used for economic or other reasons. Cationic polyelectrolytes fulfil the main requirements of materials that are suitable for rendering clays less polar and hence more hydrophobic. Some of them, in particular polyepichlorohydrin-dimethylamine (EPI-DMA), are used, as coagulants, in wastewater treatment. EPI-DMA which is a effectively water-soluble cationic polyelectrolyte with amidocyanogen and ammonium ion has been applied in printing and dyeing wastewater treatment (Ma et al., 1996).

Enormous amount of dyestuff is produced every year in different branches of industry. There are more than 100,000 commercially available dyes with over $7 \times 10^5$ t of dyestuff produced annually (Zollinger 1987). Dyes are widely used in textile, paper, food and cosmetics industries. It is estimated that 2–50% of them are lost into wastewaters, causing environmental contaminations. Dyes may be toxic and mutagenic, and, if they are discharged directly into the environment, they contaminate not only the environment but also traverse through the entire food chain, leading to biomagnification. For their removal, many physical and chemical methods are available. However, many dyes are difficult to decolorize due to their complex chemical structure and synthetic origin (Robinson et al., 2001; Neill et al., 1999). They are resistible on the exposure to light, water and many chemicals. Therefore,
there is a considerable interest in development of biological methods (microbial and enzymatic) for the removal of dyes. These procedures are considered to be attractive due to their potential lowcost, environmental compatibility and public acceptability (Kuhad et al., 2004). Different types of microorganisms, including bacteria, fungi and algae, are capable of decolorizing a diverse range of dyes. Many bacteria are able to degrade dyes both aerobically and anaerobically. Biodegradation of azo dyes by bacteria is often initiated by azo reductase-driven cleavage of azo bonds, followed by aerobic or anaerobic degradation of resulting amines. On the other hand, fungal degradation typically originates from the lignolytic activity to degrade azo dyes aerobically with the aid of lignin peroxidase (Kuhad et al., 2004). For many dyes the adsorption on appropriate adsorbents seems to be an efficient procedure for their removal. Bacterial, yeast, fungal and algal cells have been reported for their capability of partial or complete removal of industrial dyes using the adsorption process. Both living and died biomass has been tested with various success. Although the decolorization of dye wastewater by live or dead microbial biomass has been a subject of various studies, only limited information is available on interactions between the biomass and molecular structure of dyes (Fu and Viraraghavan 2002). Dead cells remove dyes through the mechanism of biosorption, which involves physicochemical interactions such as adsorption, deposition and ion exchange. The extent of dye biosorption depends on the chemical structure of dyes and the functional group of dye molecules.

Since 1856, when the first synthetic dye, mauvein, was discovered, more than 100,000 new synthetic dyes have been generated. These dyes are used in different industries, including textiles, cosmetics, paper, leather, pharmaceutical, and food, with an annual consumption of about 0.7 million ton (Crailiell et al., 1995; Chen et al., 2003). The textile industry accounts for two-thirds of the total dyestuff market. Azo dyes, the largest chemical class of dyes with the greatest variety of colors, have been used extensively for textile,
dyeing, and paper painting (Craliell et al., 1995; Fang et al., 2004). These dyes cannot be easily degraded, while some are toxic to higher animals (Fu and Viraraghavan 2001). During the dyeing process, approximately 10-15% of the used dye, depending on the structure, is released into the wastewaters, causing serious environmental and health hazards (Chen et al., 2003).

The waste water from industry has always been a potential threat to the environment. Over 4.4-106 m³ of aqueous waste and dye effluent were discharged per day in China and this effluent has high BOD loading and long lasting colour that is aesthetically and environmentally unacceptable (Annadurai and Krishnan 1997). These dyes may even be toxic and even carcinogenic (Vandevivere et al., 1998). The printing and textile industry mainly contribute to the discharge of dye effluent and the governments of different countries have enacted strict rules controlling the discharge of waste. In order to minimize the pollution, manufacturers and government officials are seeking for solutions to tackle the problem in an efficient way. Existing effluent treatment processes can only remove half of the dyestuff lost in the residual liquors. People are looking for a system which can remove most of the colour and generate reusable water from the effluent. A range of adsorption systems for dye removal have been investigated extensively, such as trickling filter (Lin and Lin 1993), activated sludge (Ganesh et al., 1994), chemical coagulation (Vandevivere et al., 1998), carbon adsorption (Walker and Weatherley 2000) and photodegradation processes (Chu and Ma 2000; Chu and Tsui 1999). Activated carbon is a highly effective adsorbent for water treatment, but it is an expensive adsorbent (Pollard et al., 1992). Cheaper precursors for activated carbon have been developed and tested with varying degrees of success; these include corn cob (Tsai et al., 1998), bagasse (Valix et al., 2004), pecan shells (Ahmedna et al., 2000), waste tire (Mui et al., 2004) among many others. In addition to activated carbons, several other available cheap resources have been studied, including peat (Brown et al.,
Sewage sludge can be applied to land to supply and recycle organic matter and nutrients. Trace elements in sludge, however, may accumulate in the soil with repeated sludge applications. Reducing metal content may therefore reduce the adverse effects of sludge application. The efficiency of bioleaching technology in reducing metal content and toxicity as measured by a battery of terrestrial and liquid-phase bioassays. Sludge–soil mixtures simulating the application of sludge to land were tested by means of terrestrial bioassays, barley (*Hordeum vulgare* L.) seed germination (5 d) and sprout growth (14 d), lettuce (*Lactuca sativa*) seed germination (5 d), and worm (*Eisenia andrei*) mortality (14 d). Liquid-phase bioassays, Microtox1 (*Vibrio fischeri*, 15 min), lettuce root elongation (*L. sativa*, 5 d), cladoceran mortality (*Daphnia magna*, 48 h), and SOS Chromotest (*Escherichia coli*) were used after elutriation of the sludge. Comparison of the bioassay results (except for *D. magna*) before and after treatment demonstrated that this bioleaching process reduced both sludge toxicity and metal content. In addition, lower Cu and Zn concentrations found in barley sprouts following treatment supported the assumption that the bioleaching process, by decreasing metal content and bioavailability, reduced sewage sludge toxicity. This study also emphasized the interest of using ecotoxicological bioassays for testing biosolids. In particular, the terrestrial bioassays after simulation of land application and the Microtox1 test after sludge elutriation proved to be the most appropriate procedures.

Zeolites are naturally occurring minerals characterized by high cation exchange and adsorption capacity and, thus are used for metal uptake from sewage sludge subjected to composting process. The composting process was carried out for 120 days in pilot bioreactors, which were filled with 20% w/w clinoptilolite and sludge. The experimental results indicated differences in the metal content of the initial sludge and essential changes in
pH, % Corg, % organic matter (OM), %N values and heavy metals content. Furthermore, the phytotoxicity tests that were performed showed that sludge samples affected seed germination and root elongation, but no phytotoxic effects were observed. According to the experimental results, it is concluded that the use of natural clinoptilolite leads to the improvement of the quality of the composted sewage sludge.

Column leaching experiments were conducted to test the ability of Chilean volcanic soils in retaining the mineral constituents and metals in sewage sludge and sludge ash that were incorporated into the soils. When they were incorporated on the surface layer of the soils and leached with 12 pore volumes of water over a 3 month period of time, less than 0.1% of the total amount of heavy metals and PO₄ in the sludge and sludge ash were collected in the drainage water. Cation exchange selectivity, specific anion adsorption and solubility are the processes that cause the reduction of leaching. The volcanic soils were capable of retaining the mineral constituents and metals in applied sewage sludge and sludge ash and gradually released them as nutrients for plant growth (Escudey et al., 2007).

Various types of activated carbons were developed from organic sewage sludge (SS) using H₂SO₄, H₃PO₄ and ZnCl₂ as chemical activation reagents, and the removal of Hg (II) from aqueous solution by these carbons was effectively demonstrated. The quality of the activated carbons was dramatically improved owing to chemical activation. ZnCl₂ activated carbon had the highest capability for Hg (II) adsorption, followed by H₃PO₄ and H₂SO₄ activated carbons. The adsorption was greatly affected by Hg (II) concentration, solution pH and carbon dosage, and followed Lagergren first order rate equation and Freundlich isotherm model. Desorption results indicated that around 60% to 80% of the adsorbed Hg (II) could be recovered from the carbons to 0.1M HNO₃ solution by sonication treatment. Accordingly, it is believed that the activated carbons developed in this study are effective and practical for utilization in industrial wastewater treatment for mercury removal (Zhang et al., 2005).

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The article focuses on the effect of microwave treatment on the dewater ability of sewage sludge. The specific resistance to filtration, capillary suction time, and dry matter content in centrifuged sludge cake were measured. The quality of sludge liquor obtained after microwave processing was also analyzed. It was found out that microwaves improve sludge dewater ability. The quantitative improvement depends on sludge type better effect of microwave processing were observed in the primary sludge compared to mixed or digested sludge. If microwave treatment is followed by polyelectrolyte conditioning, the effects are considerably better than while these conditioning methods are used separately. Microwave conditioning increased burden of organic matter (BOD and COD) in the sludge liquor (Wojciechowsk 2005).

An advanced sewage treatment process has been developed, in which excess sludge reduction by ozonation and phosphorus recovery by crystallization process are incorporated to a conventional anaerobic/oxic (A/O) phosphorus removal process. The mathematical model was developed to describe the mass balance principal at a steady state of this process. Sludge ozonation experiments were carried out to investigate solubilization characteristics of sludge and change in microbial activity by using sludge cultured with feed of synthetic sewage under A/O process. Phosphorus was solubilized by ozonation as well as organics, and acid-hydrolysable phosphorus (AHP) was the most part of solubilized phosphorus for phosphorus accumulating organisms (PAOs) containing sludge. At solubilization of 30%, around 70% of sludge was in activated by ozonation. The results based on these studies indicated that the proposed process configuration has potential to reduce the excess sludge production as well as to recover phosphorus in usable forms. The system performance results show that this system is practical, in which 30% of solubilization degree was achieved by ozonation. In this study, 30% of solubilization was achieved at 30 mgO₂/g SS of ozone consumption (Saktaywin 2005).
The ability of municipal sewage sludge to immobilize Pb, Zn and Cd contained in contaminated soil originating from a former mining area in Lavrion, Greece was investigated. The soil was cured with sewage sludge in various proportions. The stabilization was evaluated primarily by applying chemical tests and complemented by the performance of additional biological tests. On the stabilized mixtures proved that Pb, Zn and Cd solubility was reduced by 84%, 64% and 76%, respectively, at 15% wrw sludge addition, while a 10% wrw addition was sufficient to reduce Pb solubility below the U.S. EPA TCLP regulatory limit. The results of the extraction using EDTA solution showed the same trend, resulting in 26%, 36% and 53% reduction in the Pb, Zn and Cd extractable fractions, respectively. Speciation analysis of the treated soils revealed a significant decrease in the mobile fractions of heavy metals, which was attributed to their retention in sewage sludge by adsorption and organic complexation mechanisms. For the assessment of possible phytotoxicity, experiments including growing dwarf beans in the treated soil were carried out. It was found that sewage sludge addition had a positive effect on plant growth. Furthermore, the Pb and Zn uptake of plant leaves and roots was reduced, while Cd uptake was unaffected by the sludge treatment. The results of this study support the hypothesis that municipal sewage sludge is a potential effective stabilizing agent for contaminated soil containing Pb, Zn and Cd (Theodoratos et al., 2000).

Heavy metals are commonly found in municipal sewage that contains industrial effluents. Metal concentrations above toxic levels inhibit biological processes in municipal sewage treatment works and discharge of metals into surface waters can have severe effects on the environment and public health. However, trace metals at sub-toxic concentrations have also been observed to affect COD removal in activated sludge. In this study, the effects of trace metal chromium on activated sludge in a sequencing batch reactor SBR were investigated. Chromium-laden wastewater at a sub-toxic level of 0.05 mg/l affected the SBR
performance to different extents depending on the hydraulic retention time HRT. Organic removal in activated sludge was postulated to proceed by a rapid adsorption of organics on the sludge, followed by a slower metabolic assimilation mechanism. Heavy metal acted as a strong competitor for active sites on the sludge, hampering organic adsorption and affected the COD reduction efficiency under short HRTs of 2.5 days and below (Chua 1998).

Some characteristics of the binding of the ions Ca (II), Mg (II), Cu (II), Co (II), Ni (II), Zn (II), Mn (II), Pb (II) and Fe (II) on the soluble organic matter in a digested sewage sludge were determined using ion-selective electrodes. It appeared that the soluble organic matter contained two distinguishable groups of exchange sites. One group of sites was capable of binding all of the above ions plus protons, whereas the second set could bind Cu (II), Pb (II) and protons only. A numerical description of their uptake characteristics, based on two sets of ion exchange constants for each element, was able to predict the measured values of cation activity to within 10% in the pH range 5.7-7. This thermodynamic data was in reasonable agreement with the general concepts of coordination chemistry. The concentrations of calcium and magnesium in sewage sludge are high enough to compete so strongly with other metal ions that only copper, lead and cadmium will be bound significantly. Consequently, the model was simplified to predict the ion uptake behaviour of soluble organic matter, in the presence of high concentrations of calcium, using a limited set of analytical expressions (analogous to adsorption equations) rather than the complete set of equilibrium constants.

The behaviour, fate and significance of the detergent builder nitrilotri acetic acid (NTA) has been reviewed with particular reference to the removal of NTA during wastewater treatment and the effects of NTA on heavy metal solubility both during treatment and in the receiving environment. It is concluded that NTA removal during secondary biological treatment is subject to considerable variation, both temporal and between works as a result of
changes in NTA load, temperature, water hardness and treatment process parameters. As a result of such variability, effluent NTA concentrations may be sufficient to mobilise heavy metals resulting in metal contamination of receiving waters and potable waters. Particularly in areas of low effluent dilution and high water re-use. Removal of NTA during primary sedimentation and septic tank treatment is concluded to be predominantly due to adsorption to the sludge solids while removal in anaerobic sludge digestion is subject to operational characteristics of the treatment works. Disposal of NTA contaminated sludge to land may contaminate groundwater and affect heavy metal speciation, while the disposal of contaminated sludge or sewage to sea may result in toxic algal blooms, in addition to effects on metal speciation (Perry et al., 1984).

Alkaline white mud (AWM) has been investigated as a low-cost material for removal of an anionic dye, acid blue 80. The effects of contact time initial pH of dye solution, AWM dosage, and the presence of inorganic anion sulphate or phosphate ion on removal of the dye were evaluated. The results show that AWM could be used as an effective material for removal of acid blue 80 in a pre or main process, particularly at high dye concentration (>300 mg L$^{-1}$), reaching maximum removal efficiency of 95%. At low dye concentration, surface adsorption is mainly responsible for the dye removal, while chemical precipitation of the dye anions with soluble Ca$^{2+}$ and Mg$^{2+}$ may play a dominant role for the dye removal at high concentration, producing much less sludge than conventional adsorption method. Solution pH has only a limited effect on the dye removal due to high alkalinity and large pH buffer capacity of AWM suspension and thereby pH is not a limiting factor in pursuing high dye removal. The dye removal may be significantly suppressed by the presence of phosphate with increasing concentration, and the reduction in the dye removal is much larger at high dye concentrations than at low ones.
Granular activated carbon (GAC) did not show any significant adsorption ability on the disperse dyes, while resting (living) biosludge of a domestic wastewater treatment plant showed high adsorption abilities on both disperse dyes and organic matter. The dye adsorption ability of bio-sludge increased by approximately 30% through acclimatization with disperse dyes, and it decreased by autoclaving. The deteriorated bio-sludge could be reused after being washed with 0.1 N NaOH solutions. Disperse Red 60 was more easily adsorbed onto the bio-sludge than Disperse Blue 60. The Disperse Red 60, COD, and BOD adsorption capacities of acclimatized, resting bio-sludge were 40.0 ± 0.1, 450 ± 12, and 300 ± 10 mg/g of bio-sludge, respectively. The GAC–SBR system could be applied to treat textile wastewater (TWW) containing disperse dyes with high dye, BOD5, COD, and TKN removal efficiencies of 93.0 ± 1.1%, 88.0 ± 3.1%, 92.2 ± 2.7% and 51.5 ± 7.0%, respectively without any excess bio-sludge production under an organic loading of 0.18 kg BOD/m²-d. Furthermore, the removal efficiencies increased with the addition of glucose into the system. The dye, BOD, COD, and TKN removal efficiencies of the GAC–SBR system with TWW containing 0.89 g/L glucose were 94.6 ± 0.7%, 94.4 ± 0.6%, 94.4 ± 0.8% and 59.3 ± 8.5%, respectively, under an SRT of 67 ± 0.4 days (Sirianuntapiboon and Srisornask 2007).

Sewage sludge was used to develop a potential adsorbent for dye removal by pyrolysis under either N₂ or CO₂ atmospheres. The results showed that the surface area of the char increases as the pyrolysis temperature increase under the CO₂ atmosphere. The maximum surface area of the char is achieved with pyrolysis at 750 °C under the CO₂ atmosphere, 60.7 m² g⁻¹ with mainly mesopores. The FT-IR spectra of the char prepared under both N₂ and CO₂ atmospheres indicate a decrease in OH, NH and CO functionalities with increasing the pyrolysis temperature, corresponding to a decrease in the acidity of the char. The maximum adsorption capacities of acid and basic dyes were found to increase with an increase in the pyrolysis temperature while that of the reactive dye possessed no
correlation. The adsorption mechanism is governed by the combination of the electrostatic interactions and dispersive interactions. The equilibrium data fit well with the Langmuir model of adsorption suggesting a monolayer coverage of dye molecules at the outer surface of sewage sludge derived chars. The maximum adsorption capacities of acid yellow 49, basic blue 41 and reactive red 198 dyes are reported at 116, 588 and 25 mg g\(^{-1}\) of char, respectively (Jindarom et al., 2007).

Adsorption processes are alternative effective methods for removal of textile dyes from aqueous solutions. The adsorption ability of adsorbent affects by physico-chemical environment for this reason in this paper effect of initial pH, dye concentrations, temperature and dye hydrolyzation were determined in a batch system for removal of reactive dye by dried activated sludge. The Langmuir isotherm model was well described of adsorption reactive dye and maximum monolayer adsorption capacity (at pH 2) of activated sludge was determined as 116, 93 and 71 mg g\(^{-1}\) for 20°, 35° and 50 °C, respectively. Initial pH 2, 20 °C and 30 min contact time are suitable for removal of reactive dyes from aqueous solutions. Activated sludge was characterized by FT-IR analysis and results showed that active sludge has different functional groups and functional groups of activated sludge are able to react with dye molecules in aqueous solution. The pseudo first-order, second-order and intraparticle diffusion kinetics were used to describe the kinetic data. The pseudo second-order kinetic model was fit well over the range of contact times and also an intra particle diffusion kinetic model was fit well but in the first 30 min. The dye hydrolyzation was affected adsorption capacity of biomass and adsorption capacity of biomass decreased with dye hydrolyzation from 74 to 38 mg/g (Gulnaz et al., 2006).

Kinetics and equilibrium adsorption experiments were conducted to evaluate the adsorption characteristics of a cationic dye (methylene blue, MB) onto bio-sludge ash. Results showed that the ash could remove the dye effectively from aqueous solution. The
The adsorption rate was fast and about 80% of absorbed-MB was removed in 10 min. The adsorption kinetics could be expressed by the modified Freundlich equation and intra-particle diffusion model. It was found that both the initial MB concentration and ionic strength could affect the rate of adsorption. The effect of electrical double layer thickness on the adsorption kinetics was discussed. The equilibrium adsorption data were correlated well to the non-linear multilayer adsorption isotherm. The multilayer adsorption energy ranged from 4.51 to 5.02 kcal/mol, suggests that the adsorption process was the typical physical type. On the basis of the monolayer dye adsorption capacity, the specific surface area of this ash sample was estimated as 2.1–2.9 m$^2$/g which is close to the value (3.7 m$^2$/g) obtained via BET nitrogen gas adsorption measurements.

Physicochemical processes of adsorption and coagulation were systematically evaluated for the removal of reactive dyes (Orange 16 and Black 5) in a laboratory scale experimental setup. The effectiveness of combined processes of adsorption and coagulation for complete removal of dyes was also investigated. The right sequence of operation was identified for the combined treatment system. A coconut-based powdered activated carbon (PAC) was used as an adsorbent and alum chloride was chosen as a coagulant. The results indicated that adsorption capacity of Orange 16 was much higher than that of Black 5. Also, adsorption capacity on PAC was highly dependent on the pH of solution. The dye removal efficiencies for 100 mg l$^{-1}$ of Black 5 and Orange 16 by coagulation were almost 99% and 80% under the determined optimal conditions for Black 5 (250 mg l$^{-1}$ coagulant dose and pH 6) and for Orange 16 (350 mg l$^{-1}$ coagulant dose and pH 6). Coagulation followed by adsorption was found to be more efficient than having adsorption prior to coagulation. There was a significant increase in adsorption capacity of PAC for the combined process where coagulation was carried out prior to adsorption. The combined coagulation adsorption process
has the capability of complete dye removal and thus total decolourization, reduction in coagulant and adsorption amounts and thereby produce less amount of sludge.

Four adsorbents have been prepared from industrial wastes obtained from the steel and fertilizer industries and investigated for their utility to remove cationic dyes. On the other hand, carbonaceous adsorbent prepared from carbon slurry waste obtained from the fertilizer industry was found to show good porosity and appreciable surface area and consequently adsorbs dyes to an appreciable extent. The adsorption of two cationic dyes, viz., Rhodamine B and Bismark Brown R on carbonaceous adsorbent conforms to Langmuir equation, is a first-order process and pore diffusion controlled. As the adsorption of dyes investigated was appreciable on carbonaceous adsorbent, its efficiency was evaluated by comparing the results with those obtained on a standard activated charcoal sample. It was found that prepared carbonaceous adsorbent exhibits dye removal efficiency that is about 80–90% of that observed with standard activated charcoal samples. Thus, it can be fruitfully used for the removal of dyes and is a suitable alternative to standard activated charcoal in view of its cheaper cost (Bhatnagar and Jain 2005).

The more recent methods for the removal of synthetic dyes from waters and wastewater are compiled. The various methods of removal such as adsorption on various sorbents, chemical decomposition by oxidation, photodegradation, and microbiological decoloration, employing activated sludge, pure cultures and microbe consortiums are described. The advantages and disadvantages of the various methods are discussed and their efficacies are compared (Forgacsa et al., 2004).

Removal of dyestuffs from industrial wastewaters requires special advanced technologies. Since dyes are usually difficult to remove by biological methods. Adsorption of dyestuffs on solid adsorbents such as powdered activated carbon (PAC) is one of the methods commonly used for the removal of these compounds. As an alternative to PAC, a new
adsorbent material, powdered activated sludge (PAS) was used for removal of different dyestuffs from aqueous media in this study. The rate and extent of dyestuff removal by acid washed powdered activated sludge were evaluated for six different dyestuffs. Dyestuff removal performance of PAS increased with increasing concentrations of PAS for all dyestuffs tested. Removal of Direct Yellow 12 was superior to the other dyes tested and the lowest removal efficiency was obtained with Levafix rot. Different adsorption isotherms were tested to represent the equilibrium adsorption data and the Freundlich isotherm was found to be the most suitable isotherm. Adsorption isotherm constants of Direct Yellow 12 were determined for all isotherms tested (Kargi et al., 2004).

The effectiveness of a combined reduction–biological treatment system for the decolorization of non-biodegradable textile dyeing wastewater was investigated. In this treatment system, a bisulfite-catalyzed sodium borohydride reduction followed by activated sludge technique was used in order to remove the color at ambient temperature and pressure. This experimental study consisted of two major parts: reduction treatment and biological oxidation. Both synthetic and actual wastewater was used in this research. Synthetic wastewater was made by several groups of dyes such as direct, basic and reactive colors. Actual wastewater was collected from two different textile industries in the city of Isfahan, Iran. The characterization of raw and treated wastewater was carried out by infrared and ultraviolet spectrometers. The results of this study demonstrated that the newly developed treatment technique decreased color, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) by 74–88, 76–83 and 92–97%, respectively. The IR and UV analyses showed that non-biodegradable dyes are converted to biodegradable organic compounds such as alkyl and alkenes. Another major advantage of this method with respect to other methods, namely, adsorption and coagulation, was that it removes color without causing any disposal problem. The optimum dosage for treatment of actual
wastewater was found to be 50–60 mg/l for catalyst bisulfite and 200–250 mg/l for sodium borohydride. Finally, a bench-scale experimental comparison of this technique with other reported combined chemical–biological methods showed higher efficiency and lower cost for the new technique (Ghoreishi and Haghighi 2003).

A number of low cost adsorbents from steel and fertilizer industries wastes have been prepared and investigated for the removal of anionic dyes such as ethyl orange, metanil yellow and acid blue 113 from aqueous solutions. The results indicate that inorganic wastes, i.e. blast furnace dust, sludge and slag from steel plants are not suitable for the removal of organic materials, whereas a carbonaceous adsorbent prepared from carbon slurry of fertilizer industry was found to adsorb 198, 211 and 219 mg/g of ethyl orange, metanil yellow and acid blue 113, respectively. The adsorption of dyes on this adsorbent was studied as a function of contact time, concentration, particle size and temperature by batch method. The adsorption isotherm conformed to Langmuir model and the adsorption was found to be exothermic and physical in nature. Kinetic data conforms to Lagergren’s equation with good correlation coefficients varying from 0.9998 to 0.9999 indicating that the adsorption is a first-order process. The adsorption data on carbonaceous adsorbent was compared to a standard activated charcoal sample and it was found that the prepared adsorbent is about 80% as efficient as standard activated charcoal and therefore, can be used as low cost alternative (US$ 100 per ton) for color removal from effluents. (Jain et al., 2003b)

Surplus biological sludge from wastewater treatment plants was pyrolysed at 700°C in the presence of H2SO4. Sludge-based (SB) activated carbon (AC) was mainly mesoporous in nature, with a surface area of 253 m²/g and an average pore diameter of 2.3 nm. Chemviron GW, an AC commercial reference, was mainly microporous with a surface area of 1026 m²/g and an average diameter of 1.8 nm. SB AC outperformed the commercial product in the removal of three anionic dyes in solution (CI Acid Brown 283, CI Direct Red 89 and CI
Direct Black 168). Chemviron GW performed best for Basic Red 46, which may be related to the relatively small steric size of the dye molecules compared with the size of micropores, and to the greater surface area of the commercial AC. For equilibrium pH values between 5 and 9, the adsorption capacity of SB AC for dyes was significantly modified due to the presence of ionisable surface functional groups while that of Chemviron GW, with a more hydrophobic surface, remained unaltered (Martin et al., 2003).

Sewage sludge utilisation must be the preferred management solution for a residue which does not show the desired improvement on wastewater treatment. The quality of sewage sludges as starting materials has been investigated by using sludges both from an urban and from an agrofood industry Wastewater treatment plant. Dried sewage sludges, pyrolysed sewage sludges and both chemically activated and pyrolysed sewage sludges have been used as adsorbent materials in single batch liquid-phase adsorption tests. The adsorption equilibriums of methylene blue by these materials have been described in terms of both Langmuir and Freundlich equations. In order to investigate the mechanisms of adsorption, the first- and second-order kinetic models have been used. All the sludge-derived adsorbents produced have been able to uptake methylene blue from solution, the second-order rate expression being preferred to the first-order one. Nevertheless, the time needed for reaching the equilibrium and adsorptive capacity have differed from one to another adsorbent. Equilibrium and kinetic results have showed that dried urban sewage sludges are the most efficient materials for removing the methylene blue from the solution (Otero et al., 2003).

The capacity of adsorbent recycled from microwave thermal treatment to remove a synthetic dye, Rhodamine 6G, from a water bath, was examined. The acidified, de-watered sludge was microwave heated for 1-4 min. Batch adsorption tests were conducted on this sludge at various pH values and solution temperatures. Equilibrium of dye adsorption was obtained in 30 h. Three kinetic models pseudo first-order, pseudo second-order and intra-
particle diffusion were applied to elucidate the adsorption kinetic data. Experimental results indicate that higher adsorption efficiency could be derived at higher pH, temperature levels. Moreover, the sample treated for 1 min by microwaves adsorbed more dye than did the sample so treated for 4 min. Sludge samples were also characterized to interpret the experimental findings. Energy cost analysis demonstrated the feasibility of the present microwave process (Annadurai et al., 2003).

The capacity and mechanism of metal hydroxide sludge in removing azo reactive dyes from aqueous solution was investigated with different parameters, such as charge amount of dyes, system pH, adsorbent particle size, and adsorbent dosage. The three anionic dyes used were CI Reactive Red 2, CI Reactive Red 120, and CI Reactive Red 141, increasing in number of sulfonic groups, respectively. Only 0.2% (w/v) of powdered sludge (o75 mm) achieved color removal from 30 mg/L reactive dye solutions within 5 min without pH adjustment. The larger the charge amount of the dyes, the greater the adsorption (>90%) on the metal hydroxide sludge. The system pH played a significant role in the adsorption on metal hydroxides and formation of dye metal complexes. The optimum system pH for dye adsorption was 8–9 which was close to the pH zpc of the sludge while the precipitation of dye–metal complexes occurred at system pH 2. The maximum adsorption capacity (Ql) of the sludge for the reactive dyes was 48–62 mg g⁻¹ adsorbent. The Langmuir and Freundlich models showed that the higher charged dyes had a higher affinity of adsorption. The smaller particle size and the greater amount of adsorbent showed the faster process, due to an increase in surface area of adsorbent. Desorption studies elucidated that metal hydroxide sludge had a tendency for ion exchange adsorption of sulfonated azo reactive dyes. Leaching data showed that the treated water was nontoxic at a system pH above 5 or a solution pH above 2 (Netpradi et al., 2003).
The rate processes for the adsorption of Basic Yellow 24 dye on activated sludge biomass have been studied. Influences of various factors on adsorption rate, such as shaking rate, initial dye concentration, biomass particle size, and dye solution temperature have been investigated. The experimental results indicate that there is a boundary layer surrounding the biomass particles, the kinetics of the adsorption process is mainly controlled by intraparticle diffusion. The activation energy for the same process was 1.45 kcal mol\(^{-1}\) (Chu et al., 2002).

The biosorption of reactive dyes (Reactive Blue 2-RB2 and Reactive Yellow2-RY2) onto dried activated sludge was investigated. The dye binding capacity of biosorbent was shown as a function of initial pH, initial dye concentration and type of dye. The equilibrium data fitted very well to both the Freundlich and Langmuir adsorption models. The results showed that both the dyes uptake processes followed the second-order rate expression (Aksu 2001).

The dye adsorption characteristics of sludge particulates, both primary and secondary, were studied. Major factors such as pH, SS (suspended solid), and ionic strength on dye adsorption were evaluated. An anionic dye, new coccine acid red #18 was used as the adsorbate. Results show that dye adsorption is a fast process and can reach equilibrium in 30 min. Results also show that pH is the most important factor determining the dye adsorption. Decreasing pH can significantly increase the adsorption of the dye. Greater adsorption density can be achieved at SS less than 1 g/L. However, at SS concentration greater than 1 g/L, the dye adsorption density remains relatively unchanged. It is found that the increase in the ionic strength decreases the dye adsorption density. Dye adsorption can be described by a multilayer adsorption isotherm. The multilayer adsorption model allows the calculation of both the monolayer adsorption density (i.e., the maximum first layer adsorption density) and the equilibrium constants for the first layer and subsequent adsorption. Based on the
monolayer adsorption capacity, it is possible to determine the specific surface area of various sludge particles (Wang et al., 1998).

Heavy metals are commonly found in municipal sewage that contains industrial effluents. Metal concentrations above toxic levels inhibit biological processes in municipal sewage treatment works and discharge of metals into surface waters can have severe effects on the environment and public health. However, trace metals at sub-toxic concentrations have also been observed to affect COD removal in activated sludge. The effects of a trace metal chromium. On activated sludge in a sequencing batch reactor SBR were investigated. Chromium-laden wastewater at a sub-toxic level of 0.05 mg/l affected the SBR performance to different extents depending on the hydraulic retention time (HRT). Organic removal in activated sludge was postulated to proceed by a rapid adsorption of organics on the sludge, followed by a slower metabolic assimilation mechanism.

The sewage sludge ash (SSA) can potentially be used for removal of heavy metals from wastewater due to its similar chemical composition to that of fly ash and blast-furnace slag. This study investigated the adsorptive characteristics of SSA including specific surface area, cation-exchange capacity (CEC), and pH of zero point of charge (pH ZPC). In addition, the adsorption isotherms of SSA with synthetic wastewater containing copper ions were tested. Experimental results indicated that the CEC and pH ZPC of SSA were 24.1-25.7 meq/100 g and 3.1-3.4, respectively, which exhibited the capability of removing heavy metals from wastewater. The adsorption test of applying SSA into synthetic wastewater revealed that the adsorption isotherm of SSA for copper ions generally followed the Langmuir model. The estimated maximum capacity of copper adsorbed by SSA was 3.2-4.1 mg/g and close to that of fly ash. The primary mechanisms of copper removal by SSA included electrostatic attraction, surface complex formation, and cation exchange. The precipitation of copper hydroxide occurred only when the dosage of SSA and the equilibrium pH of wastewater were
at a high level (30-40 g/l and greater than 6.2, respectively). In general, similar to fly ash and blast-furnace slag, the SSA can be reused as an adsorbent for copper removal from wastewater and the removal efficiency was greater than 98%.

Various types of activated carbons were developed from organic sewage sludge (SS) using H₂SO₄, H₃PO₄ and ZnCl₂ as chemical activation reagents, and the removal of Hg (II) from aqueous solution by these carbons was effectively demonstrated. The quality of the activated carbons was dramatically improved owing to chemical activation. ZnCl₂ activated carbon had the highest capability for Hg (II) adsorption, followed by H₃PO₄ and H₂SO₄ activated carbons. The adsorption was greatly affected by Hg (II) concentration, solution pH and carbon dosage, and followed Lagergren first order rate equation and Freundlich isotherm model. Desorption results indicated that around 60% to 80% of the adsorbed Hg (II) could be recovered from the carbons to 0.1M HNO₃ solution by sonication treatment. Accordingly, it is believed that the activated carbons developed in this study are effective and practical for utilization in industrial wastewater treatment for mercury removal (Zhang et al., 2005).

Four adsorbents have been prepared from industrial wastes obtained from the steel and fertilizer industries and investigated for their utility to remove cationic dyes. Studies have shown that the adsorbents prepared from blast furnace sludge, dust, and slag have poor porosity and low surface area, resulting in very low efficiency for the adsorption of dyes. On the other hand, carbonaceous adsorbent prepared from carbon slurry waste obtained from the fertilizer industry was found to show good porosity and appreciable surface area and consequently adsorbs dyes to an appreciable extent. The adsorption of two cationic dyes, viz., rhodamine B and Bismark Brown R on carbonaceous adsorbent conforms to Langmuir equation, is a first-order process and pore diffusion controlled. As the adsorption of dyes investigated was appreciable on carbonaceous adsorbent, its efficiency was evaluated by comparing the results with those obtained on a standard activated charcoal sample. It was
found that prepared carbonaceous adsorbent exhibits dye removal efficiency that is about 80-90% of that observed with standard activated charcoal samples. Thus, it can be fruitfully used for the removal of dyes and is a suitable alternative to standard activated charcoal in view of its cheaper cost (Bhatnagar and Jain, 2005).

Biosorption of heavy metal ions, such as Cu$^{2+}$, Cd$^{2+}$ and Zn$^{2+}$ was carried out using waste activated sludge & municipal sewage treatment plant as an adsorption material, and the effects of parameters, such as pH value, temperature, reaction time and sorption duration, were studied in detail. The results indicate that the removal rates of Cu$^{2+}$, Zn$^{2+}$ and Cd$^{2+}$ with low concentration are 96.47%, 80% and 90%, respectively, adsorbed by waste activated sludge. Little effect of dosage of activated sludge on the adsorption of Cu$^{2+}$ and more effects on the adsorption of Zn$^{2+}$ and Cd$^{2+}$ are observed. Little effect of temperature is observed, while pH value and adsorption time exert important influence on the sorption process. The adsorption behaviors of heavy metal ions all have parabolic relationships with pH value. The optimum pH value is between 6 and 10, and the optimum adsorption time is 1 h. In single heavy metal ion system, the sorption processes of Cu$^{2+}$, Zn$^{2+}$ and Cd$^{2+}$ are in accordance with Freundlich model, which indicates that it is suitable for the treatment of these three heavy metal ions using intermittent operation. In addition, the sorption capacity of the sludge for Cu$^{2+}$ is preferential to the other two ions (Sheng-lian et al., 2006).

To evaluate the influences of sewage sludge-derived organic matters on metal sorption and on the resultant sludge loading estimates, a batch experiment was conducted to compare the sorption of Ni, Cu and Pb in sewage sludge filtrates (1:20 sewage sludge to water) on eight soils and the adsorption of metals in a reference solution which had the same matrix as the sewage sludge filtrate except dissolved organic material. Metal sorption could be well fitted by linear isotherm and the dissolved organic matter in sludge significantly depressed the sorption ($p < 0.01$). The main factor controlling sorption of Ni on different soils
was dominated by soil cation exchange capacity (CEC) and sorption of Cu and Pb was by soil organic matter (SOM). The parameters obtained from the sorption isotherm equations were then used to estimate sludge loadings into the soils. When the sorption parameters derived from the reference solution were used for calculation, that is the effect of dissolved organic matter was not considered, the calculated safe application rates are approximately 47.8, 51.4, 34.2, 31.3, 21.7, 46.3, 187.1 and 27.6 t-sludge/ha for the Beijing, Jiangxi, Xiamen, Jilin, Guangdong, Wuhan, Gansu and Xinjiang soils, respectively. However, when the sorption parameters derived from the dissolved organo-metallic complexes are used for calculation, the corresponding application rates are reduced to approximately 6.0, 3.4, 1.9, 10.0, 6.3, 3.6, 7.3 and 3.5 t-sludge/ha, respectively.

The behaviour, fate and significance of the detergent builder nitrilotriacetic acid (NTA) has been reviewed with particular reference to the removal of NTA during wastewater treatment and the effects of NTA on heavy metal solubility both during treatment and in the receiving environment. It is concluded that NTA removal during secondary biological treatment is subject to considerable variation, both temporal and between works as a result of changes in NTA load, temperature, water hardness and treatment process parameters. As a result of such variability, effluent NTA concentrations may be sufficient to mobilise heavy metals resulting in metal contamination of receiving waters and potable waters. Particularly in areas of low effluent dilution and high water re-use. Removal of NTA during primary sedimentation and septic tank treatment is concluded to be predominantly due to adsorption to the sludge solids while removal in anaerobic sludge digestion is subject to operational characteristics of the treatment works. Disposal of NTA contaminated sludge to land may contaminate groundwaters and affect heavy metal speciation, while the disposal of contaminated sludge or sewage to sea may result in toxic algal blooms, in addition to effects on metal speciation (Perry et al., 1984). Alkaline white mud (AWM) has been investigated as
a low-cost material for removal of an anionic dye, acid blue 80. The effects of contact time, initial pH of dye solution, AWM dosage, and the presence of inorganic anion sulphate or phosphate ion on removal of the dye were evaluated. The results show that AWM could be used as an effective material for removal of acid blue 80 in a pre or main process, particularly at high dye concentration (>300 mg L\(^{-1}\)), reaching maximum removal efficiency of 95%. At low dye concentration, surface adsorption is mainly responsible for the dye removal, while chemical precipitation of the dye anions with soluble Ca\(^{2+}\) and Mg\(^{2+}\) may play a dominant role for the dye removal at high concentration, producing much less sludge than conventional adsorption method. Solution pH has only a limited effect on the dye removal due to high alkalinity and large pH buffer capacity of AWM suspension and thereby pH is not a limiting factor in pursuing high dye removal. The dye removal may be significantly suppressed by the presence of phosphate with increasing concentration, and the reduction in the dye removal is much larger at high dye concentrations than at low ones.

The application of wheat shell (WS) was an agricultural by-product, for the removal of direct blue 71 (DR) from aqueous solution. The characteristics of WS surface, such as surface area, Bohem titration and scanning electron microscopy (SEM) were obtained. The removal of direct blue 71 onto WS from aqueous solution was investigated by using parameters, such as pH, temperature, adsorbent dose, contact time and initial concentration. The adsorption process attains equilibrium within 36 h. The extent of dye removal decreased with increasing adsorbent dosage and also increased with increasing contact time, temperature, in solution concentration. Optimum pH value for dye adsorption was determined between 6 and 8. The experimental data were analysed by the Langmuir and Freundlich models of adsorption. It was found that the Langmuir equation fit better than the Freundlich equation. Maximum adsorption capacity \((Q_m)\) was calculated as at different temperatures (293, 303 and 313 K) 40.82, 45.66 and 46.30 mg g\(^{-1}\), respectively. In addition, the adsorption
data obtained at different temperatures of DR by WS were applied to pseudo first-order, pseudo second-order and Weber–Morris equations, and the rate constants of first-order adsorption ($k_1$), the rate constants of second-order adsorption ($k_2$) and intraparticle diffusion rate constants ($k_3$) at these temperatures were calculated, respectively. Furthermore, the results indicate that WS could be employed as a low-cost alternative to other adsorbents in the removal of direct blue 71 from aqueous solution. The adsorption is highly dependent on contact time, adsorbent dosage and initial concentration.

The sorption of C.I. Reactive Black 5, a reactive dye, onto high lime fly ash, obtained from Soma Thermal Power Plant (Turkey), to be low cost adsorbent. The effect of various experimental parameters such as contact time, adsorbent dose and initial dye concentration were investigated. Determination of the adsorption equilibrium concentrations was determined by UV–vis spectrophotometry analytical method. Equilibrium data were fitted to the Freundlich and Langmuir isotherm equations and the equilibrium data were found to be well represented by the Freundlich isotherm equation. The adsorption kinetics of C.I. Reactive Black 5 onto high lime fly ash was also studied to characterize of the surface complexation reaction. A pseudo-second-order mechanism has been developed to predict the rate constant of the adsorption, the equilibrium capacity and initial adsorption rate with the effect of initial concentration. A single-stage batch adsorber design of the adsorption of C.I. Reactive Black 5 onto high lime fly ash has been studied based on the Freundlich isotherm equation. The sorption of pollutants from aqueous solutions plays a significant role in water pollution control. Generation of thermal and electric energy in the process of solid fuel combustion is inevitably related to production of significant amounts of combustion. The amount of combustion wastes was estimated as million tonnes, including fly ashes. The amount of fly ashes considerably has increased. The equilibrium capacity of high lime Soma fly ash was found as 7.184 mg/g dye. The equilibrium and Kinetic of adsorption of RB5 on
high lime fly ash, obtained from Soma Thermal Power Plant, showed that fly ash can be used as low cost potential adsorbents for dye wastewater.

The adsorption of Methylene Blue, up to 1000 mg L$^{-1}$, and Acid Blue 25, up to 500 mg L$^{-1}$, onto ground hazelnut shells was studied in comparison with sawdust of various species of wood, in order to explore the potential use of this material as low cost adsorbent for dye removal in dye house effluents. The adsorption kinetics was investigated according to Lagergren’s model, but the best fit was achieved by a second order equation. The equilibrium data were processed according to Langmuir’s model and higher adsorption capacity values towards both dyes were shown by hazelnut shells than wood sawdust. Moreover, fixed bed adsorption of Methylene Blue was performed on hazelnut shell columns and the breaks through curves were determined by varying bed depth, flow rate and influent concentration. The data were processed according to Bohart–Adams model and the column performances could be predicted by the bed depth service time (BDST) approach. The results obtained in batch adsorption of Methylene Blue and Acid Blue 25 onto hazelnut shells in comparison with wood sawdust showed that the adsorption kinetics with both adsorbents can be explained by a second order equation better than Lagergren’s first order model. This material could be used more advantageously than wood sawdust as low cost adsorbent in colour removal from dye house effluents. The adsorption capacity values of hazelnut shells toward Methylene Blue are even higher than those reported for activated carbon obtained from the same material and some other lignocellulosic sources. The curves obtained in fixed bed adsorption of Methylene Blue on hazelnut shell columns was found similar to that observed with other adsorbents.

Column kinetics of methylene blue and red basic 22 adsorption using on mild acid-hydrolysed beech sawdust were investigated, using untreated beech sawdust as control in order to explore its potential use as a low cost adsorbent for wastewater dye removal. The
adsorption capacities, estimated according to Freundlich’s model, and the adsorption capacity coefficient values, determined using the Bohart and Adams’ bed depth service model, indicated that prehydrolysis enhances the adsorption properties of the original material. This enhancement can possibly be attributed to (a) the removal of the hemicelluloses during sulphuric acid treatment, resulting in the ‘opening’ of the lignocellulosic matrix’s structure and the increasing of the BET surface area and (b) the activation of the material’s surface owing to an increase in the number of dye binding sites. This can be attributed to (a) the ‘opening’ of the structure of the lignocellulosic substrate and the increasing of the BET surface area of the absorbent material by the removal of the hemicelluloses, and (b) the higher activation of the inner surface due to the sulphuric acid pretreatment. The linear correlations of the KF values, the adsorption capacities (qm) and the adsorption capacity coefficient values (N) vs. the BET surface area were found to be statistically significant. Prehydrolysis is commonly employed in various processes owing to the simplicity, the effectiveness and the low cost of the process. The resulting adsorbent is a suitable low cost material that can be used as an alternative to commercial activated carbons for the removal of basic dyes from water/wastewater effluents.

The use of activated carbon obtained from Euphorbia rigida for the removal of a basic textile dye, which is methylene blue, from aqueous solutions at various contact times pHs and temperatures was investigated. The plant material was chemically modified with H₂SO₄. The surface area of chemically modified activated carbon was 741.2 m² g⁻¹. The surface characterization of both plant- and activated carbon was undertaken using FTIR spectroscopic technique. The adsorption process attains equilibrium within 60 min. The experimental data indicated that the adsorption isotherms are well described by the Langmuir equilibrium isotherm equation and the calculated adsorption capacity of activated carbon was 114.45 mg g⁻¹ at 408°C. The adsorption kinetics of methylene blue obeys the pseudo-second-
order kinetic model and also followed by the intraparticle diffusion model up to 60 min. The thermodynamic parameters such as DG₈, DH₈ and DS₈ were calculated to estimate the nature of adsorption. The activation energy of the system was calculated as 55.51 kJ mol⁻¹. According to these results, prepared activated carbon could be used as a low-cost adsorbent to compare with the commercial activated carbon for the removal textile dyes from textile wastewater processes. The activated carbon from E. rigida acts a well adsorbent for the removal of a basic dye (methylene blue) from aqueous solutions. The functional groups of E. rigida and activated carbon were found by using FTIR spectrometer. The straight lines obtained for the Langmuir and Freundlich models obey to fit to the experimental equilibrium, but the Langmuir model gives better fitting than Freundlich model. The mechanism of the dye-activated carbon interaction is thus likely to be complicated involving a wide range of sites differing in a number of aspects including energy considerations.

The effect of pH on the batch kinetics of methylene blue adsorption on beech sawdust was simulated in order to evaluate sawdust potential use as low cost adsorbent for wastewater dye removal. The zero point of charge pH pzc of the sawdust, in order to explain the effect of pH in terms of pH pzc, was measured by the mass titration and the automatic titration methods. The adsorption capacity, estimated according to Freundlich’s model, indicate that increase of the pH enhances the adsorption behaviour of the examined material. The lower adsorption of methylene blue at acidic pH is due to the presence of excess H⁺ ions that compete with the dye cation for adsorption sites. As the pH of the system increases, the number of positively charged sites decreases while the number of the negatively charged sites increases. The negatively charged sites favour the adsorption of dye cation due to electrostatic attraction. The increase in initial pH from 8.0 to 11.5 increases the amount of dye adsorbed. The adsorption capacity, estimated according to Freundlich’s model, of methylene blue adsorption on beech sawdust as low cost adsorbent for wastewater dye
removal, indicate that increase of the pH enhances the adsorption behaviour of this material. The significantly lower adsorption of methylene blue at acidic pH can be attributed to the presence of excess H\(^+\) ions that compete with the dye cation for adsorption sites. As the pH of the system increases, the number of positively charged sites decreases while the number of the negatively charged sites increases. The negatively charged sites favor the adsorption of dye cation due to electrostatic attraction. The increase in initial pH from 8.0 to 11.5 increases the amount of dye adsorbed.

Column kinetics of methylene blue adsorption on calcium chloride, zinc chloride, magnesium chloride and sodium chloride treated beech sawdust were simulated using untreated beech sawdust as control, in order to explore its potential use as a low-cost adsorbent for wastewater dye removal. The adsorption capacity, estimated according to Freundlich’s model, the Langmuir constant \(K_L\) and the adsorption capacity coefficient values, determined using the Bohart and Adams’ bed depth service model indicate that salts treatment enhanced the adsorption properties of the original material. Since sawdust is an industrial waste/by-product and the salts used can be recovered as spent liquids from various chemical operations, this process of adsorbent upgrading/modification might be considered to take place within an ‘Industrial Ecology’ framework. The Freundlich adsorption capacity \(K_F\) (batch studies) for methylene blue increased up to 98% by calcium chloride treatment, 87% by zinc chloride-treatment, 90% magnesium chloride-treatment and 108% by sodium chloride-treatment. This low cost adsorbent could be made widely available for use as an alternative to commercial activated carbons for the removal of basic dyes from water/wastewater effluents.

The palm ash, an agriculture waste residue from palm-oil industry in Malaysia was investigated as a replacement for the current expensive methods of removing direct blue 71 dye from an aqueous solution. The experimental data were analyzed by the Langmuir and
Freundlich models of adsorption. Equilibrium data fitted well with Freundlich model in the range of 50–600 mg/L. The equilibrium adsorption capacity of the palm ash was determined with the Langmuir equation and found to be 400.01 mg dye per gram adsorbent at 30°C. The rates of adsorption were found to conform to the pseudo-second-order kinetics with good correlation. The results indicate that the palm ash could be employed as a low-cost alternative to commercial activated carbon. Palm ash was used as an adsorbent for the removal of direct blue 71 dye from an aqueous solution. The palm ash had very high adsorption capacity to remove the dye, with a maximum monolayer adsorption capacity was 400.01 mg/g at 30°C. The adsorption capacities were affected by the initial dye concentration. The uptake increased with the increase in initial dye concentration. The Freundlich equation agrees very well with the equilibrium isotherm. The pseudo-second-order kinetic model fits very well with the dynamical adsorption behavior of direct blue dye. This agriculture waste residue could therefore substituted be in place of activated carbon as adsorbent due to its availability, high adsorption capacity and low cost.

The industrial tanning of leather usually produces considerable amounts of chromium-containing solid waste and liquid effluents and raises many concerns on its environmental effect as well as on escalating landfill costs. Actually, these short comings are becoming increasingly a limit in factor to this industrial activity that claims for alternative methods of residue disposals. The adsorption isotherm pattern for the wet blue leather from the A’urea tanning industry in Erechim-RS (Brazil) showed that these materials present high activity on adsorbing the reactive red textile dye as well as other compounds. The adsorbent materials were characterized by IR spectroscopy and SEM and tested for the dye adsorption (reactive textile and methylene blue dyes). The concentrations of dyes were measured by UV–vis spectrophotometry and the chromium extraction from leather waste was realized by basic hydrolysis and determined by atomic absorption. As a low cost abundant adsorbent
material with high adsorption ability on removing dye methylene blue (80 mg g⁻¹) and textile dye reactive red (163 mg g⁻¹), the leather waste is revealed to be a interesting alternative relatively to more costly adsorbent materials.

The B-phycoerythrin is a major light-harvesting phycobiliprotein in some marine algae. It is widely used as a fluorescent probe and analytical reagent, and could also be used as a natural dye in foods and cosmetics. The operation of expanded bed technology was first optimized on a small scale using a column of 15mm internal diameter. The chromatographic parameters studied were the sample load, viscosity and expansion degree. The optimal conditions proved to be a sample load of 0.88 mg B-PE/mL Streamline DEAE, an expanded bed volume twice the settled bed volume and a sample viscosity of 1.068mP. The expanded bed adsorption process was then scaled up 16 times by increasing the column diameter, while maintaining the sedimented bed height, linear flow rate and protein load at constant values. The success of the scale-up process was verified by determining the protein breakthrough capacity and product recovery. A comparative study was made of the performance of four columns of 15, 25, 40 and 60mm internal diameters. The standard deviation of the breakthrough curves ranged from 0.81 to 0.76; the higher the internal diameter the lower the standard deviation. The yield of the EBA chromatography was in the range of 71–78%. These results show that small diameter columns can be effectively used for mimicking the behaviour in scaled up systems providing a useful tool for method scouting studies. The results also show that the large-scale assay (60mm diameter column) was as efficient as the lab scale one (15mm diameter column) in recovering B-phycoerythrin from the unclarified crude extract.

The fly ash treated by H₂SO₄ was used as a low-cost adsorbent for the removal of a typical dye, methylene blue, from aqueous solution. An increase in the specific surface area and dye-adsorption capacity was observed after the acid treatment. The adsorption isotherm
and kinetics of the treated fly ash were studied. The experimental results were fitted using Langmuir and Freundlich isotherms. It shows that the Freundlich isotherm is better in describing the adsorption process. Two kinetic models, pseudo-first order and pseudo second order, were employed to analyze the kinetic data. It was found that the pseudo-second-order model is the better choice to describe the adsorption behavior.

The potential of two low-cost adsorbents such as sunflower seed shells (SS) and mandarin peelings (MP) in the removal of the synthetic anionic dye Reactive Black 5 (RB5) from aqueous solutions was investigated. SS led to a percentage of dye removal higher than MP (85% and 71% after 210 min respectively, for an initial RB5 concentration of 50 mg L$^{-1}$ and an initial pH of 2.0). The rate of adsorption followed a pseudo-second-order kinetic model and the intra-particle diffusion was found to be the rate controlling stage. In addition, the equilibrium data fitted well both the Freundlich and multilayer adsorption isotherm equations indicating the heterogeneity of the adsorbent surface. This was also corroborated by the SEM photographs. On the whole, the results in this study indicated that SS were very attractive materials for removing anionic dyes from dyed effluents. Sunflower seeds shells, which are discarded as waste material from the food industry, are promising bio-adsorbents for the removal of dyes from aqueous solutions. Hence, in the present study their potential to adsorb an anionic dye in extremely acidic conditions (pH 2) was shown. The dyed SS have potential to be used as substrates in solid state fermentation (SSF). Thus, degradation of the adsorbed dye takes place whilst simultaneously enriching the protein content of the substrate by the presence of fungal biomass. The fermented mass can be utilised as a fertilizer or a soil conditioner. Another alternative is to burn the dyed SS to generate power. The utilisation of this waste would contribute to the so-called green biotechnology.

Wastewater containing direct dyes discharged from various industries in particular, textile industry often causes many environmental problems. Considering the possibility of the
adsorption process of synthetic dyes and their removal from aqueous solutions using orange peel as an eco-friendly and low-cost adsorbent before discharging to the receiving environment is the most important task. The CTRNW model was integrated with SEEP/W model and modified to solve mathematical equations describing the problem at hand. The modelling accuracy was first verified with an analytical equation for a reactive mass transport problem including advection, dispersion and linear adsorption processes through groundwater flow medium. The modelling results were then compared to those results obtained from experimental tests for the removal of Direct Red 23 and Direct Red 80 dyes from textile wastewater using orange peel adsorbent. The model predictions somewhat agree with the experimental measurements. It was found that the adsorption process by orange peel adsorbent could be well described by the Langmuir isotherm. Furthermore, a pseudo-second order kinetics showed to be well-suited with the rate of sorption. Although the generation of such wastewater by the different industries is nearly unavoidable, the results of model presented here can help to design an appropriate environmental management strategy to minimise the adverse impacts caused by industrial wastewater. The parameter values in the model were obtained from an experimental test for the removal of dyes Direct Red 23 and Direct Red 80 from textile wastewaters using orange peel as a low-cost adsorbent. The initial concentrations of both Direct Red 23 and Direct Red 80 dyes were increased from 50 to 75 mg/l, the rate of removal by the orange peel adsorbent decreased.

Palm oil and textile industries are important contributors to Malaysia’s economic growth. However, these industries also generate various pollutants of the environment. This research explores the possibility of using a low cost adsorbent ash produced from palm oil factory, for the removal of dyes from aqueous solution. For the treatment to be truly low cost not only should the adsorbent be easily and cheaply available in abundance but it should also require minimal or no pre-treatment, for expensive pre-treatment procedures would add to the
overall treatment cost. Two commercial dyes i.e. disperse blue and disperse red were used. The study incorporates both batch as well as continuous flow experiments. The effects of different system variables, viz., pH, initial dye concentration, and agitation time were studied in the batch tests. Acidic pH was found to favour dye removal. The optimum pH and agitation time for the removal of the two dyes were 2 and 60 min, respectively. Both Langmuir and Freundlich isotherms could be used to describe the adsorption of the dyes, with the former yielding somewhat better fits. The experimental data fitted well to the pseudo-second-order kinetic model with $R^2 > 0.98$ for all concentrations (50-250 mg/l) tested. Column plugging was the main problem encountered due to the fine particle size of the ash. Pelletisation of ash using calcium oxide and calcium sulphate was not successful. For industrial application, pelletisation will have cost implications and may not be recommended. Ash may be better used in its natural form in batch process. The adsorption capacity of the ash for the dye removal was found to be affected by the solution’s pH, with lower pH favouring adsorption. This was attributed to the presence of excess positive charge on its surface. Over 99% removal was achieved for both the dyes at pH 2. The required low pH will have an impact on the operating cost in real practice, but the adsorbent (ash) itself is virtually free. An analysis of the economy of ash application as adsorbent will have to take into consideration both these factors. An attempt to convert the ash into pellet also failed and the mixture of ash, calcium oxide and calcium sulphate remained in powder form after compression. Ash is an unwanted by-product of the palm oil industry and its pre-treatment is not desirable especially from the view point of economy.

The adsorption of Reactive Blue 19 (RB 19), Reactive Red 195 (RR 195) and Reactive Yellow 145 (RY 145) onto wheat bran, generated as a by-product material from flour factory, was studied with respect to initial pH, temperature, initial dye concentration, adsorbent concentration and adsorbent size. The adsorption of RB 19, RR 195 and RY 145
onto wheat bran increased with increasing temperature and initial dye concentration while the adsorbed RB 19, RR 195 and RY 145 amounts decreased with increasing initial pH and adsorbent concentration. The Langmuir and Freundlich isotherm models were applied to the experimental equilibrium data depending on temperature and the isotherm constants were determined by using linear regression analysis. The monolayer coverage capacities of wheat bran for RB 19, RR 195 and RY 145 dyes were obtained as 117.6, 119.1 and 196.1 mg/g at 60 °C, respectively. It was observed that the reactive dye adsorption capacity of wheat bran decreased in the order of RY 145 > RB 19 > RR 195. The pseudo-second order kinetic and Weber–Morris models were applied to the experimental data and it was found that both the surface adsorption as well as intraparticle diffusion contributed to the actual adsorption processes of RB 19, RR 195 and RY 145. Regression coefficients (R²) for the pseudo-second order kinetic model were higher than 0.99. Thermodynamic studies showed that the adsorption of RB 19, RR 195 and RY 145 dyes onto wheat bran was endothermic in nature. The monolayer adsorption capacity of wheat bran was obtained as 117.6, 119.1 and 196.1 mg/g for RB 19, RR 195 and RY 145, respectively. It was observed that the biosorption data of RB 19, RR 195 and RY 145 fitted well to the Langmuir model according to R². The pseudo-second order kinetic and Weber–Morris models were applied to the experimental data and it was found that both the surface adsorption as well as intraparticle diffusion.

Dyes are usually presents in the effluent water of many industries, such as textiles, leather, paper, printing and cosmetics. The effectiveness of dye adsorption from wastewater has made to get alternative different low cost adsorbent to other expensive treatment methods. The adsorption of methylene blue onto dehydrated wheat bran (DWB) was investigated at temperatures (25–45°C), initial methylene blue (MB) concentrations (100-500 mg L⁻¹) and adsorbent dosage at the given contact time for the removal of dye. The optimum adsorption conditions were found to be as medium pH of 2.5 and at the temperature of 45°C
for the varying adsorbent dosage. Equilibrium isotherms were analysed by Freundlich, Langmuir and Redlich-Peterson isotherm equations using correlation coefficients. Adsorption data were well described by the Langmuir model, although they could be modelled by the Freundlich and Redlich-Peterson model as well. The pseudo-first order and pseudo-second order kinetic models were applied to test the experimental data. It was concluded that the pseudo-second order kinetic model provided better correlation of the experimental data rather than the pseudo-first order model. The mass transfer model as intraparticle diffusion was applied to the experimental data to examine the mechanisms of rate controlling step. It was found that at the higher initial MB concentration, intraparticle diffusion is becoming significant controlling step. The kinetics of MB adsorption onto DWB was studied using the pseudo-first and pseudo-second order kinetic models. The results indicated that the pseudo-second order equation provided the better correlation of the adsorption data. It was also seen that the intraparticle diffusion kinetics can also be one of the rate determining steps as well as pseudo-second order kinetics.

Erythrosine is a popular dye that is widely used in cosmetics, foodstuffs, medicines, and textiles. It is highly toxic to mankind and can lead to many diseases including carcinogenicity. Removal of erythrosine has been carried out using waste material hen feathers as adsorbent. The effects of pH, concentration of the dye, temperature, and adsorbent dosage have been studied. Adsorption of erythrosine over hen feathers has been correlated with Freundlich and Langmuir isotherms and satisfies both models. The adsorption process has been found endothermic in nature and thermodynamic parameters, Gibb’s free energy ($G_0$), change in enthalpy ($H_0$), and change in entropy ($S_0$) have been calculated. By rate expression and treatment of data it has been ascertained that the adsorption of erythrosine over hen feathers follows a particle diffusion mechanism. The strong linearity of the Freundlich and Langmuir isotherm represented the sorption of erythrosine onto hen feathers.
at different temperatures. The adsorption of the dye was found feasible and endothermic in nature. While values of separation factor indicated that the ongoing adsorption process is much favorable at higher temperatures.

The use of low-cost and ecofriendly adsorbents was investigated as an ideal alternative to the current expensive methods of removing dyes from wastewater. Sepiolite was used as an adsorbent for the removal of methyl violet (MV) and methylene blue (MB) from aqueous solutions. The rate of adsorption was investigated under various parameters such as contact time, stirring speed, ionic strength, pH and temperature for the removal of these dyes. Kinetic study showed that the adsorption of dyes on sepiolite was a gradual process. Quasi-equilibrium reached within 3 h. Adsorption rate increased with the increase in ionic strength, pH and temperature. Pseudo-first-order, the Elvoich equation, pseudo-second order, mass transfer and intra-particle diffusion models were used to fit the experimental data. The sorption kinetics of MV and MB onto sepiolite was described by the pseudo-second-order kinetic equation. Intra-particle diffusion process was identified as the main mechanism controlling the rate of the dye sorption. The diffusion coefficient, D, was found to increase when the ionic strength, pH and temperature were raised. Thermodynamic activation parameters such as DG, DS and DH were also calculated. The adsorption rate of dyes on sepiolite increased with increase in initial dye concentration, ionic strength, pH and temperature but stirring speed had no effect on it. The intra-particle diffusion was the rate-limiting step for the adsorption process. The diffusion coefficient increased with increase in the initial dye concentration, ionic strength, pH and temperature. The activation energy was very low and the process is governed by interactions of physical nature.

Fast technologically changing situation related to waste management practices, it is desirable that disposal of plant waste should be done in a scientific manner by keeping in view economic and pollution considerations. This is only possible when the plant waste has
the potential to be used as raw material for some useful product. In the present study, groundnut shell, an agricultural waste, was used for the preparation of an adsorbent by chemical activation using ZnCl₂ under optimized conditions and its comparative characterisation was conducted with commercially available powdered activated carbon (CPAC) for its physical, chemical and adsorption properties. The groundnut shell based powdered activated carbon (GSPAC) has a higher surface area, iodine and methylene blue number compared to CPAC. Both of the carbons were used for the removal of malachite green dye from aqueous solution and the effect of various operating variables, viz. adsorbent dose (0.1–1 g l⁻¹), contact time (5–120 min) and adsorbate concentrations (100-200 mg l⁻¹) on the removal of dye, has been studied. The experimental results indicate that at a dose of 0.5 g l⁻¹ and initial concentration of 100 mg l⁻¹, GSPAC showed 94.5% removal of the dye in 30 min equilibrium time, while CPAC removed 96% of the dye in 15 min. The experimental isotherm data were analyzed using the linearized forms of Freundlich, Langmuir and BET equations to determine maximum adsorptive capacities. The equilibrium data fit well to the Freundlich isotherm, although the BET isotherm also showed higher correlation for both of the carbons. The results of comparative adsorption capacity of both carbons indicate that groundnut shell can be used as a low-cost alternative to commercial powdered activated carbon in aqueous solution for dye removal. That groundnut shell based powdered activated carbon is an effective adsorbent for the removal of malachite green dye from aqueous solutions, and its adsorption capacity is quite comparable to the commercial powdered activated carbon. The BET isotherm provided the best correlation for adsorption of dye but the Freundlich model fits a little better than the other two models for the adsorption equilibrium data in the examined concentration range.

The effectiveness of adsorption for dye removal from wastewaters has made it an ideal alternative to other expensive treatment options. The removal of acid red 183 (AR) and
acid green 25 (AG) onto shells of bittim (Pistacia khinjuk Stocks) (BTS) from aqueous solutions was investigated using parameters such as contact time, pH, temperature, adsorbent doses, and initial dye concentration. Adsorption isotherms of dyes onto BTS were determined and correlated with common isotherm equations such as the Langmuir and Freundlich models. Adsorption equilibrium was reached within 30 min. It was found that the Langmuir isotherm appears to fit the isotherm data better than the Freundlich isotherm. Parameters of the Langmuir and Freundlich isotherms were determined using adsorption data. The maximum adsorption capacities for AR and AG onto BTS at 308, 313, and 318 K were found to be 33, 28, and 20; 16, 18, and 7 mg/g, respectively. The adsorption kinetics of AR and AG could be described by the pseudo-second order reaction model. The data obtained from adsorption isotherms at different temperatures were used to calculate several thermo-dynamic quantities such as the Gibbs energy ($\Delta G_0$), enthalpy ($\Delta H_0$), and entropy ($\Delta S_0$) of adsorption. The adsorption process was found to be spontaneous, endothermic and physical in nature. Locally available adsorbent BTS was found to have a low cost and was promising for the removal of AR and AG from aqueous solutions. Adsorption tests were carried out as a function of contact time, pH, temperatures adsorbent doses and initial dye concentration. The adsorption experiments indicated that BTS was effective in removing acid dyes such as AR and AG from aqueous solution. The amount of dye uptake (in mg/g) was found to increase with an increase in solution dye concentration and contact time and found to decrease with an increase in pH, adsorbent dosage, and temperature. The adsorption kinetics of AR and AG can be described by the pseudo-second-order reaction model. Equilibrium data fitted very well with a Langmuir isotherm equation.

Fly ash is a waste substance from thermal power plants, steel mills, etc. that is found in abundance in the world. In recent years, utilisation of fly ash has gained much attention in public and industry, which will help reduce the environmental burden and enhance economic
benefit. Instead of using commercial activated carbon or zeolites, a lot of researches have been conducted using fly ash for adsorption of NOx, SOx, organic compounds, and mercury in air, and cations, anions, dyes and other organic matters in waters. It is recognized that fly ash is a promising adsorbent for removal of various pollutants. Chemical treatment of fly ash will make conversion of fly ash into a more efficient adsorbent for gas and water cleaning. Investigations also revealed that unburned carbon component in fly ash plays an important role in adsorption capacity. Fly ash can be regarded as a low-cost resource or industrial minerals. It is mainly composed of aluminosilicate and unburned carbon. Investigations have demonstrated that fly ash possesses adsorption capacity for removal of gaseous pollutants in air, inorganic ions and organic compounds in water. Comparison with other adsorbents, fly ash could be effective adsorbent depending on the compositions and treatment. The unburned converted to activated carbon, which will enhance the adsorption capacity. Separation of unburned carbon from the minerals can bring benefits for applications of unburned carbon and carbon in fly ash also plays an important role for adsorption. The unburned carbon can be utilization of mineral section for cements production and zeolite synthesis.