Utilization from Cement Kiln Dust in Removal of Acid Dyes

Mohamed El-Shahate Ismaiel Saraya and Mahmoud El-Saied Aboul-Fetouh
Department of Chemistry, Faculty of Science,
Al-Azhar University, Nasr City, P.O 11884, Cairo, Egypt

Abstract: Problem statement: The growth of industries and day to day changes in human activities has resulted in an increase in the volume and complexity of wastewater to the environment. Textile industry is one of the most water consumers industries of Egypt, thus discharges large amounts of wastewater effluents during processing, especially, in the coloring and washing steps. Cement kiln dust is a solid waste in cement manufacturing. Approximately 2.5-3.0 (6-9%) million tons of cement kiln dust is produced annually in Egypt and that cause significant environmental problems.

Approach: This study aims to investigate removal of some acid dyes from aqueous solution using cement kiln dust and monitoring the dye in colored cement kiln dust. Solution with 0.4 g L$^{-1}$ concentration was treated with cement kiln dust until the color of dye disappears. The colored cement kiln residue was separate by filtration and dried. The concentration of dye was measured before and after treatment by UV-Vis spectroscopy as well as after washing of colored residue. Also, the colored residue was investigated with, XRD, IR and DSC techniques as well as the loss on ignition at 450°C.

Results: The results found that the cement kiln dust has the power to remove all existing acid dyes and the residue has the same color of dye. When colored residue was washed with water, there was no back diffusion of dye in to water. This may be mainly due to chemical reaction that took place between cement kiln dust and dye. Thus analysis such as IR, XRD and DSC are in agreement with these results.

Conclusion: CKD is efficient in the processes of dye removal from aqueous solutions. The interaction between acid dye and CKD is fast (just minutes). So, we suggest using spent CKD for dye removal of waste water.

Key words: Waste water, cement dust, acid dye, visual inspection, UV-Vis spectroscopy, Acid Red 73 (AR), Acid Blue 74 (AB), washing steps, Chemical Oxygen Demand (COD)

INTRODUCTION

Colored dyes are important water pollutants which are generally present in the effluents of the textile and other industries such as study mills, leather and food. The high level of production and extensive use of dyes generates colored wastewater which produces toxicological and technical problems and environmental pollution. Some dyes, for instance, are reported to cause allergy, dermatitis, skin irritation, cancer and mutation in human. The presence of the dye component in the discharge not only increases the overall loading of Chemical Oxygen Demand (COD) to the receiving water but also creates an aesthetic nuisance to the environment even when the concentration is as low as 1ppm. Thus, the removal of color dyes from wastewater before they are contacted with unpolluted natural water bodies is important (Iqbal and Ashiq, 2007; Li et al., 2010; Mui et al., 2010; Valix et al., 2006; Hameed and El-Khaiary, 2008; Namavivam and Snggeetha, 2006).

Various techniques have been employed for the removal of dyes from wastewaters (Kavitha and Namavivam, 2007; Olgun and Atar, 2009; Cestari et al., 2009; Nandi et al., 2009; Nemr et al., 2009; Hameed, 2009; Crini, 2006; Lian et al., 2009; Zhu et al., 2005; Ozcan et al., 2005; Kanawade and Gaikwad, 2011). The most widely used methods for removing color effluents from water include chemical precipitation, ion-exchange, osmosis, ozonation, solvent extraction, adsorption, membrane filtration, but only that of adsorption is considered to be superior to other techniques (Zhu et al., 2005; Ozcan et al., 2005).

Consequently, many researchers have studied the feasibility of using low-cost substances such as agricultural by-products (Kanawade and Gaikwad, 2011; Khan et al., 2010; Yan et al., 2009; Kumar and Porkadi, 2009; Xua et al., 2010; Demirbas, 2009;
Acid dyes are organic sulphonic acids; the commercially available forms are usually sodium salts, which exhibit good water solubility. In sequence of their importance, acid dyes are mostly used with certain fiber types such as polyamide, wool, silk, modified acrylic and polypropylene fibers, as well as blends of the aforementioned fibers with other fibers such as cotton, rayon, polyester, regular acrylic. According to their structure, acid dyes belong to the following chemical groups: azo, anthraquinone, triphenylmethane, pyrazolone, nitro and quinoline. Azo dyes represent the largest and most important group followed by anthraquinone and triarylmethane dyes.

Many researchers have studied the removal of some acid dyes. Commercial activated carbon (Prolabo) was used for adsorption of iodine, Acid Blue 74 (AB), Acid Red 73 (AR) and Acid Yellow 23 (AY) from aqueous solution (Attia et al., 2006). Textile dyes (Acid Yellow 17 and Acid Orange 7) were removed from its aqueous solution in batch and continuous packed bed adsorption systems by using thermally activated Euphorbia macroclada carbon (Gercela and Gercela, 2009). Activated carbons prepared from sunflower seed hull have been used as adsorbents for the removal of Acid Blue 15 (AB-15) from aqueous solution (Thinakaran et al., 2008b). Activated carbons, prepared from low-cost mahogany sawdust and rice husk have been utilized as the adsorbents for the removal of acid dyes from aqueous solution (Malik, 2003). Removal of acid dyes Acid Blue 45, Acid Blue 92, Acid Blue 120 and Acid Blue 129 from aqueous solutions by adsorption onto high area Activated Carbon Cloth (ACC) was investigated (Hoda et al., 2006).

The capability of surfactant modified-bentonite for adsorption of dyestuff from aqueous solution was investigated (Koswojo et al., 2010). The adsorption of an acid dye from water onto pristine and HCl-activated montmorillonites in fixed beds was investigated (Teng and Lin, 2006 and Lin et al., 2004). The adsorption of an industrial dye Supranol Yellow 4GL onto Cetyltrimethylammonium-bentonite (CTAB-bentonite) is investigated (Khenifi et al., 2007). Batch adsorption of Methylene Blue and Acid Blue 25 onto ground hazelnut shells was studied (Ferrero, 2007). The adsorption of Acid Red 14 and Acid Blue 92 onto the microporous and mesoporous egg shell membrane was investigated (Arami et al., 2008). Use of slag for removal of Basic Blue 9 dye, Acid Blue 29 dye, Acid Red 91 dye and Disperse Red dye was studied (Ramakrishna and Viraraghavan, 1997). (DP), agricultural wastes were evaluated for its ability to remove acid dye from aqueous solutions such as Durian peel (Hameed and Hakimi, 2008).

Cement kiln dust is a solid waste in cement manufacturing. It is composed of micronized particulates collected from electrostatic precipitators during the production of cement clinker. The chemical composition of cement kiln dust depends both on the raw materials used to produce the clinker. The major constituents are compounds of lime, iron, silica, alumina and some of alkalis. The pH of cement kiln dust water mixtures is generally around 12. Approximately 2.5-3.0 (6-9%) million tons of cement kiln dust is produced annually in Egypt cement kiln dust has the potential for reuse in many different channels, but the proper to reuse this by product material is to reciprocate it in cement making process.

The present study aims to utilization from cement kiln dust in removal of acid dyes from aqueous solution and monitored the dye in colored cement kiln dust.

MATERIALS AND METHODS

Materials: Types of acid dyes were used in this investigation, namely acid orange 10 dye, Acid yellow 17 dye, Acid violet 7 dye, Acid red 88 dye, Acid green 25 dye. These dyes were obtained from ISMA Dye Company, Kafer Eldawar, Egypt and were used without further purification. Chemical structures of acid dyes are shown in Table 1. A stock solution of each dye was prepared by dissolving 0.4 g of dye in 1000 mL water to make a stock solution.

The cement kiln dust was received and collected from Tourah Portland Cement Factory. A complete chemical analysis of the cement kiln dust was done by XRF. The properties of cement kiln dust are shown in Table 2.

Equipments: All spectrophotometric measurements of the acid dyes were done with a PerkinElmer Lambada35 UV-Vis spectrophotometer using 1.0 cm matched quartz cuvettes. The XRD patterns were recorded on (M/S. Shimadzu Instruments, Japan)diffractometer XRD 7000 with Ni filtered CuKα as a radiation source at 2θ scan speed of 4° min⁻¹. The
IR absorption measurements were carried out using a Fourier Transform IR (FTIR) spectrophotometer (Perkin Elmer 880). The FT-IR spectra in the wave number range from 400-3500 cm\(^{-1}\) were obtained with the use of the KBr pellet technique (1: 99) (Perraki and Orfanoudaki, 2004). Some selected colored cement kiln dust was investigated using a differential thermal analysis of the Type a PerkinElmer DTA7 with rate 20°C min\(^{-1}\) alumina crucible. The free lime content was determined with ethylene glycol (Strydom \textit{et al.}, 1999).

**Procedure:** Experiments for adsorption equilibrium were conducted at 25°C temperature by shaking 1 g of cement kiln dust with 250 mL of dye solution for the equilibrium contact time, agitation rate 500 rpm. To determine the minimum amount of by-pass kiln dust which realizes good decolonization, amounts of cement kiln dust which were added until the dye color disappears were calculated as shown in Table 3.

Table 1: Structures of the dyes, M wt and C.I.

| Dye          | Chemical Formula | MW g/mol | C.I.   |
|--------------|------------------|----------|--------|
| Acid orange10|                  | 452.36   | 16230  |
| Acid yellow17|                  | 551.24   | 18965  |
| Acid violet 7|                  | 566.4    | 15670  |
| Acid red 88  |                  | 312.00   | 15620  |
| Acid green 25|                  | 583.6    | 61570  |

Table 2: Chemical Composition of Cement Kiln Dust

| Oxide         | (%)  |
|---------------|------|
| CaO           | 43.87|
| SiO\(_2\)     | 10.17|
| Al\(_2\)O\(_3\)| 1.880|
| FeO\(_2\)     | 1.030|
| MgO           | 0.520|
| Na\(_2\)O     | 2.660|
| K\(_2\)O      | 6.270|
| SO\(_3\)      | 1.150|
| Cl             | 5.600|
| Free lime     | 23.40|
| LOI (105°C)   | 26.85|

Table 3: Amount of cement kiln dust which was consumed for g/250 mL of each dye

| Dye              | CKD |
|------------------|-----|
| Acid orange10    | 12.5|
| Acid yellow17    | 20.0|
| Acid violet 7    | 20.0|
| Acid red 88      | 10.0|
| Acid green 25    | 15.0|

After the sorption experiment, the mixture was filtrated and the residual dye concentration in the supernatant was determined spectrophotometrically. The colored residue dried in microwave oven. Three samples from each dye were weighted and ignited at 450°C for 2 h. The loss on ignition is calculated from the difference in weight before and after ignition and subtracted from blank sample. To study the effect of water on the coloured cement kiln dust and ability of dye to dissolve in water again, 1g of each coloured cement kiln dust washed with 100 g of water, stirred for 15 min. and then filtrated. The concentration of dye in filtrate is determined by a UV-visible spectrometer.

**RESULTS**

**Visual inspection:** The presence of very small amounts of dyes in water (less than 1 ppm for some dyes) is highly visible and undesirable (Robinson \textit{et al.}, 2001). The typical visual inspection of the investigated samples of dyes solution, filtrate after treatment with cement kiln dust and washing of coloured cement kiln dust with water as well as precipitate from dye treatment with cement kiln dust are shown in Fig. 1-5. It was observed that the color of original dye was disappearing after treatment with required amount of cement kiln dust for all dyes, expect Acid yellow17 that still has some color, as show in Table 3 Also, the filtrate was produced from treatment of coloured residue with water don’t have any color visually, that means the water cannot dissolve any dye from coloured residue i.e., there are chemical bonding between dye and Ca\(^{2+}\). On the other side, the cement kiln dust was dyed with color of investigated dye (Epolito \textit{et al.}, 2005; Lin \textit{et al.}, 2008).

![Fig. 1: Color of Acid orange 10, 0.4 g L\(^{-1}\) (1), filtrate from precipitation by CCK (2), after washing of residue by water (3), residue after filtration (4)](image1)

![Fig. 2: Color of Acid yellow 17, 0.4 g L\(^{-1}\), (1), filtrate from precipitation by CCK (2), after washing of residue by water (3), residue after filtration (4)](image2)
Fig. 3: Color acid violet 7, 0.4 g L\(^{-1}\), (1), filtrate from precipitation by CCK (2), after washing of residue by water (3), residue after filtration (4)

Fig. 4: Color of acid red 88, 0.4 g L\(^{-1}\), (1), filtrate from precipitation by CCK (2), after washing of residue by water (3), residue after filtration (4)

Fig. 5: Color of acid green 25, 0.4 g L\(^{-1}\), (1), filtrate from precipitation by CCK (2), after washing of residue by water (3), residue after filtration (4)

Fig. 6: UV-Vis spectra of Acid orange 10 dye

Fig. 7: UV/Vis spectra of Acid yellow 17 dye

Fig. 8: UV-Vis spectra Acid violet 7 dye

**UV/visible spectrophotometric analysis:** The UV-Vis spectra obtained before and after treatment of dye by CKD as well as filtrate of washing colored residue with UV/visible spectrophotometric analysis: The UV-Vis spectra obtained before and after treatment of dye by CKD as well as filtrate of washing colored residue with water are exhibited in Fig. 6-10.

All of the absorbance band in the visible region of the spectra disappears. The adsorption process induces a very significant removing of dyes, diagnosed by the total suppression of the characteristics absorbance signals for each dye. The corresponding spectrum obtained in washing of colored cement kiln dust displayed the complete vanishing of absorptions attributed to the azo group, but the Uv-Vis spectra present a small absorbance.
Effect of ignition on the colored cement kiln dust: Effect of ignition on the colored cement kiln dust is shown in Fig. 11-15. It is show the color of residue disappears after thermal treatment and the color of cement kiln dust returned to its original color. Also, the loss of weight due ignition at 450°C for 2 hrs is graphically plotted in Fig. 16. It is direct proportional with molecular weight of dye.

FT-IR spectra: Another parameter which can provide information on the mechanism of dye binding onto CKD sorbent is infrared analysis.
The FTIR spectra of the CKD before and after the sorption of acid dye from aqueous solutions are presented in Fig. 17. The FTIR spectrum of CKD shows that the peak positions at 3640, 3452, 1470, 1136, 970 and 876 cm\(^{-1}\). The band at 3640 is due to OH\(^-\) and 3452 is due to H\(_2\)O while the bands at 1470 and 876 reflect the carbonate. Bands at 1136 and 970 cm\(^{-1}\) correspond to carbonate and silicate, respectively (Al-Ghouti et al., 2003).

A comparison between these spectra shows that the intensity of peak assigned to OH\(^-\) from calcium hydroxide of cement kiln dust was either minimized or slightly shifted after sorption of acid dye. In addition, two new peaks are found at 1050 and 1420 cm\(^{-1}\) due to the sulphonic substituents and triazine ring of the azo dyes (Thinakaran et al., 2008a). This confirms the attachment of the dyes on cement kiln dust. Other much weaker absorption bands at 2819 and 2920 cm\(^{-1}\) due to asymmetric and symmetric vibration modes of methyl and methylene groups are also detected. All absorption peaks display less absorption intensity after interaction with the cement kiln dust. Also, the intensity of band at 1136 cm\(^{-1}\) reduced after treatment with dye due to dissolution of sulfate in water.

**Thermal analysis, DSC:** The thermal behavior of washed cement kiln dust (blank) and coloured cement kiln dust with acid red 88 dyes are illustrated in Fig. 18. DSC curve of CKD show the existence of some endothermic peaks at 60-105, 430-550 and 810-840°C. Also, DSC curve of CCKD show the existence of some endothermic peaks at 58-105, 125-200, 285-350, 430-550 and 717-770°C.

The peaks around 60-105°C is due to the evaporation of free water and 430-550°C is due to dehydration of calcium hydroxide as well as 717-770, 810-840°C is due calcination of calcium carbonate (Ramachandran and Beaudoin, 2003). There are new peaks at 125-200 and 285-350 in CCKD related to the decomposition of organic compound (dye) which is confirmed the binding of dye with cement kiln dust. On the other side the area under peak related to calcium hydroxide in CCKD is lower than that of CKD as a result of consumption of calcium hydroxide in chemical reaction with dye.

**X-ray diffraction, XRD:** Figure 19 shows the XRD pattern of washed cement kiln dust and coloured cement kiln dust with acid yellow 17 and acid red 88. It is show the characteristic peaks of calcium hydroxide, at 2.628 and 4.90\(\) and also the peaks of silicate overlapped with calcium carbonate at 3.03 (Ramachandran and Beaudoin, 2006). The identification of all samples were
confirmed by computer-aided search of the PDF Database obtained from the Joint Committee on Powder Diffraction Standards-International Center for Diffraction Data (JCPDS-ICDD), 2001).

**DISCUSSION**

In this study we have exposed to removal of some acid dyes from aqueous solution by cement kiln dust and followed the dye in colored cement kiln dust. Solution with 0.4 g L\(^{-1}\) concentration was treated with cement kiln dust until the color of dye disappears, as shown from visual tests. This is mainly due to accompanied by a chemical reaction which occurred between the dye molecules and the dissolved portion of the dust. The soluble substances may help in the removal process by very rapid homogeneous chemical reaction that may occur in addition to the adsorption process. Also, the filtrate was produced from treatment of coloured residue with water don’t have any color visually, that means the water cannot dissolve any dye from coloured residue i.e., there are chemical bonding between dye and \(\text{Ca}^{++}\). On the other side, the cement kiln dust was dyed with color of investigated dye. This is indicating that the process involves color removal of the dye solution without -N=N-bond cleavage or degradation (Lin et al., 2008; Al-Ghouti et al., 2003). These changes can be attributed to electrostatic interactions between positively cations of cement kiln dust and the anionic dye and confirms the chemical nature of the sorption process (Monem et al., 1999). The UV-Vis spectra obtained before and after treatment of dye by CKD as well as filtrate of washing colored residue with water conformed to these results. The loss on ignition of colored cement kiln dust is showed the loss of weight proportion with M wt of dye as indication on the presence of dye and changes its color to original. Also, the thermal analysis conformed appear new peaks don’t present in original cement kiln dust. This is mainly due to decomposition of dye which is presented in cement kiln dust.

The FTIR spectra of the CKD before and after the sorption of acid dye from aqueous solutions are showed that two new peaks are found at 1050 and 1420 cm\(^{-1}\) due to the sulphonic substituents and triazine ring of the azo dyes (Epolito et al., 2005). This confirms the attachment of the dyes on cement kiln dust. Other much weaker absorption bands at 2819 cm\(^{-1}\) and 2920 cm\(^{-1}\) due to asymmetric and sym-metric vibration modes of methyl and methylene groups are also detected (Koswojo et al., 2010).

**X-ray diffraction, XRD:** shows the decrease of the peak intensity of CH phase in case of coloured cement kiln dust indicates that the removal process is mainly accompanied by a chemical reaction which occurred between the dye molecules and the dissolved portion of the dust.

**CONCLUSION**

The main conclusions derived from this study may be summarized as follows:

- Cement kiln dust is able to decolorize synthetic solution different types of acid dye
- The color removal process was very fast and can be occur at room temperature
- Cement kiln dust can be used dust for decolorization of an industrial effluent as a low price sorbent
- Colored CKD may be used for brick, asphalt or concrete (future work)

**REFERENCES**

Al-Ghouti, M.A., M.A.M. Khraisheh, S.J. Allen and M.N. Ahmad, 2003. The removal of dyes from textile wastewater: A study of the physical characteristics and adsorption mechanisms of diatomaceous earth. J. Environ. Manage., 69: 229-238. DOI: 10.1016/J.JENVMAN.2003.09.005

Arami, M., N.Y. Limaee, N.M. Mahmoodia, 2008. Evaluation of the adsorption kinetics and equilibrium for the potential removal of acid dyes using a biosorbent. Chem. Eng. J., 139: 2-10. DOI: 10.1016/J.CEJ.2007.07.060

Attia, A.A., W.E. Rashwan and S.A. Khedr, 2006. Capacity of activated carbon in the removal of acid dyes subsequent to its thermal treatment. Dyes Pigments, 69: 128-136. DOI: 10.1016/J.DYPEPIG.2004.07.009

Cestari, A.R., E.F.S. Vieira, G.S. Vieira, L.P.D. Costa and A.M.G. Tavares et al., 2009. The removal of reactive dyes from aqueous solutions using chemically modified mesoporous silica in the presence of anionic surfactant-the temperature dependence and a thermodynamic multivariate analysis. J. Hazardous Mater., 161: 307-316. DOI: 10.1016/J.JHAZMAT.2008.03.091

Crini, G., 2006. Non-conventional low-cost adsorbents for dye removal: A review. Bioresource Technol., 97: 1061-1085. DOI: 10.1016/J.BIORTECH.2005.05.001
Demirbas, A., 2009. Agricultural based activated carbons for the removal of dyes from aqueous solutions: A review. J. Hazardous Mater., 167: 1-9. DOI: 10.1016/J.JHAZMAT.2008.12.114

Dizge, N., C. Aydinler, E. Demirbas, M. Kobya and S. Kara, 2008. Adsorption of reactive dyes from aqueous solutions by fly ash: Kinetic and equilibrium studies. J. Hazardous Mater., 150: 737-746. DOI: 10.1016/J.JHAZMAT.2007.05.027

Epolito, W.J., Y.H. Lee, L.A. Bottomley and S.G. Pavlostathis, 2005. Characterization of the textile anthraquinone dye reactive blue 4. Dyes Pigments, 67: 35-46. DOI: 10.1016/J.DYEPIG.2004.10.006

Ferrero, F., 2007. Dye removal by low cost adsorbents: Hazelnut shells in comparison with wood sawdust. J. Hazardous Mater., 142: 144-152. DOI: 10.1016/J.JHAZMAT.2006.07.072

Gercela, O. and H.F. Gercela, 2009. Removal of acid dyes from aqueous solutions using chemically activated carbon. Separation Sci. Technol., 44: 2078-2095. DOI: 10.1080/01496390902885338

Hameed, B.H. and H. Hakimi, 2008. Utilization of durian (Durio zibethinus Murray) peel as low cost sorbent for the removal of acid dye from aqueous solutions. Biochem. Eng. J., 39: 338-343. DOI: 10.1016/J.BEIJ.2007.10.005

Hameed, B.H. and M.I. El-Khaiary, 2008. Kinetics and equilibrium studies of malachite green adsorption on rice straw-derived char. J. Hazardous Mater., 153: 701-708. DOI: 10.1016/J.JHAZMAT.2007.09.019

Hameed, B.H., 2009. Spent tea leaves: A new non-conventional and low-cost adsorbent for removal of basic dye from aqueous solutions. J. Hazardous Mater., 161: 753-759. DOI: 10.1016/J.JHAZMAT.2008.04.019

Hoda, N., E. Bayram and E. Ayrun, 2006. Kinetic and equilibrium studies on the removal of acid dyes from aqueous solutions by adsorption onto activated carbon cloth. J. Hazardous Mater., 137: 344-351. DOI: 10.1016/J.JHAZMAT.2006.02.009

Iqbal, M.J. and M.N. Ashiq, 2007. Adsorption of dyes from aqueous solutions on activated charcoal. J. Hazardous Mater., 139: 57-66. DOI: 10.1016/J.JHAZMAT.2006.06.007

Jano, P., P. Michlek and L. Turek, 2007. Sorption of ionic dyes onto untreated low-rank coal – oxihumolite: A kinetic study. Dyes Pigments, 74: 363-370. DOI: 10.1016/J.DYEPIG.2006.02.017

Kanawade, S.M. and R.W. Gaikwad, 2011. Removal of dyes from dye effluent by using sugarcane bagasse ash as an adsorbent. Int. J. Chem. Eng. Appli., 2: 202-206.

Kavitha, D. and C. Namasivayam, 2007. Recycling coir pith, an agricultural solid waste, for the removal of procion orange from wastewater. Dyes Pigments, 74: 237-248. DOI: 10.1016/J.DYEPIG.2006.01.040

Khan, T., S. Rahman, M. Kutty and M. Chaudhuri, 2010. Adsorptive removal of reactive yellow 15 from aqueous solution by coconut coir activated carbon. Adsorption Sci. Technol., 28: 657-668.

Khenifi, A., Z. Boubker, F. Sekrane, M. Kameche and Z. Derriche, 2007. Adsorption study of an industrial dye by an organic clay. Adsorption, 13: 149-158. DOI: 10.1007/s10450-007-9016-6

Koswojo, R., R.P. Utomo, Y.H. Ju, A. Ayucitra and F.E. Soetaredjo et al., 2010. Acid Green 25 removal from wastewater by organo-bentonite from Pacitan. Applied Clay Sci., 48: 81-86. DOI: 10.1016/J.CLAY.2009.11.023

Kumar, K.V. and K. Porodi, 2009. Equilibrium and thermodynamics of dye removal from aqueous solution by adsorption using rubber wood saw dust. Int. J. Environ. Techn. Manage., 10: 295-307 DOI: 10.1504/IJETM.2009.023736

Li, Q., Q.Y. Yue, Y. Su, B.Y. Gao and H.J. Sun, 2010. Equilibrium, thermodynamics and process design to minimize adsorbent amount for the adsorption of acid dyes onto cationic polymer-loaded bentonite. Chem. Eng. J., 158: 489-497. DOI: 10.1016/J.CEJ.2010.01.033

Lian, L., L. Guo and C. Guo, 2009. Adsorption of Congo red from aqueous solutions onto California bentonite. J. Hazardous Mater., 161: 126-131. DOI: 10.1016/J.JHAZMAT.2008.03.063

Lin, J.J., X.S. Zhao, D. Liu, Z.G. Yu and Y. Zhang et al., 2008. The decoloration and mineralization of azo dye C.I. Acid Red 14 by sonochemical process: Rate improvement via Fenton's reactions. J. Hazardous Mater., 157: 541-546. DOI: 10.1016/J.JHAZMAT.2008.01.050

Lin, S.H., R.S. Juang and Y.H. Wang, 2004. Adsorption of acid dye from water onto pristine and acid-activated clays in fixed beds. J. Hazardous Mater., 113: 195-200. DOI: 10.1016/J.JHAZMAT.2004.06.028

Malik, P.K., 2003. Use of activated carbons prepared from sawdust and rice-husk for adsorption of acid dyes: A case study of Acid Yellow 36. Dyes Pigments, 56: 239-249. DOI: 10.1016/S0143-7280(02)00159-6

Monem, N.M.A., N.M. Al-Mansi and M.S. El-Nawasra, 1999. Utilization of by-pass kiln dust for colour removal of wastewater streams. Environ. Manage., 10: 290-297. DOI: 10.1108/09566169910289540
Mui, E.L.K., W.H. Cheung, M. Valix and G. McKay, 2010. Dye adsorption onto char from bamboo. J. Hazardous Mater., 177: 1001-1005. DOI: 10.1016/J.JHAZMAT.2010.01.018

Namasivayam, C. and D. Sgngeetha, 2006. Recycling of agricultural solid waste, coir pith: removal of anions, heavy metals, organics and dyes from water by adsorption onto ZnCl$_2$ activated coir pith carbon. J. Hazardous Mater., 135: 449-452. DOI: 10.1016/J.JHAZMAT.2005.11.066

Nandi, B.K., A. Goswami and M.K. Purkait, 2009. Adsorption characteristics of brilliant green dye on kaolin. J. Hazardous Mater., 161: 387-395. DOI: 10.1016/J.JHAZMAT.2008.03.110

Nemr, A.E., O. Abdelwahab, A. El-Sikaily and A. Khaled, 2009. Removal of direct blue-86 from aqueous solution by new activated carbon developed from orange peel. J. Hazardous Mater., 161: 102-110. DOI: 10.1016/J.JHAZMAT.2008.03.060

Olgun, A. and N. Atar, 2009. Equilibrium and kinetic adsorption study of Basic Yellow 28 and Basic Red 46 by a boron industry waste. J. Hazardous Mater., 161: 148-156. DOI: 10.1016/J.JHAZMAT.2008.03.064

Ozcan, A.S., B. Erdem and A. Ozcan, 2005. Adsorption of Acid Blue 193 from aqueous solutions onto BTMA-bentonite. Colloids Surf. A: Physicochem. Eng. Aspects, 266: 73-81. DOI: 10.1016/J.COLSURFA.2005.06.001

Perraki, T. and A. Orfanoudaki, 2004. Mineralogical study of zeolites from Pentalofos area, Thrace, Greece. Applied Clay Sci., 25: 9-16. DOI: 10.1016/S0169-1317(03)00156-X

Ramachandran, V.S. and J.J. Beaudoin, 2003. Handbook of Thermal Analysis of Construction Materials. 1st Edn., William Andrew, New York, USA., ISBN: 0815514875, pp: 680.

Ramachandran, V.S. and J.J. Beaudoin, 2006. Handbook of analytical Techniques in Concrete Science and Technology. 1st Edn., Standard Publishers Distributors, ISBN: 8180140873, pp: 994.

Ramakrishna, K.R. and T. Viraraghavan, 1997. Use of slag for dye removal. Waste Manage., 17: 483-488. DOI: 10.1016/S0956-053x(97)10058-7

Robinson, T., G. McMullan, R. Marchant and P. Nigam, 2001. Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative. Bioresource Technol., 77: 247-255. DOI: 10.1016/S0960-8524(00)00080-8

Strydom, C.A., J.H. Potgieter, W.T. Mhlongo and C. Masina, 1999. Extraction of free lime from clinker using microwave energy. World Cem., 30: 101-104.

Teng, M.Y. and S.H. Lin, 2006. Removal of methyl orange dye from water onto raw and acidactivated montmorillonite in fixed beds. Desalination, 201: 71-81. DOI: 10.1016/J.DESAL.2006.03.521

Thinakaran, N., P. Baskaralingam, K.V.T. Ravi and P.S. Sivanesan, 2008b. Adsorptive Removal of Acid Blue 15: Equilibrium and Kinetic Study. CLEAN-Soil, Air. Water, 36: 798-804 DOI: 10.1002/clen.200800027

Thinakaran, N., P. Panneerselvam, P. Baskaralingam and D. Elangoand, 2008a. Equilibrium and kinetic studies on the removal of Acid Red 114 from aqueous solutions using activated carbons prepared from seed shells. J. Hazardous Mater., 158: 142-150. DOI: 10.1016/J.JHAZMAT.2008.01.043

Tsai, W.T., K.J. Hsien and J.M. Yang, 2004. Silica adsorbent prepared from spent diatomaceous earth and its application to removal of dye from aqueous solution. J. Colloid Int. Sci., 275: 428-433. DOI: 10.1016/J.JCIS.2004.02.093

Tunali, S., A.S. Ozcan, A. Ozcan and T. Gedikbey, 2006. Kinetics and equilibrium studies for the adsorption of Acid Red 57 from aqueous solutions onto calcined-alunite. J. Hazardous Mater., 135: 141-148. DOI: 10.1016/J.JHAZMAT.2005.11.033

Valix, M., W.H. Cheung and G. McKay, 2006. Roles of the textural and surface chemical properties of activated carbon in the adsorption of acid blue dye. Langmuir, 22: 4574-4582. DOI: 10.1021/LA051711J

Xua, X., B.Y. Gao, Q.Y. Yue and Q.Q. Zhong, 2010. Preparation and utilization of wheat straw bearing amine groups for the sorption of acid and reactive dyes from aqueous solutions. J Hazardous Mater., 182: 1-9. DOI: 10.1016/J.JHAZMAT.2010.03.071

Yan, L., Y. Fan and J. Lin, 2009. Preparation of cationic wheat straw and its application on anionic dye removal. J. Biobased Mater. Bioenergy, 3: 205-212. DOI: 10.1166/jbmb.2009.1024

Zhu, M.X., Y.P. Li, M. Xie and H.Z. Xin, 2005. Sorption of an anionic dye by uncalcined and calcined layered double hydroxides: A case study. J. Hazardous Mater., 120: 163-171. DOI: 10.1016/J.JHAZMAT.2004.12.029