

Adsorption of acid dyes from aqueous solution onto the surface of acid activated Nirgudi Leaf powder (AANLP): A case study

Ratna Shelke, Jagdish Bharad¹, Balaji Madje¹ and Milind Ubale^{1*}

Pemraj Sarda College, Ahmednagar (M. S.) India.

¹Post Graduate Department of Chemistry, Vasantao Naik Mahavidyalaya,
Aurangabad, 431 003 ,MS,India

*Corres.author: mbubale@yahoo.com

Abstract: The plant powder of Nirgudi (*L. Vitex negundo*) were activated with sulphuric acid and used as low cost easily available and renewable biological adsorbent for the removal of acid dyes (Acid blue, Acid red and Malachite green) from aqueous solution. Batch experiments were carried out for adsorption kinetics and isotherms. Operating variable studied were pH, temperature, adsorbent dose, initial concentration of adsorbate. Adsorption capacity seems to be enhanced by increasing temperature, adsorbent dose and for pH. Maximum dye adsorption was found to be in acidic range. Nirgudi Leaf powder (NLP) treated with Sulphuric acid (H_2SO_4) solution increased the adsorption efficiency upto 80 percent. Experimental adsorption kinetic data were fitted to be Lagergren first order. Equilibrium data were well represented by the Freundlich Langmuir isotherm model for all tested adsorption systems. Beside these the thermodynamic study has showed that the acid dye adsorption onto the surface of Acid Activated Nirgudi Leaf powder (AANLP) was physical adsorption and the process was spontaneous and exothermic.

Keywords: Acid dyes, AANLP, Adsorption Isotherms and Freundlich.

Introduction

Synthetic dyes have been increasingly used in the textile, paper, rubber, plastic, cosmetic, pharmaceutical and food industries because of their ease of use, inexpensive cost of synthesis, stability and variety of color compared with natural dyes¹⁻³. Today there are more than 10,000 dyes available commercially⁴. Most of which are difficult to biodegrade due to their complex aromatic molecular structure and synthetic origin⁵. The extensive use of dyes often poses pollution problems in the form of colored wastewater discharge into environmental water bodies, which interferes with transmission of sunlight into streams therefore reduces photosynthetic activity⁶. In addition, some dyes or their metabolites are either toxic or mutagenic and carcinogenic. A lot of case throughout the world is reported about the role of dyes in connection with variety of skin, lung, and other

respiratory disorders⁷. Use of variety of dyes and chemicals in the dyeing processes causes considerable variation in the wastewater characteristics like pH, color and chemical oxygen demand (COD). The presence of these heat and light stable complex dye molecule in wastewater made the conventional methods of sewage treatment, such as primary and secondary treatment systems unsuitable. The adsorption process provides an attractive alternative treatment, especially if the adsorbent is inexpensive and readily available. Granular activated carbon is the most popular adsorbent and has been used with great success⁸ but is expensive. Consequently, many investigators have studied the feasibility of using low cost substances, such as plum kernels⁹, rice husk¹⁰⁻¹¹, peat¹², banana pith¹³, orange peel¹⁴, Eichhornia ash¹⁵, saw dust¹⁶⁻¹⁷, wall nut shells charcoal¹⁸, etc. as adsorbents for the removal of dyes from wastewater.

Critical review of low cost adsorbents for waste and wastewater treatment has been represented by pollard *et al*¹⁹, Mall *et al*²⁰ and Bailey *et al*²¹.

The purpose of the present work was to investigate the possibility of plant material (Nirgudi) which is locally available, free of cost all over India as an adsorbent for the removal of acid dyes from aqueous solution. The acid dyes selected as an adsorbate were acid blue, acid red and malachite green. The effects of various operating parameters on adsorption such as pH, initial concentration, adsorbent dosage, temperature and dye concentration were studied.

Materials and Methods

Adsorbent

The adsorbent used in the present investigation were leaves of Nirgudi Plants collected from Ahmednagar District of Maharashtra State (India). The leaves of Nirgudi were dried in shadow avoiding direct sunlight on them. The dried plant leaves were grinded into powder and were boiled in distilled water to remove the suspended dust for one hour and filtered. The residue left was treated with formaldehyde and finally with very dilute solution of sulphuric acid, stirred for 30 minutes vigorously using mechanical stirrer at room temperature, it was filtered and washed with distilled water repeatedly to remove free acid. After chemical treatment residue was dried first in air and finally in oven at 90-100°C for 8-10 hours and powdered using electric grinder. The homogeneous powder was then passed through mesh for desired particle size (9.8 - 41.8 micron). The adsorbent once prepared were used throughout the experimental work. The particle size selected for these experiments were on the basis of their settlement at the bottom of the system, so that the portion of the solution could be taken out conveniently from the supernatant liquid.

FT - IR Spectrum of Nirgudi Leaf Powder (NLP)

The surface chemistry of NLP was determined by the type, quantity and bonding of oxygen containing functional groups such as hydroxyl, carbonyl, carboxyl, nitro groups²²⁻²³.

The FT - IR spectrum of NLP adsorbent can be summarized from the bands observed as:

- I) Medium based overlapping bands at 3399.89 cm^{-1} may be attributed to -OH group stretching present in tertiary alcohol of NLP.
- II) The bands at 2913.31 cm^{-1} indicates C-H stretching assigned to secondary asymmetric carbon.
- III) The bands at 2226.42 cm^{-1} ascribes to C-N stretching in the Cyanide group.

- IV) The bands at 1684.52 cm^{-1} indicates C=O stretching in α - β unsaturated Ketones.
- V) The bands at 1518.67 cm^{-1} ascribes to NO_2 stretching in aromatic nitro compounds of NLP.
- VI) The bands at 1621.84 cm^{-1} attributes to NH_3 -deformation.
- VII) The bands at 1132.97 cm^{-1} ascribes to C-O stretching in tertiary alcohol and also attributes to -OH deformation in tertiary alcohols of NLP.
- VIII) The bands range of 600.70 cm^{-1} to 666.28 cm^{-1} ascribes to NH deformation in primary, secondary amines of NLP.

Preparation of Adsorbate Solution

Acid blue, Acid red and Malachite green were the acid dyes selected for the present investigation. The chemicals used were of Analar grade and used without further purifications. The solutions were prepared in doubly distilled water. A distilled water prepared by using first metal distillation unit and then all quick fit glass assembly in permanganatic condition, wherever necessary the prepared solutions were standardized as per literature²⁴.

Batch Adsorption Experiments

Each batch adsorption study was carried out by contacting Acid Activated Nirgudi Leaf Powder (AANLP) with acid dyes. i.e. acid blue, acid red and malachite green under different conditions for 60 minutes in a glass tube. Stock solutions ($1.0 \times 10^{-3}\text{M}$) were prepared by dissolving weighed quantities of dyes in double distilled water. The concentration of dye solution were determined from calibration curve spectrophotometrically (Shimatzu-1211) at their respective wavelength, i.e. Acid blue ($\lambda_{\text{max}} = 664\text{nm}$) Acid Red ($\lambda_{\text{max}} = 548$) and for Malachite Green ($\lambda_{\text{max}} = 616\text{nm}$).

Results and Discussion

Effect of Temperature

The data of dye adsorption onto AANLP at different temperature indicates a change in the dye removal efficiency. This effect is shown in Figure 1. The increase in the equilibrium adsorption capacity of Acid dyes indicates that a high temperature favors dye removal. Indeed by increasing the temperature of the reaction from 308.15 K to 318.15 K, The percentage removal of all three acid dyes average increased range was from 67 % to 77 %. Consequently it is clear that adsorption equilibrium is a thermo-dependent process. This effect may be due to the fact that at higher temperature, an increase in the movement of the solute

occurs. Similar findings are also reported by other researchers²⁵⁻²⁶.

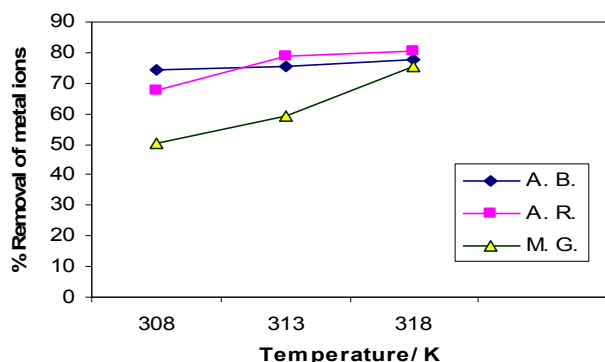


Figure 1. Effect of temperature on removal of metal ions.

Effect of pH solution

The initial pH value of the solution can significantly influence the adsorption of dyes. In the present study the effect of pH on the amount of dye removal was analyzed over the pH range from 3.5 to 7.2 and is presented in graphical form as given in figure 2. The adsorption at lower pH may be attributed to the increase in the concentration of hydrogen ion in dye solution which neutralizes hydroxyl group in the vicinity of adsorbent surface and facilitates the diffusion of dye molecule towards the surface of adsorbent. Similar diminishing adsorption was also reported by Bahadur et.al²⁷, at higher pH which may be due to the availability of large number of OH⁻ (hydroxyl ions) and consequently the diffusion barrier is increased which results in poor adsorption. Our findings are in good agreement with Prasad et.al²⁸⁻²⁹. The study restricted at higher pH level upto 7.2 which may be attributed to the adsorbent which is a plant material and consists of various organic acid components and may lead to the aqua complex formation and thus retards dye adsorption onto the surface of AANLP. Our findings are supported by Mohan et.al³⁰.

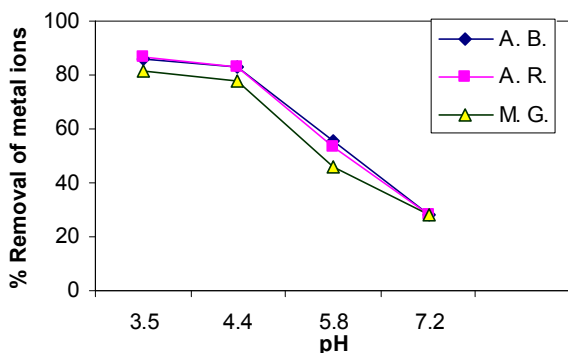


Figure 2. Effect of pH on removal of metal ions.

Effect of adsorbent dose

Effect of adsorbent dose plays an important role in standardizing the adsorption process with quantification of adsorbate solution and the adsorbent. In our present investigation with increase in the amount of AANLP adsorbent i.e. from 0.5gms to 0.8gms the removal efficiency of all three acid dyes increase rapidly (figure-3) which may be attributed to the greater availability of the exchangeable sites or surface areas at higher concentration of the adsorbent. Our findings are in good support with Hussein et al.³¹⁻³².

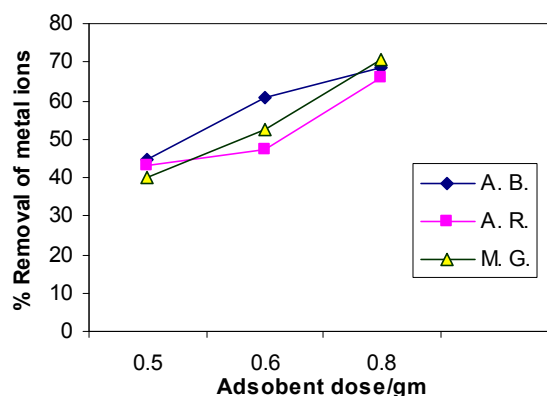


Figure 3. Effect of adsorbent dose on removal of metal ions.

Effect of Initial Concentration

The adsorption of all three acid dyes onto the surface of AANLP were rapid initially, slow down later on and finally reached towards equilibrium (figure-4) indicating saturated adsorption as also reported by McKay et al.³³⁻³⁵. The increased adsorption of the acid dyes onto the AANLP may be attributed to increase in surface activity and due to micelle formation or the aggregation of dye molecule in the concentration range studied. Similar results have been also reported by several researchers³⁶⁻³⁷.

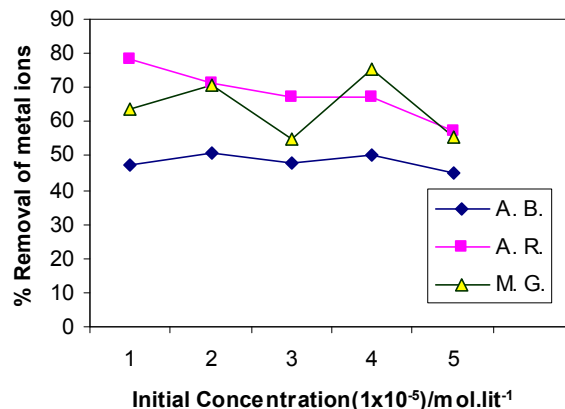


Figure 4. Effect of initial concentration on removal of metal ions.

Adsorption Kinetics

Kinetics of adsorption describes the solute uptake rate which in turn governs residence time or adsorption reaction. It is one of the important characteristics in defining the efficiency of adsorption³⁸. A simple analysis of adsorption is the pseudo-first order rate expression of the Lagergren equation³⁹⁻⁴¹. The kinetic data reveals that adsorption follows the first order reaction kinetics. From the pH study it can be concluded that in acidic media the dye removal percentage is maximum. Our findings are in good agreement with Mumin *et al.*⁴². The decrease in adsorption rate may be explained on the basis of aqua complex formation and subsequent acid-base dissociation at solid-solution interface⁴³. The increase in adsorbent dose from 0.5gm to 0.8gm the rate constant increases i.e. the removal efficiency of dye increases. The available adsorption site increase which furnishes more adsorption and, therefore rate constant (K_1) also increases. Similar finding were also reported by other workers⁴⁴. The rate constant K_1 at different temperature were applied to estimate the activation energy of the adsorption of dyes onto AANLP by Arrhenius equation⁴⁵

$\ln k = \ln A - E_a/RT$

Where E_a , R and A refers to Arrhenius activation energy, the gas constant and Arrhenius factor respectively. The slope of the plot K_1 versus $1/T$ were found to be 8849.870J, 7794.870J and 8586.800 J respectively for acid blue, acid red and malachite green. The minimum value of 7794.870 J was for Acid Red – AANLP system which is an indicative of higher adsorption and which may be attributed to lesser energy barrier.

Adsorption Isotherm

The adsorption isotherm is a graphical representation of amount of substance adsorbed against the residual concentration of the adsorbate in the solution⁴⁶. The adsorption data for a wide range of adsorbate concentration and adsorbent doses were analyzed using Langmuir and Freundlich isotherm in order to find the adsorption capacity of AANLP adsorbate.

Freundlich Theory: Freundlich theory suggested that the ratios of the amount of solute adsorbed onto a given mass of adsorbent to the concentration of the solute in the solutions are not constant at different

concentration of solution⁴⁷. The Freundlich isotherm was verified by using least square fit and regression analysis and computer programming in EXCEL. The value of regression coefficient r^2 found to be very close to one which indicates the good correlation exists between $\log x/m$ and $\log C$. The Langmuir model⁴⁸ represents monolayer adsorption on a set of distinct localized adsorption sites having the same adsorption energies no interaction between adsorbed molecules. The essential characteristic of Langmuir isotherm is expressed in terms of dimensionless constant separation factor or equilibrium factor R_L , which is indicative of the nature of the isotherm and is enlisted below as:

R_L Value	Types of Isotherm
$R_L > 1$	Unfavorable
$R_L = 1$	Linear
$0 < R_L < 1$	Favorable
$R = 0$	Irreversible

The adsorption of all three acid dyes are favorable onto the surface of AANLP as R_L value in the present study falls in the type $0 < R_L < 1$ and the range found to be 0.009 to 0.010 and is in good agreement with the findings of Lodha *et al.*⁴⁹.

Thermodynamic Parameters

Thermodynamic parameters such as free energy (ΔG°) enthalpy (ΔH°) and entropy (ΔS°) of adsorption were calculated from the binding constant K^1 which is obtained from Langmuir equation using following relations:

$$G^\circ = -RT \ln k \quad \dots\dots\dots 1$$

$$\ln k = -\Delta H^\circ / RT + \text{constant} \dots\dots\dots 2$$

The ΔH° values were calculated from the slopes of linear variation of $\ln K$ vs $1/T$; furthermore, the values of ΔS° were calculated using the relation $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. The negative value of ΔG° indicates high affinity of dye to the surface of AANLP, also negative value of ΔH° indicates exothermic process and the randomness of adsorption phenomena can be explained on the basis of entropy (ΔS°) which is also negative (Table 1). The values demonstrate a spontaneous and favourable adsorption process and are in good agreement with Saleem *et al.*⁵⁰.

Table 1: Thermodynamic Parameters at different temperature.

Adsorbate	Temperature /K	-ΔG /KJ	ΔH /KJ	-ΔS / J.
Acid Blue	308	3.834	6.956	10.039
	313	3.881		
	318	3.734		
Acid Red	308	4.005	13.255	29.954
	313	3.927		
	318	3.705		
Malachite Green	308	4.067	35.545	10.910
	313	3.567		
	318	3.045		

Conclusions

The adsorption mechanism of dyes onto the surface of AANLP adsorbent and the calculated ΔG° (free energy) found to be below -15KJ which is indicative of physical adsorption. The calculated dimensionless equilibrium parameter R_L found to be

in the range between 0 to 1 is indicative of favorable adsorption onto the surface of AANLP. Adsorption of acid dyes onto AANLP was first order kinetic process with low activation energy which is an indicative of rapid adsorption process.

References

- Ramkrishna KR & Viraraghavan T, *Water Sci. Technol.*, 36 (1997)189.
- Chagas E P & Durrant L R, *Enzybe Microb. Technol.*, 29(2001) 473.
- Malik P K, *Dyes pigments*. 56 (2003) 239.
- Nigam P, Armour G, Banat I, Sing M D & Merchant R, *Bior. sour. Technol*, 72 (2000) 219.
- Seshadri S, Bishop P L & Agha A M, *Waste Manage.* 15 (1994) 127.
- Namasivayam C, Radhika R & Suba S, *Waste Manage.* 21(2001) 381.
- Mickay G, Allen S J, Meconney I F & Ottrburn M S, *J. Colloid. interface Sci.* 80(2)(1981) 323.
- Mckay G, *J.Chem.Technol. Biotechnol*, 32(1982) 759.
- Mckay G, Ottrburn M S & Sweeney A G. *Water Res.* 14(1980) 15.
- Malik P K, *Dyes pigments*, 56 (2003) 239.
- Sumanjit Kaur & Prasad N, *Indian. J. Chem.*, 40A (2001) 388.
- Allen S J, *Fuel.* 66 (1987) 1171.
- Namasivayam C, Muniasami N, Gayathri K, Rani M & Rananathan K, *Bioresor. Technol.*, 64 (1998) 77.
- Namasivayam C, Muniasami N, Gayathri K, Rani M & Rananathan K, *Bioresour. Technol.*, 57 (1996) 37.
- Sumanjit Kaur & Prabhpreet Singh, *Colourage.* 54(3) (2007) 52.
- Sumanjit Kaur, Navneet & Prabhpreet Singh, *J. Environ. Pollution*, 8 (2001) 229.
- Sumanjit Kaur & Kamaldeep Paul, *Poll. Res.* 2(4)(2001) 557.
- Sumanjit Kaur & Manpreet Kaur, *J. Environ. Poll.*, 6(1999)173.
- Pollard S J, Fowler G D, Sollars C J & Perry R, *Total Environ.* 116 (1992) 31.
- Mall I D, Upadhyay S N & Sharma Y C, *Int. J. Environ. Stud.* 51 (1996) 77.
- Bailey S E, Olin T J, Bricka R M & Adrian D D, *Water Res.* 33(11)(1999) 2469.
- Wang S, Zhu Z H, Coomes A & Haghsereshi F, *J. Colloid and Interface Sci.*, 284 (2005) 440.
- Collin G J, Awang B Duduku K & Kok Onn. *J. Mater. Science*, 13(1) (2007) 83.
- Jeffery G H, Bassett Mendnam J & Denny R C, *Vogels Text book of Quantitative Chemical Analysis*. 5th Edition ELBS with Longman Group U.K (1999).
- Ncibi M C, Mahjoub B & Seffen M, *Int. J. Environ. Sci. Tech.*, 4(4) (2007) 433.
- Chakraborty S, Basu J K, De S & DasGupta S, *Chemosphere*, 58 (2005) 1079.
- Bahadur P, Desai M, Dogra A, Vora S & Ram R N, *Indian J. Chem.*, 36 A (1997) 938.
- Prasad Sumanjit N, *Indian J. Chem.*, 40 (2001) 388.
- Arumina Sarma & Bhattacharya K G, *Indian J. Env. Proct.*, 21 (10) (2001) 899.
- Mohan S V, Rao. N C & Karthikeyan J, *J. Hazard Mater.*, 90 (2002)189.
- Hussein M, Nahala A Taha & Amer A A, *J. Appl. Sci. Res.*, 3(11) (2007) 1352.

- 32 Raghuvanshi S P, Singh R, Kaushik C P, *Appl. Ecology. Env. Res.*, 2(2) (2004) 35.
- 33 Mekay G, *Chem. Engg. Res. Des.*, 61 (1964) 29.
- 34 Mekay G, Blair H S & Garden J R, *J. App. pol. sci.*, 27 (1982) 3043.
- 35 Shelke R S, Bharad J V, Madje B R & Ubale M B, *Arch. Appl. Sci. Res.*, 2(3)(2010) 260.
- 36 Stephen J A, Mekay G & Kadar K Y H, *J. Chem. Tech. Bio. Tech.*, 45 (1989) 291.
- 37 Giles C H, Society of Chemical Industry London. (1970) 242-246.
- 38 Arivoli S & Thenkuzhali M, *E. J. Chem.*, 2 (2008) 187.
- 39 Chiou M S & Li H Y, *J. Hazard. Mat B.*, 9 (2002) 233.
- 40 Dogen M & Alkan M, *Chemosphere* 50 (2003) 517.
- 41 Sreelatha G & Padmaja P, *J. Env. Prot. Sci.*, 2 (2008) 63.
- 42 Mumim M A, Khan M M R, Akhtar KF & Uddin M J, *Int. J. Environ. Sci. Tech.*, 4(4) (2007) 525.
- 43 Netpradita S, Thiravetyanb P & Towprayoon S, *Water Res.*, 37(2003) 763.
- 44 Degs Al, Kharaishah Y & Ahmed M A, *Jordan. Inter. Chem. Engg. Conference*, 1 (2000) 159.
- 45 Singh D K & Srivastava B, *Indian. J. Env. Health Proct.*, 41 (1999) 333.
- 46 Collin Joseph, Awang B & Duduku K, *Materials Sci.*, (MedZiagotyra) 13(1) (2007) 83.
- 47 Freundlich H, *Colloidal and Capillary Chemistry Methner London, UK* (1926) 397-414.
- 48 Langmuir I, *J. Am. Chem.*, 38 (1916) 2221.
- 49 Lodha A, Gupta A B, Bohra K & Singh S V, *Indian J. Env. Proct.*, 17 (9)(1997) 675.
- 50 Saleem M, afzad M, Mahmood F & Hameed A, *J. Chem. Soc. Pak.*, 16(2) (1994) 83.
