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REMOVAL OF SOME NEW DIRECT SULPHO ARYL AZO DYES FROM AQUEOUS SOLUTIONS BY ADSORPTION ONTO DIFFERENT TYPES OF CARBON

إزالة بعض صبغات السلفو أريل أزو المباشره الجديده من المحاليل المائيه بالإمتزازعلى انواع الكربون المختلفه

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الملخص العربى

تم تحضير مجموعة جديدة من اصباغ أريل آزو المباشرة والتى تعتمد على نواة سبيرو ٢-أكسو اندول (٣،٢´)–١´،٣´ ثيازول وتقييم إمكانية إستخدام تكنولوجيا الإمتزاز للتخلص من الوانها المتبقية فى اوساطها المائية . وقد تم اختيار خمسه أصباغ (تمثل المجموعات المختلفة من أصباغ آريل آزو التى تم تحضيرها) لدراسة كفاءة تطبيق طريقة الإمتزاز على أنواع مختلفة من الكربون للتخلص من متبقيات هذه الأصباغ فى محاليلها المائية بعد عملية الصباغة ولتحقيق ذلك تم اختيار ثلاثة أنواع من الكربون لوسط الامتزاز وهى الكربون المنشط الناعم والكربون المحبب والسناج الناتج من مصنع سماد طلخا.ولقد تم تعيين الزمن اللازم للوصول إلى نقطة الإتزان فى عملية الامتزاز على أنواع الكربون الثلاثة المستخدمة كوسط امتزاز وذلك عند اربع درجات حرارة مختلفة هى ٢٥، ٤٠ ، ٥٠ ، ٦٠ درجة منوية .وتم تطبيق معادلات لانجمير وفريندلش وبارنر ايمت وتيلر ووجد ان النتائج متوافقه مع تطبيق هذه المعادلات.

ABSTRACT

A new group of direct arylazo dyestuffs that are based on the spiro 2-oxoindole (3,2´)-1´,3´-thiazolone moiety was successfully synthesized by the authors [1]. In view of the current interest in utilizing the sulpho arylazo dyestuffs for dyeing different types of fibers, the present paper describes the possibility of using carbon for their removal, as organic pollutants, from aqueous solutions. The removal of these dyestuffs from their aqueous solutions was carried out by using different adsorbents such as granular carbon, carbon soot, and powdered activated carbon (PAC) at different temperatures ranging from 25 °C to 60 °C. The adsorption of these dyes on different types of carbon has been found to obey the adsorption isotherms like Langmuir, Freundlich and Branuer Emmitte and Teller (BET) isotherms. It was found that PAC has the highest capacity of adsorption .Carbon soot is recommended to be used for the removal of such type of dyes from their aqueous solutions due to the low cost of its production with respect to PAC and to solve the problem of its accumulation, as a polluting solid waste. Different adsorption parameters were calculated from these models for the interpretation of the adsorption process. It was found that the removal efficiency for color of dyes was over 90 % in case of carbon soot and PAC at higher temperatures.

KEY WORDS*:* Adsorption, Langmuir, Freundlisch and Burnaur Emmette & Teller (BET) isotherms, sulpho arylazo dyestuffs.

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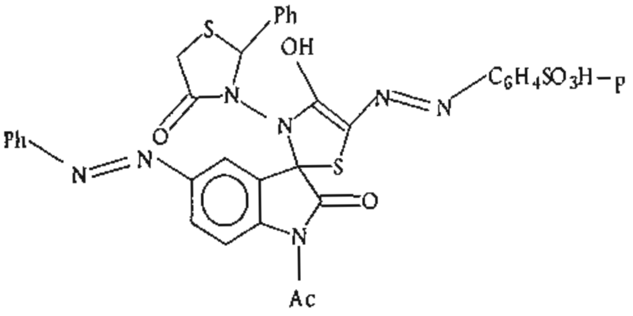
1. INTRODUCTION

In Egypt the problem of color removal from textile wastewater has been considered to be of great importance because of the need to satisfy the increasing demand for water for various uses. For this reason, a national effort has been launched to deal with this problem using natural, local adsorbents. Investigations have been undertaken to determine whether cheap commercially available materials hold promise in the treatment of wastewater. In spite of the presence of a huge number of dyestuffs which are widely used in dyeing processes, little data are available about their removal from dyeing wastewater.

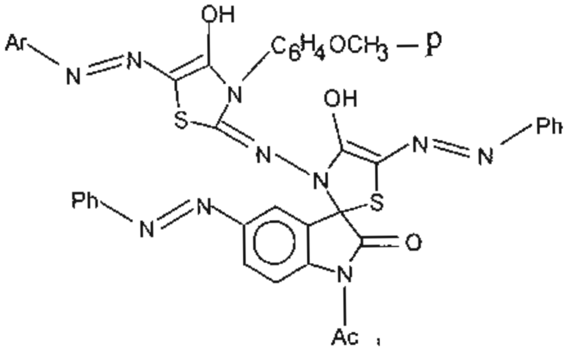
Adsorption is used in industrial wastewater treatment to remove organic materials such as color, phenols, detergents, and other toxic or non biodegradable. The most important component of the cost of using PAC is the cost of PAC itself; therefore, searching for inexpensive sources or substitutes for PAC is a must. Asfour *et al.* [2, 3] studied the adsorption of basic dyes on hardwood sawdust. Ahmed *et al.* [4],Sen [5],Gupta *et al.*[6] and Banerjee *et al.* [7] used coal fly ash which is a solid waste of thermal power plants as adsorbent. EL-Gundi [8, 9, 10] studied the adsorption of two basic dyestuffs (Astrazone-blue and Maxilon-red), two acid dyestuffs (Telon-blue and Erionyl- red), Basic Blue 69 (BB 69) and Basic Red 22 (BR 22) onto maize cobe (an agricultural solid waste). Mckay *et al.*[11,12] studied the adsorption of four dyestuffs onto bagasse pith (by-product of the sugar industry remaining after the extraction of juice), for the adsorption of two basic dyes(basic-blue 69 and basic-red 22) and two acid dyes (acid-blue 25 and acid-red 114). El-Saiid *et al.*[13] used the Egyptian bagasse (a waste by-product of the sugar industry) as adsorbent for the removal of basic dyes namely Rosaniline and Methylene Blue from industrial wastewater. Rashed *et al.* [14, 15] reported that carbon soot is a promising material for different industrial applications as a substitute for commercial powdered activated carbon. Sarkar *et al.* [16] studied the adsorption of Methyl Violet (C.I. Basic Violet) from aqueous solutions onto coal and fly ash. Al-Sarawy [17] studied the using of carbon soot and PAC as good adsorbents for the removal of colors of some dyes from their aqueous solutions. Safarik *et al.* [18] used the magnetic charcoal to adsorb a variety of organic compounds. Sankar *et al.* [19] studied the removal of diazo and triphenylmethane dyes from aqueous solutions using Rice Bran-based Activated Carbon. Ruey-Shin *et al.* [20] and Feng-Chin *et al.* [21] used chitosan for removing chlorotriazine reactive dyes and reactive dyes (RR222, RY 145, and RB222) from aqueous solutions. Attia [22] used soot and PAC as adsorbents for the removal of some heavy metals from water. Cheung *et al.* [23] studied the removal of cadmium ions from effluents using bone charcoal. Shawwa *et al.* [24] studied the removal of color and chlorinated organics from pulp mills wastewater using activated petroleum coke.

2. MATERIALS AND METHODS

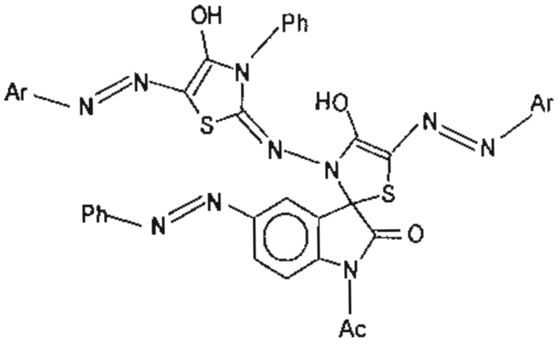
All chemicals and solvents used in this research were of the highest grade of purity. Sodium salts of five dyes of the hitherto synthesized dyestuffs and considered as arylazo spiro thiazolo isatin dyestuffs; their chemical structure is shown in Figure 1 which were previously synthesized by the authors [1]were chosen for studying their adsorption behavior on different types of carbon at different temperatures. PAC and granulated carbon were obtained from El-Nasr pharmaceutical chemical company. Carbon soot was produced as a result of partial oxidation of natural gas at SEMADCO. Procedures were carried out to study the adsorption of these dyestuffs from their aqueous solutions by using a shaker with water bath controlling temperature [1] .The remaining dye concentration was measured using a spectrophotometer (Qualen kamp visi-spec SPR-590-010-W).The separation of absorbents from solutions was performed by centrifuge using a bench top centrifuge model T-54.



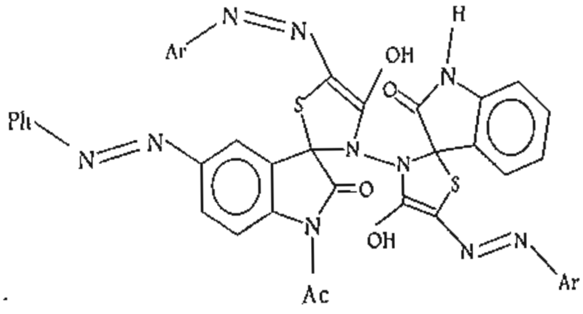
Dye 1 (Orange, 529 nm)



Dye 4 (Blue, 610 nm)

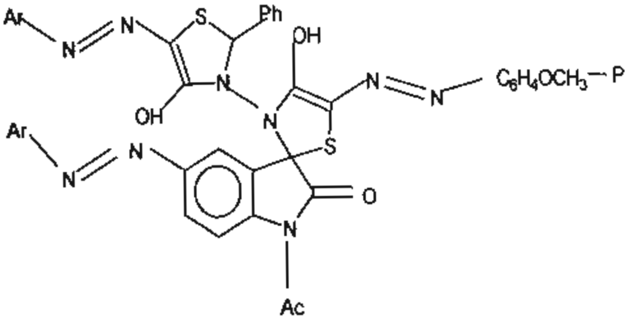


Dye 2 (Dark red, 541 nm)



Dye 5 (Dark blue, 613 nm)

Ar 4-sulphophenyl



Dye 3 (Red, 548 nm)

Fig. 1. Chemical structure of the five direct arylazo dyestuffs.

3. RESULTS AND DISCUSSION

3.1. Effect of Temperature and Retention Time on Adsorption

The results shown in figures (2-6) indicate that the remaining concentration of the five dyes in their aqueous solutions decreases with increasing time till equilibrium time is attained and the remaining concentration becomes constant after a time specific for each dye. Results indicate that, the equilibrium times for the five dyes on different adsorbents at different temperatures were in the range 50-100 minutes. It was found that the suitable doses of adsorbents were; 0.1 mg (soot), 0.5mg (granular carbon) and 0.05 mg (PAC) /10 ml of dye solution .The effect of temperature (25 °C, 40 °C, 50 °C and 60 °C) is clear from these figures since the equilibrium time decreases with increasing temperature due to the fact that by increasing temperature the rate of adsorption increases and equilibrium time decreases [7] .Generally, it was found that, equilibrium time for the adsorption of these dyes on different types of carbon varies significantly for the five dyes and depends only on temperature and is specific for each dye, adsorbate and adsorbent. Also it was found that the removal efficiency for color of dyes was a very good efficiency (over 90 % in case of carbon soot and PAC at higher temperatures).

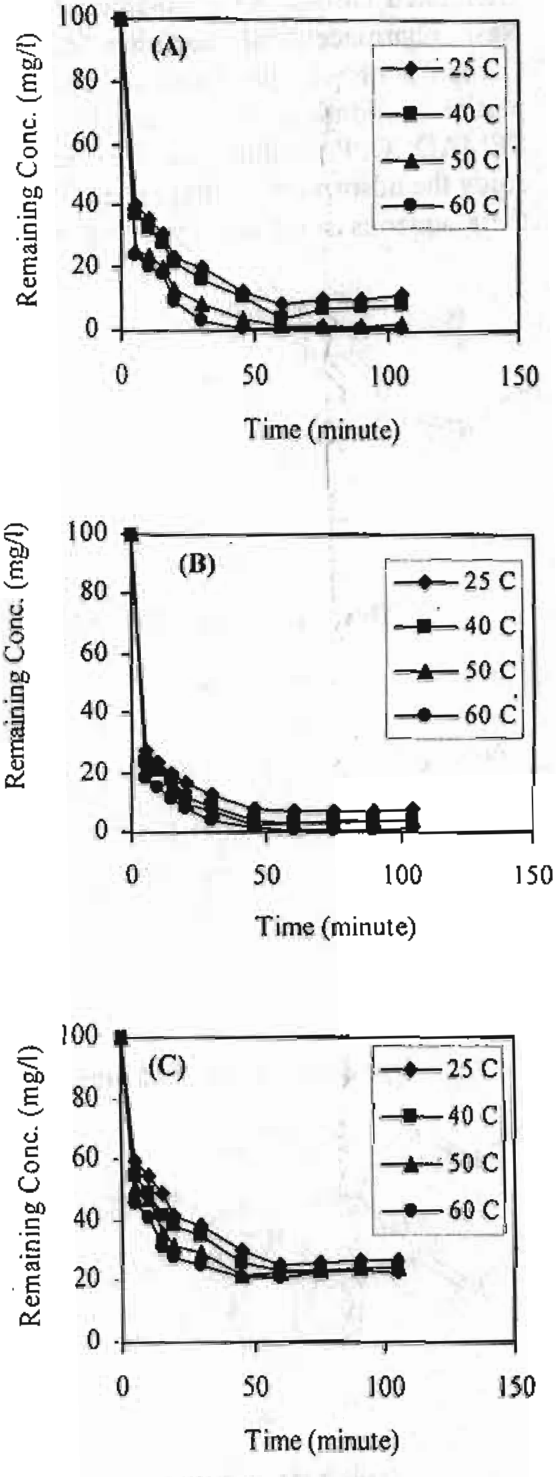


Fig. 2. Effect of time for the adsorption of dye (1): (A) soot, (B) PAC and (C) granular carbon at different temperatures.

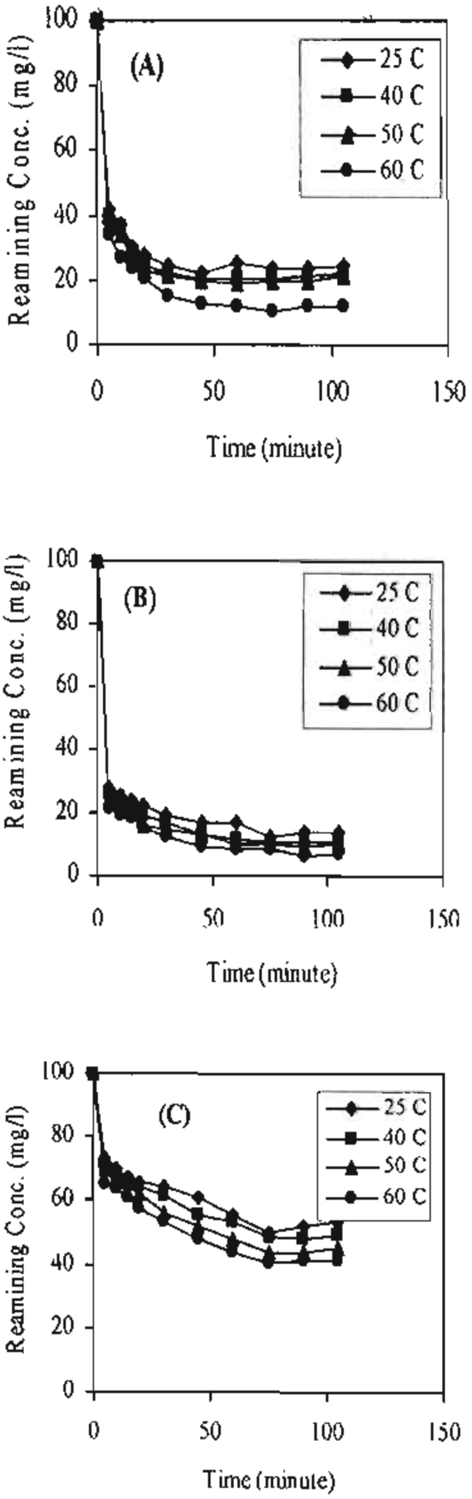


Fig. 3. Effect of time for the adsorption of dye (2): (A) soot, (B) PAC and (C) granular carbon at different temperatures.

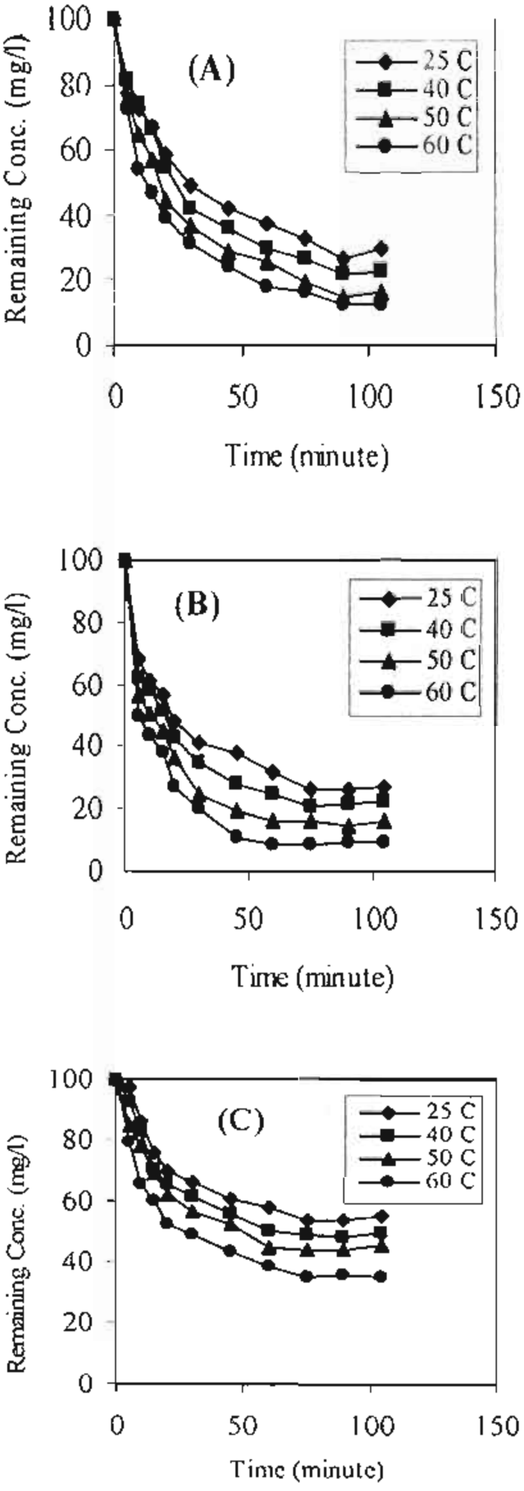


Fig. 4. Effect of time for the adsorption of dye (3) : (A) soot, (B) PAC and (C) granular carbon at different temperatures.

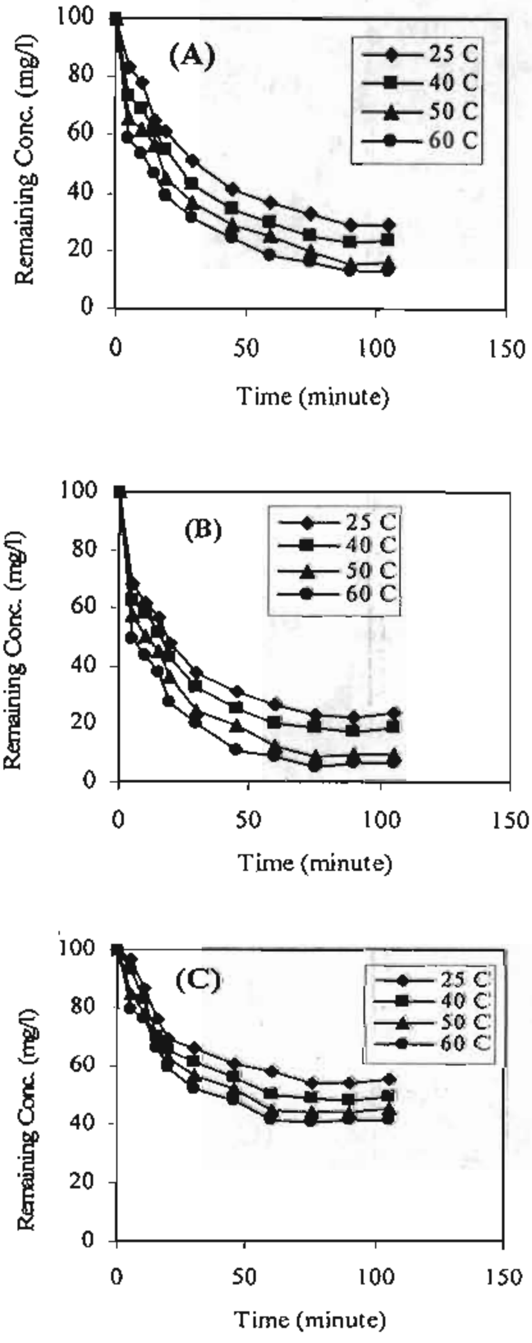


Fig. 5. Effect of time for the adsorption of dye (4) : (A) soot, (B) PAC and (C) granular carbon at different temperatures.

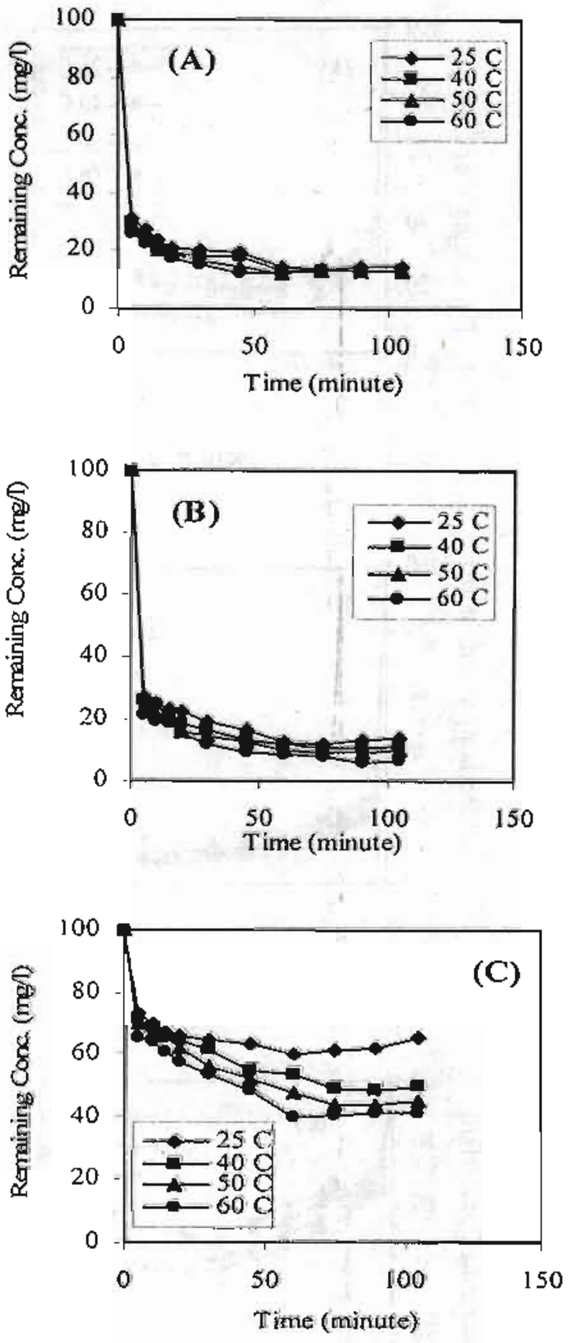


Fig. 6. Effect of time for the adsorption of dye (5) : (A) soot, (B) PAC and (C) granular carbon at different temperatures.

3.2. Adsorption Isotherms

Analysis of equilibrium data for the adsorption of the dyes on the three types of carbon have been done according to Langmuir,[25], Freundlich,[26] and Burnauer, Emmett, and Teller[27] models. All adsorption studies were carried out at four different temperatures (25°C, 40°C, 50°C and 60°C).

3.2.1. Langmuir Isotherm

The plots of the reciprocal of the amount of adsorbed dye x/m (mg dye / mg carbon) against the reciprocal of equilibrium concentration (1/C) for the studied dyes gave straight lines as shown in figures (7 -11). This indicates that the adsorption process conforms to the Langmuir adsorption isotherm and Langmuir equation is applicable [25]:

$$x/m = abC/(1 + aC) \qquad (1)$$

The slope of the best fit (1/ab) and the intercept (1/b) of linear plots of Langmuir isotherm for the five dyes were obtained and Langmuir parameters (a) and (b) for adsorption of the dyes on soot, granular carbon and PAC are calculated at the previously mentioned temperatures and listed in table (1). From these results, it was found that (b) values (the indication of monolayer coverage) for PAC > carbon soot > granulated carbon. This is in agreement with the finding in literatures concerning the increase in (b) value with the decrease in the particle size of adsorbent [13, 17, 22]. The monolayer coverage parameter (b) generally increases with increasing temperature.

It was found from electron micrographs that, the particle size of granular carbon > of soot > PAC [28]. This is appeared to indicate that the surface area associated with pores inside the particle is being at least partially occupied by the large dye molecules, and that the effective regime is confined to the external surface and a narrow layer just below the surface in the case of PAC [17, 29, 30], whereas in the case of carbon soot the effective adsorption regime is confined in a less extent to the external surface and to the formation of thick layers below the surface. Table (1) contains the equilibrium parameter (R_L) which is defined from the relation [17, 29, 30]:

$$RL = 1 / [1 + a\,Co] \qquad (2)$$

The values of R_L for the studied systems were found to be < 1 showing a favorable adsorption for the tested dyes on carbon soot, granular carbon and PAC [17, 31].

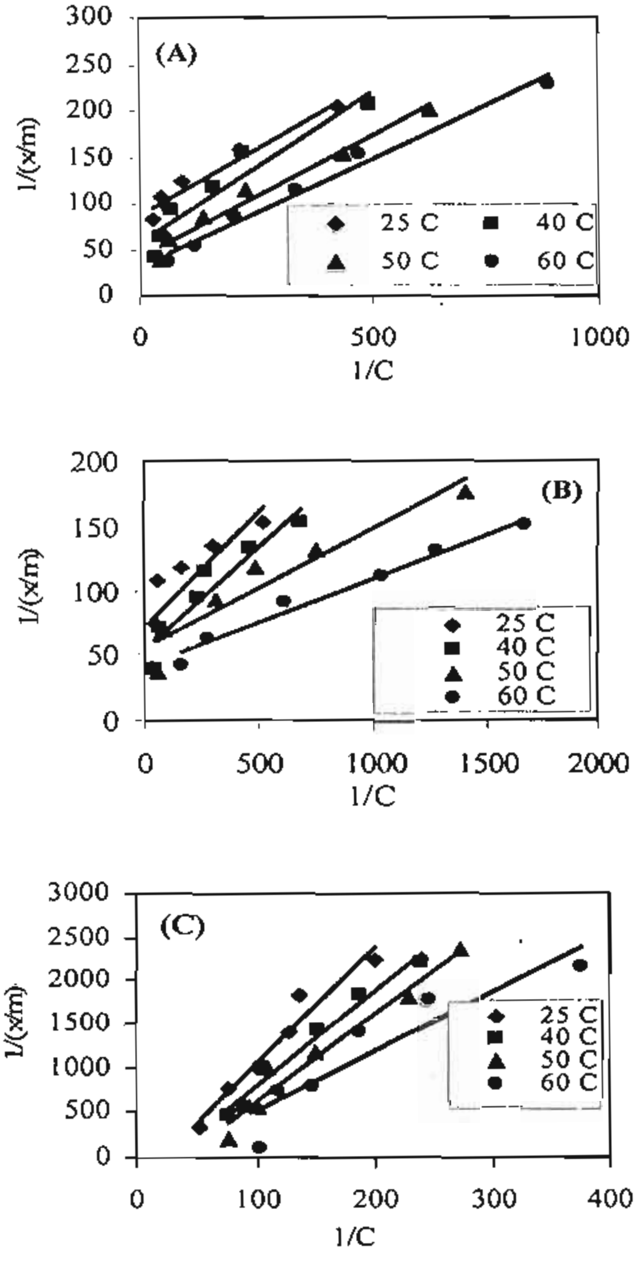


Fig. 7: Plot of Langmuir equation for the adsorption of dye (1) :(A) soot, (B) PAC, and (C) granular carbon at different temperatures.

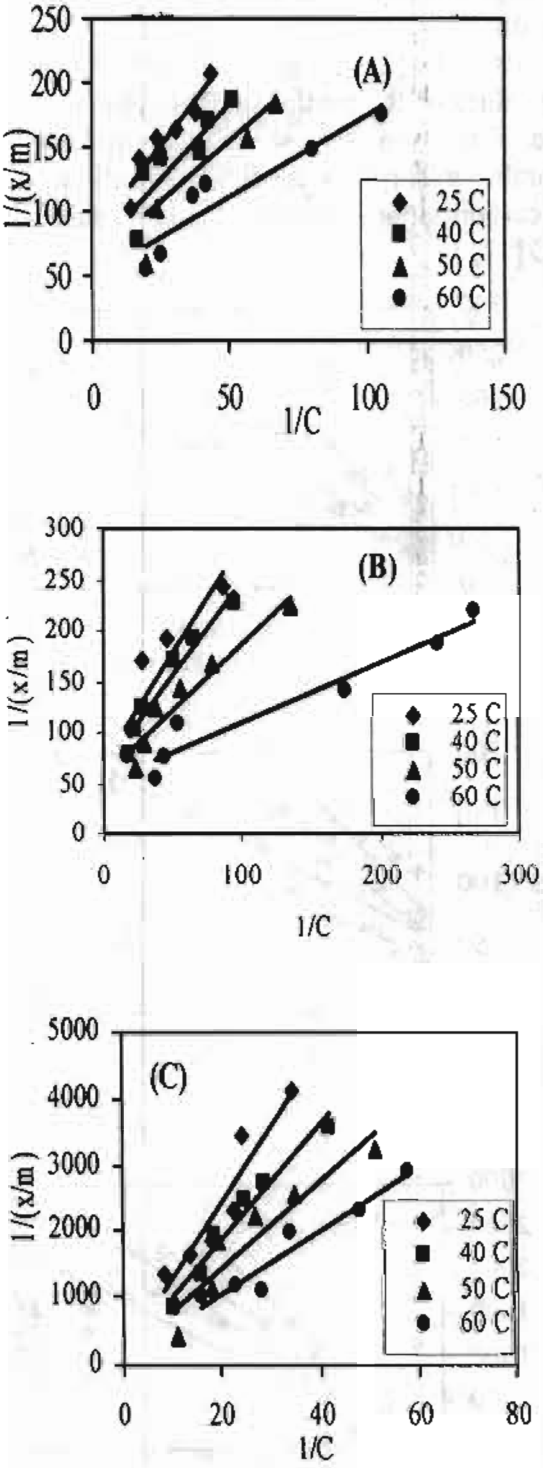


Fig. 8: Plot of Langmuir equation for the adsorption of dye (2) :(A) soot,(B) PAC, and (C) granular carbon at different temperatures.

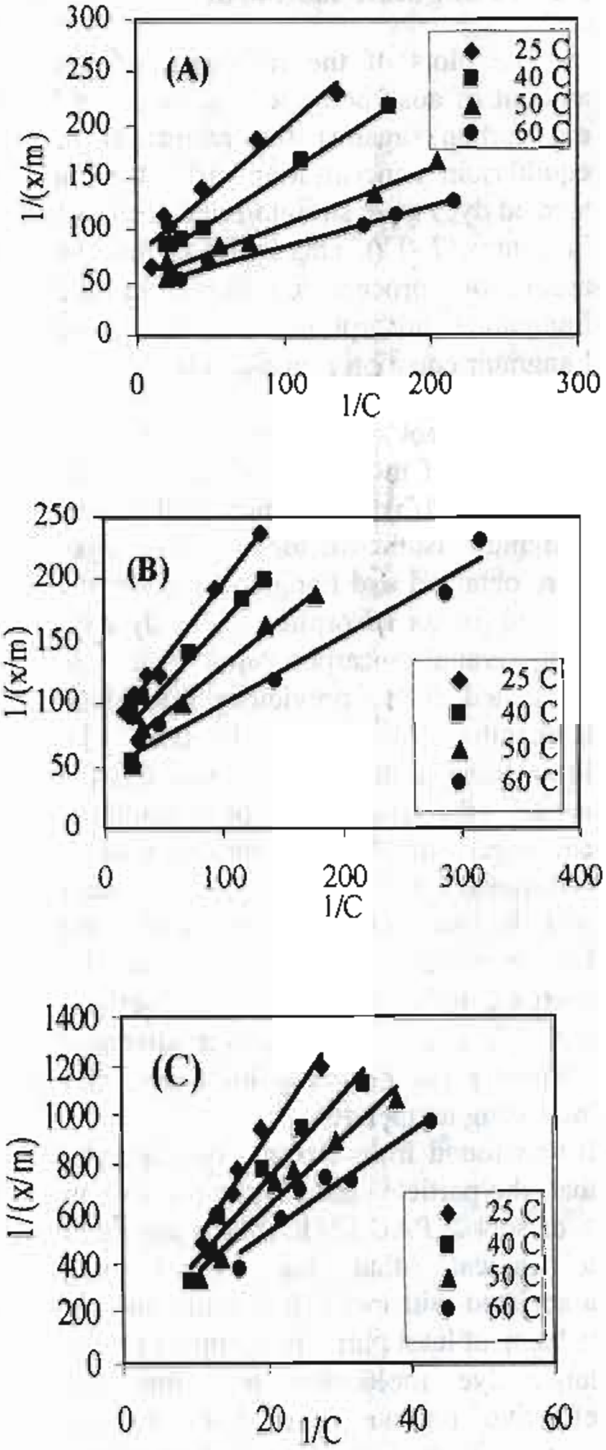


Fig. 9: Plot of Langmuir equation for the adsorption of dye (3): (A) soot, (B) PAC, and (C) granular carbon at different temperatures.

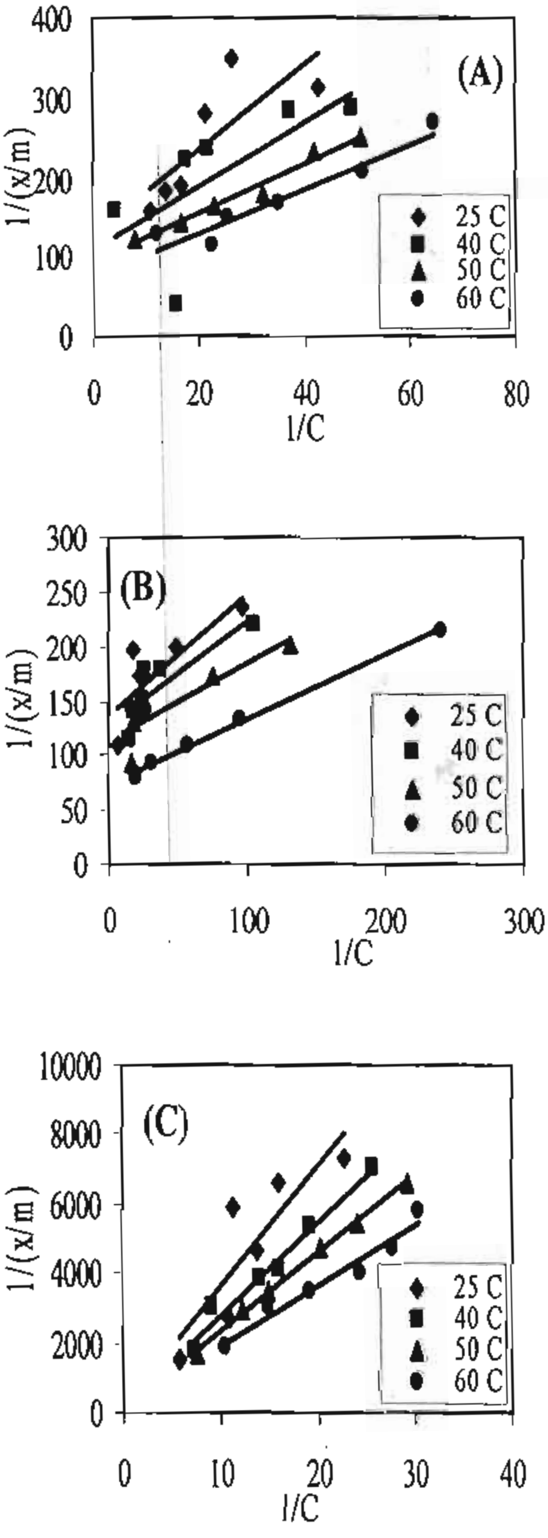


Fig.10: Plot of Langmuir equation for the adsorption of dye (4) :(A) soot , (B) PAC, and (C) granular carbon at different temperatures.

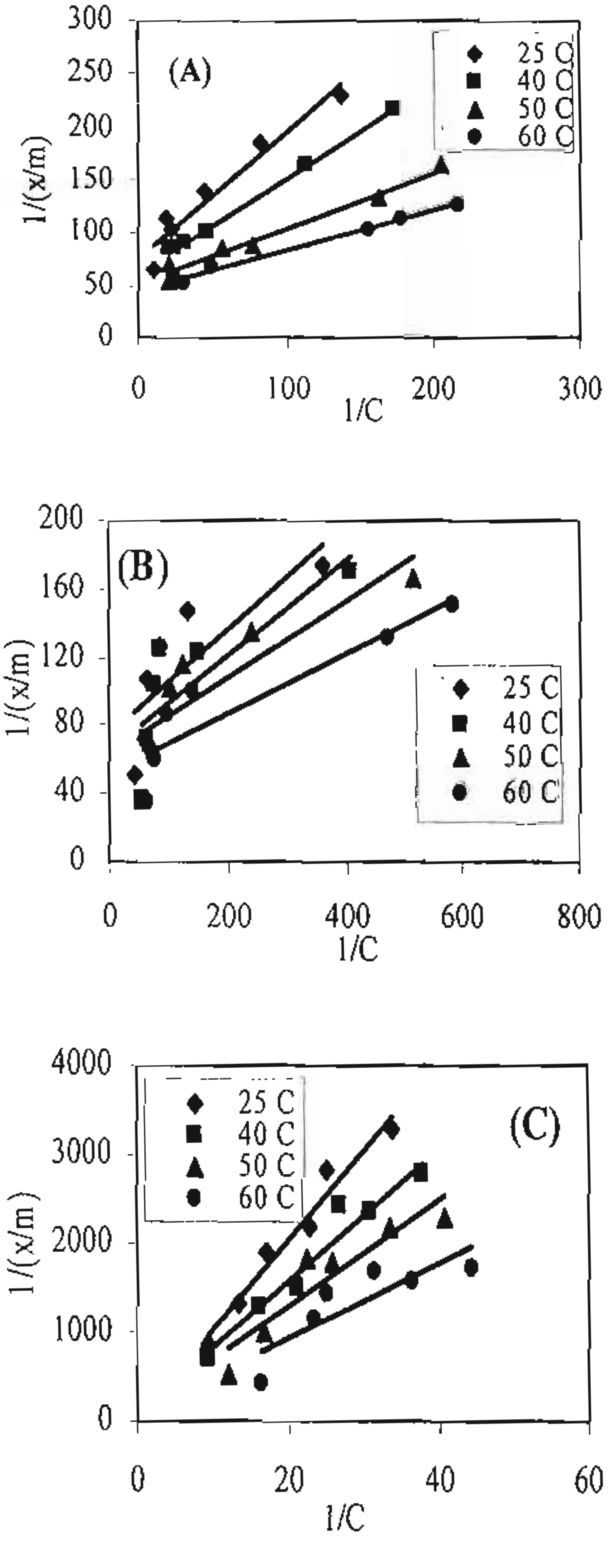


Fig. 11: Plot of Langmuir equation for the adsorption of dye (5) :(A) soot, (B) PAC, and (C) granular carbon at different temperatures.

3.2.2: Freundlich Isotherm

Test of validity of Freundlich adsorption isotherm for adsorption process was followed according to the equation [26, 31]:

$$\text{Log}\,(x/m) = \log k + (1/n)\log C \qquad (3)$$

Plotting log (x/m) against log C gave rise to a group of straight lines, Figures. (12-16) corresponding to adsorption of the tested dyes on different types of carbon at different temperatures.

From slope and intercept (1/n) and K (adsorption capacity) values were calculated respectively and delineated in table (2). The delineated data reveals that adsorption capacity values (K) increase as the pore size of carbon change from PAC to carbon soot and finally to granular carbon. This might be explained in view of freundlich equation [17, 26], which implies the two important parameters (K) and (1/n) which are related to the capacity of adsorbent for the adsorbate and the strength of adsorption process respectively. It was found that (n) values are in the range that indicates a good adsorption since (n) values are higher than unity [17, 26]. Moreover these data revealed that direct dependence of adsorption capacity on temperatures. Generally the capacity of the three used types of carbon for adsorption of the chosen dyes could be arranged in the order of PAC >carbon soot >granular carbon.

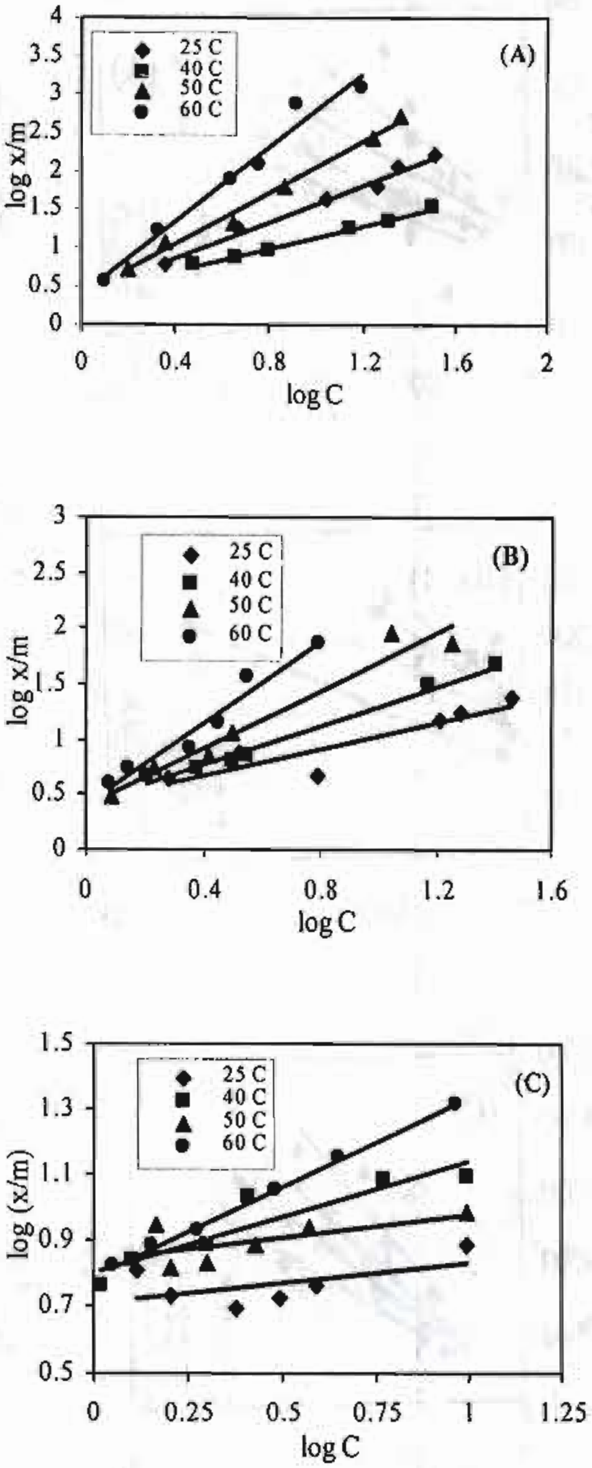


Fig. 12: Plot of Freundlich equation for the adsorption of dye (1): (A) soot,(B) PAC, and(C) granular carbon at different temperatures.

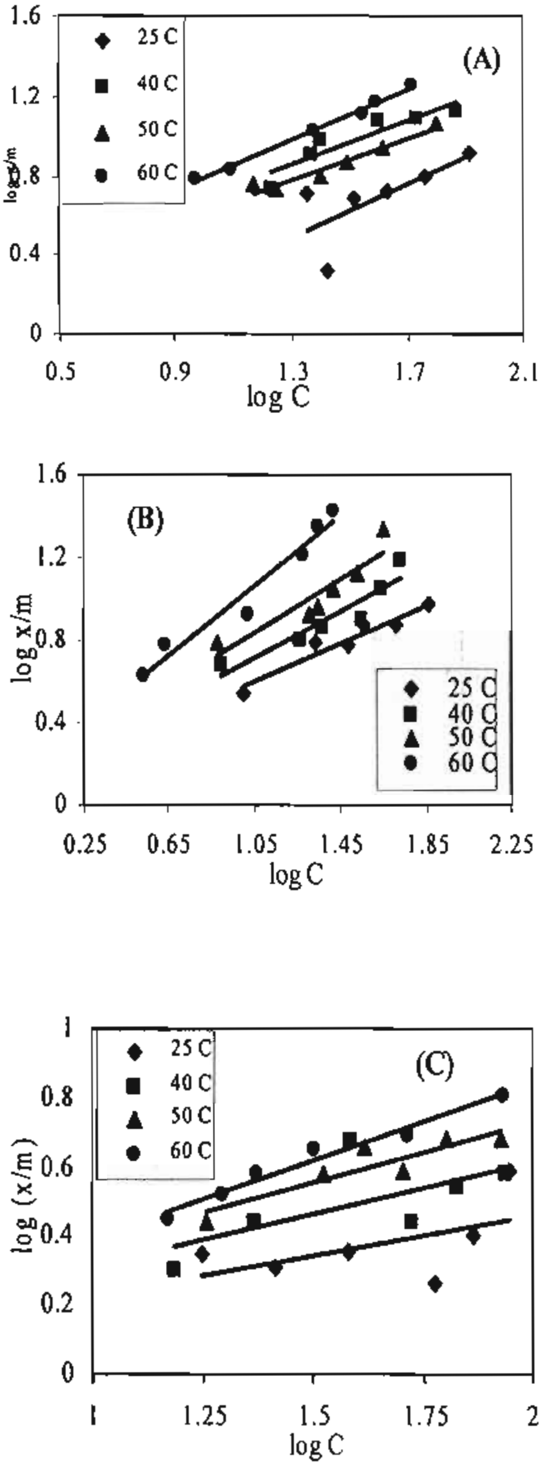


Fig.13: Plot of Freundlich equation for the adsorption of dye (2): (A) soot, (B) PAC, and (C) granular carbon at different temperatures.

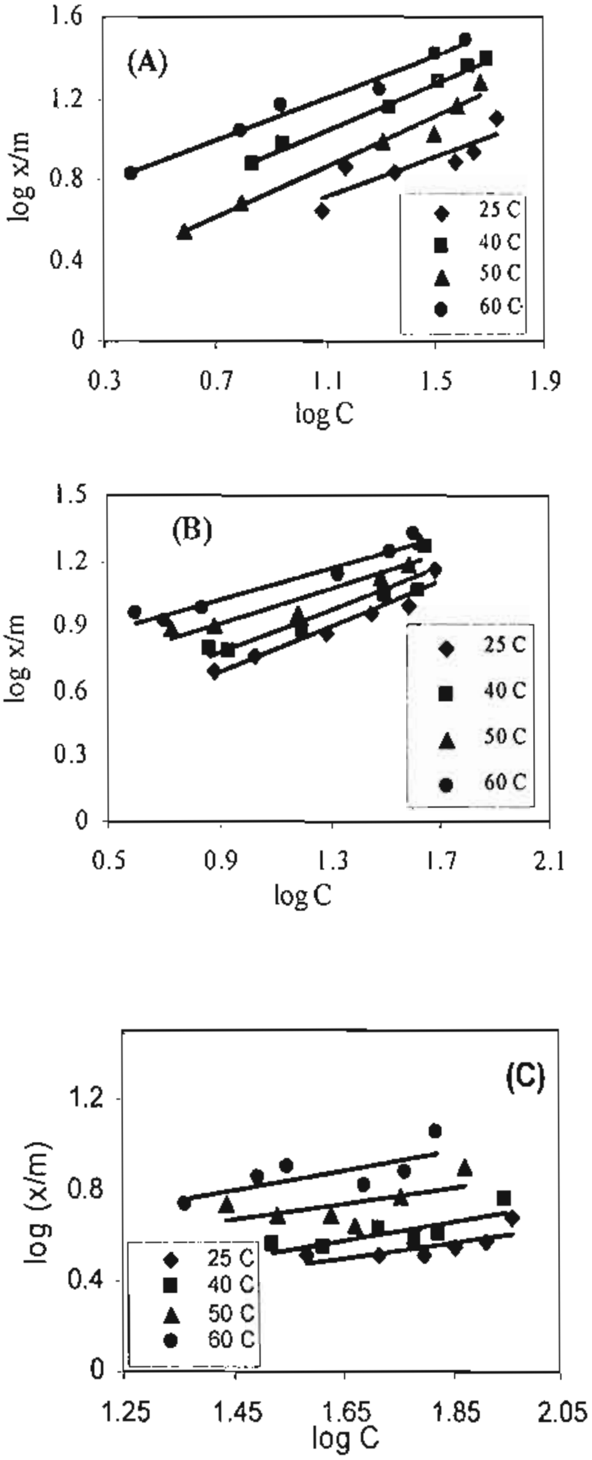


Fig.14: Plot of Freundlich equation for the adsorption of dye (3): (A) soot, (B) PAC, and (C) granular carbon at different temperatures.

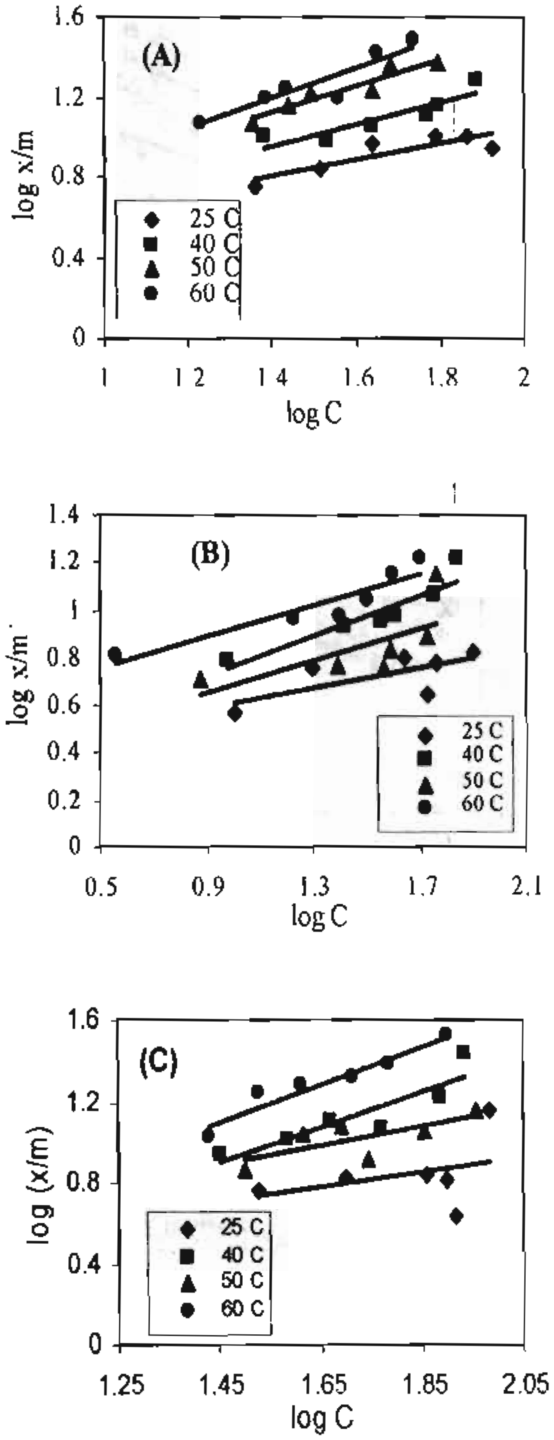


Fig.15: Plot of Freundlich equation for the adsorption of dye (4) : (A) soot,(B) PAC, and (C) granular carbon at different temperatures.

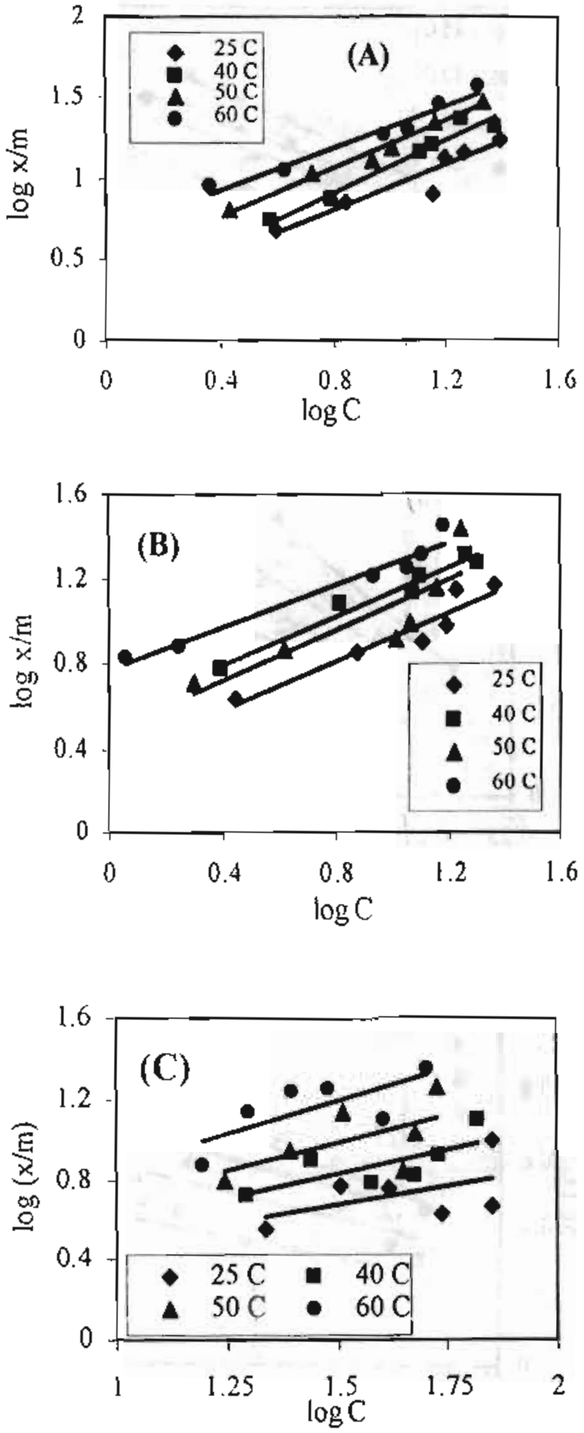


Fig.16: Plot of Freundlich equation for the adsorption of dye (5) : (A) soot,(B) PAC and (C) granular carbon at different temperatures

3.2.3: BET Isotherm

Brunauer, Emmett and Teller [27] derived an adsorption isotherm based on the assumption that molecules could be adsorbed in more than one layer thick on the surface of the adsorbent. This equation, like Langmuir equation assumes that the adsorbent surface is composed of uniform, localized sites and that the adsorption at one site does not affect adsorption at neighboring sites. Moreover, it was assumed that the energy of adsorption holds the first monolayer but that the condensation energy of the adsorbate is responsible for adsorption of successive layer. The equation, known as BET equation, is commonly written as follows [17, 27]:

$$x/m = ACXm/(Cs-C)[1+(A-1)C/Cs] \quad (4)$$

Rearranging the BET equation yields:

$$\frac{C}{(Cs-C)X/m} = \frac{1}{AXm} + \frac{A-1}{AXm}\left(\frac{C}{Cs}\right) \quad (5)$$

Data obtained from adsorption processes, for the tested dyes on different types of carbon are utilized to conform the BET equation when plotting C/(Cs-C)(x/m) against C/Cs. Figures (17-21) illustrate the resulting straight lines obtained from the BET equation of the tested dyes on different types of carbon, the slope of these lines equal to A - ($1/AX_m$) and intercept equal to $1/AX_m$. . Values of both (A) and (Xm) for the tested dyes on carbon soot, granular carbon and PAC are given in table 3.

It's evident that the amount of solute adsorbed utilized in forming a complete monolayer on PAC > carbon soot > granular carbon. The effect of temperature is clearly obvious, hence the value of Xm increase as the temperature increasing from 25 °C to 60 °C. This may be explained on the basis that, the increasing temperature increases the rate of adsorption, moreover, increase the temperature increases the mobility of the large dye ions for further penetration[9, 17, 27] consequently the adsorption process becomes more favorable with increasing temperature.

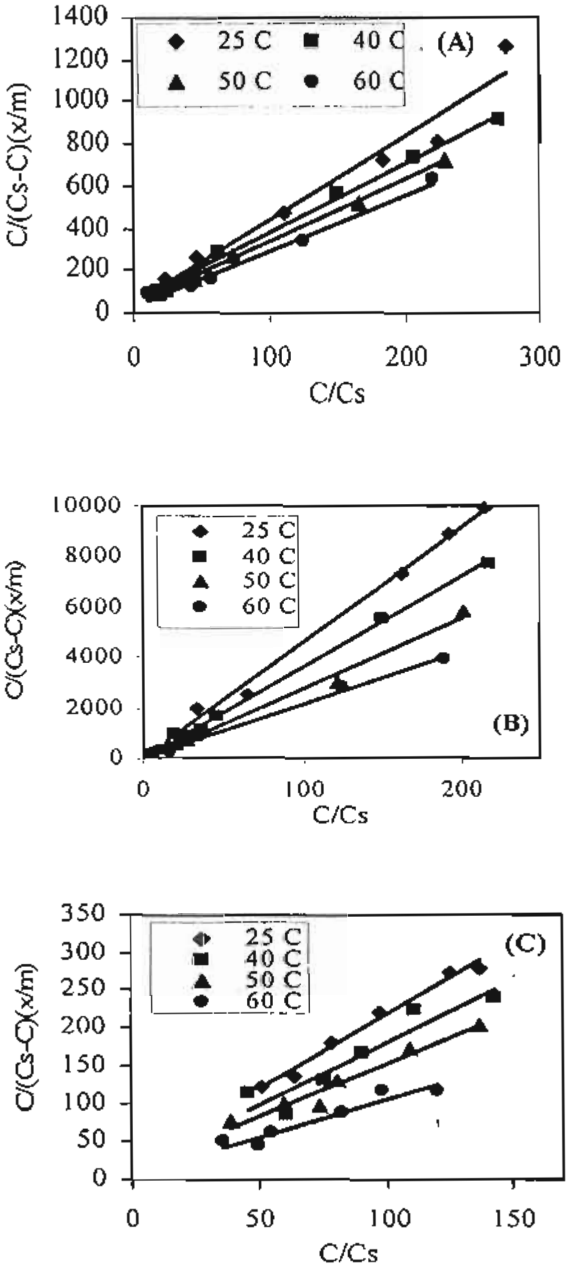


Fig.17: Plot of BET equation for the adsorption of dye (1) : (A) soot,(B) PAC, and (C) granular carbon at different temperatures.

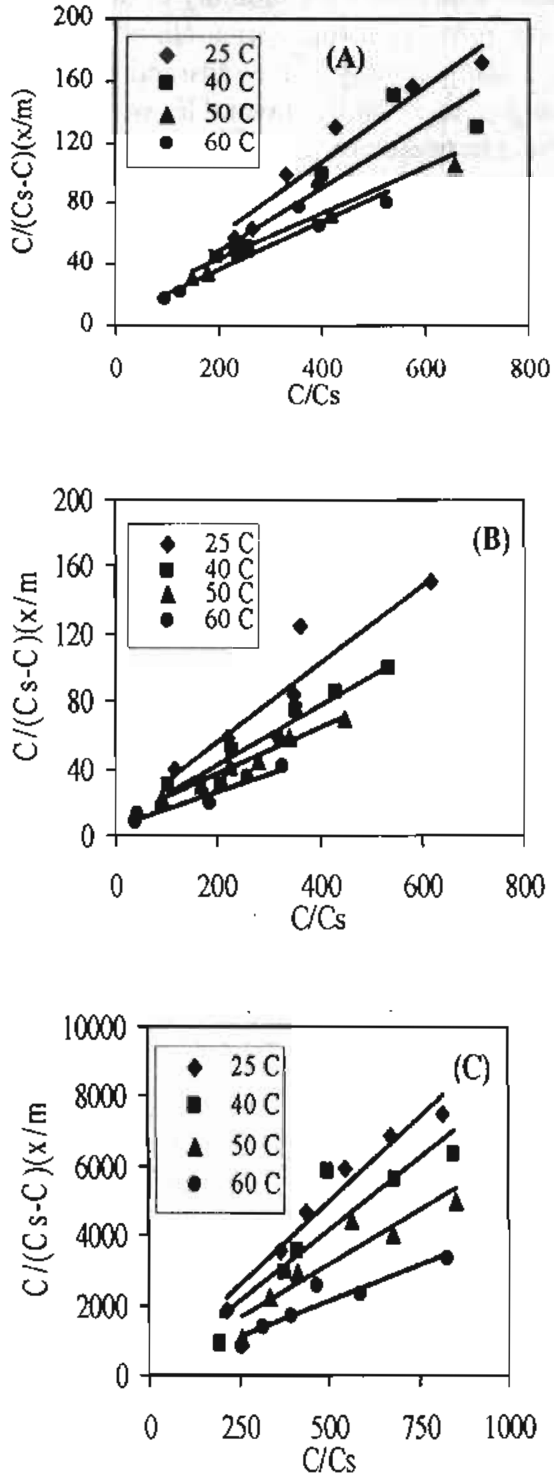


Fig. 18: Plot of BET equation for the adsorption of dye (2) : (A) soot, (B) PAC, and(C) granular carbon at different temperatures.

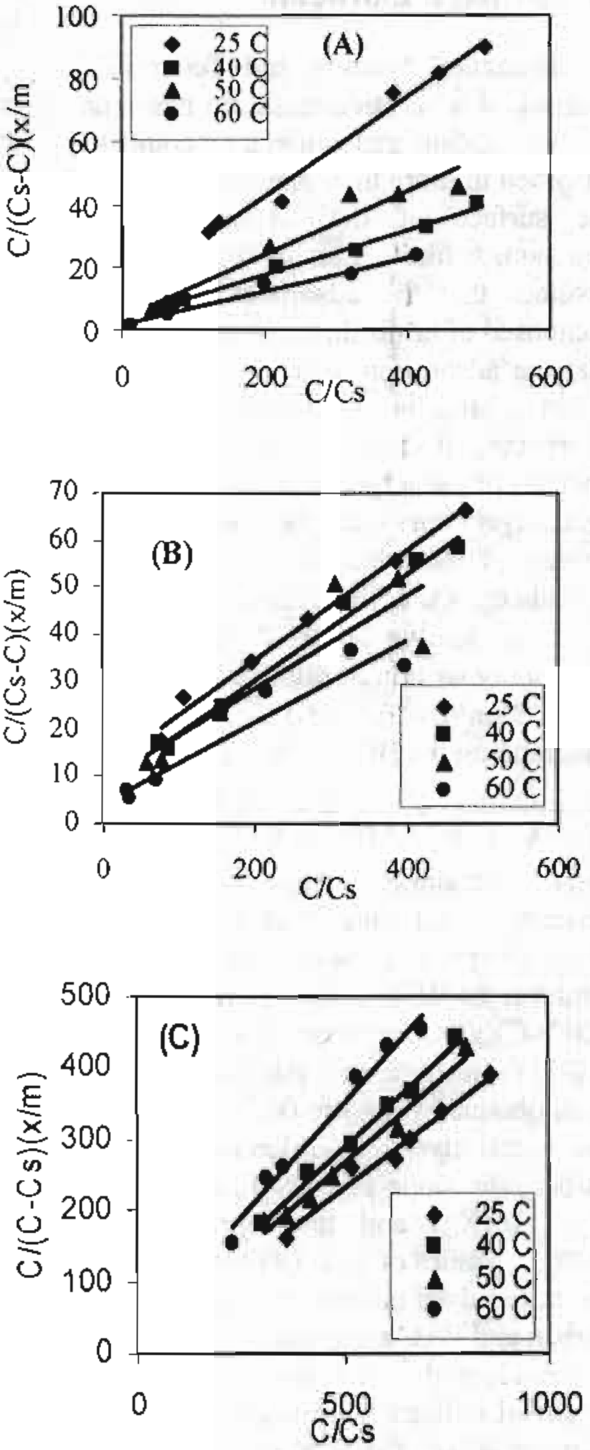


Fig. 19: Plot of BET equation for the adsorption of dye (3) : (A) soot, (B) PAC, and (C) granular carbon at different temperatures.

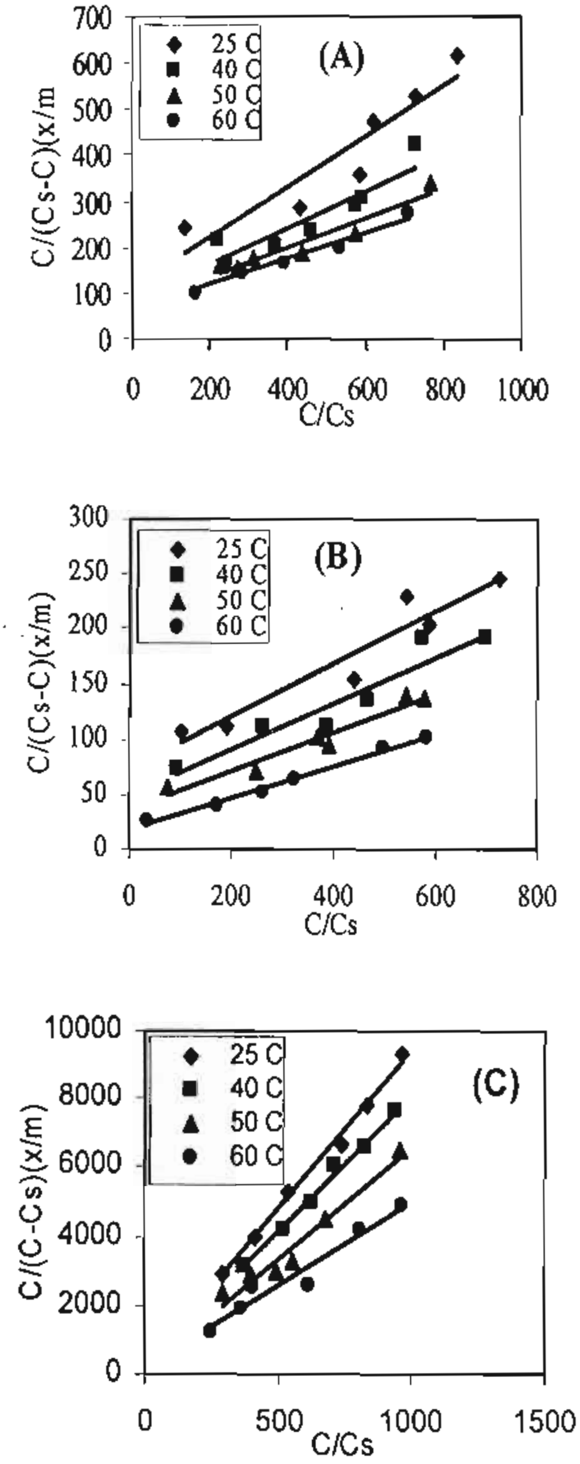


Fig. 20: Plot of BET equation for the adsorption of dye (4): (A) soot,(B) PAC, and (C) granular carbon at different temperatures.

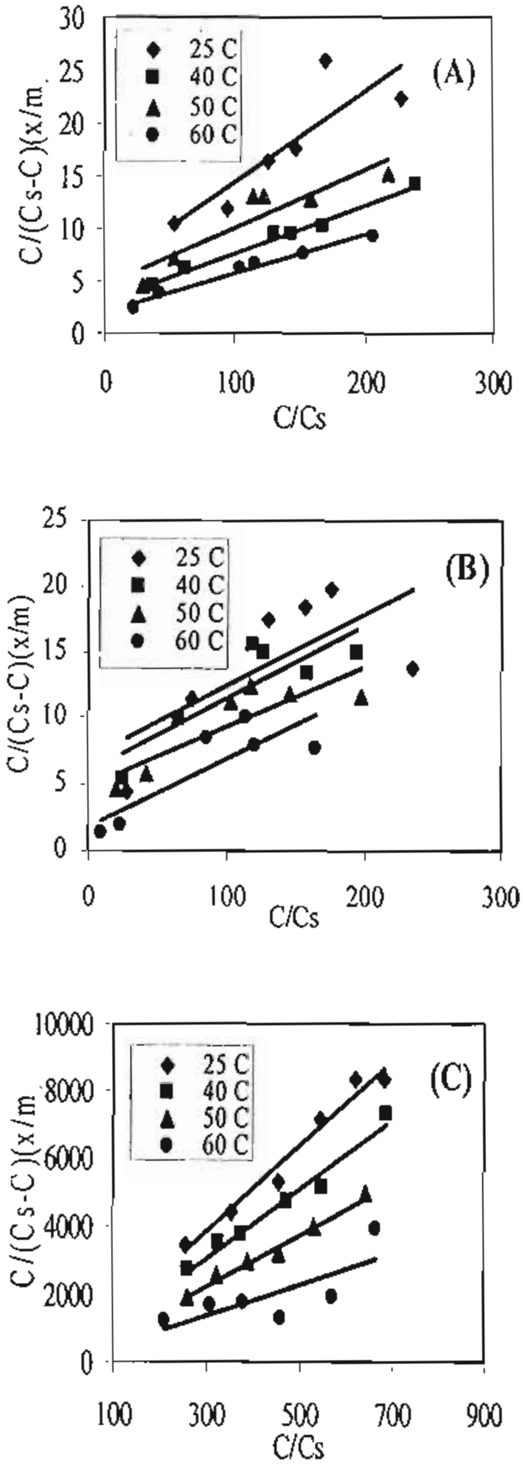


Fig. 21: Plot of BET equation for the adsorption of dye (5): (A) soot, (B) PAC, and (C) granular carbon at different temperatures.

4. CONCLUSIONS

This paper studied aims to identify the ability of soot produced as a byproduct from the partial oxidation of a natural gas as adsorbent material (for some of newly synthesized dyestuffs) against conventional carbon adsorbents (PAC and granular carbon). The study reveals that:

Carbon soot is a good adsorbent for removal of these prepared dyestuff from their aqueous solutions at 60 °C, the color of dye is reduced with a very good efficiency over 90 % as shown in figures (2-6).

The data of all parameters obtained in the adsorption study are explained through several adsorption models, all the calculated parameters were found to be in agreement with the finding in literature as indicated from the following:

- Fitting the Longmuir model to the experimental data at different temperatures suggest that the monolayer coverage of the adsorbed dyes at the outer surface of the adsorbent, this monolayer coverage increase with increasing temperature.
- Fitting the Freundlich model to the experimental data at different temperatures show that the adsorption of tested dyes on PAC is slightly higher than carbon soot and highly greater than granular carbon.
- Fitting the of Burnaur Emmett & Teller (BET) model to the experimental data at different temperatures show that the amount of dye adsorbed in forming a complete monolayer (Xm) on PAC is slightly higher than carbon soot and highly greater than granular carbon. It is found also that the amount of dye adsorbed in forming a complete monolayer (Xm) increase with increasing temperature.

NOMENCLATURE

A: Constant describing the energy of interaction between the solute and the adsorbent surface

a : Langmuir isotherm constant

b : monolayer coverage constant

C : Concentration of solute in solution at equilibrium (mg/l).

C_o : Initial dye concentration.

C_s: Saturation concentration of solute (mg/l)

K : adsorption capacity (Freundlich)

m : Weight of adsorbent (mg)

n : Freunlich adsorption constant

RL: dimensionless seperation factor (Langmuir)

x : Amount of solute adsorbed (mg)

x/m: Amount of dye adsorbed per adsorbent

X_m : Amount of solute adsorbed used in forming a complete monolayer, (mg/mg).

5. REFERENCES

[1] Farid M.A., M.Sc. Thesis ; Faculty of Science (Damietta), Mansoura University, Egypt (2007).

[2] Asfour H. M., Nassar M. M, Fadali O. A. and El-Geundi M.S., J. Chem. Tech. Biotechnol., **35A**, pp 28-35 (1985).

[3] Asfour M.M., Fadali O.A.; Nassar M. M. and El-Geundi M.S., J. Chem. Tech. Biotechnol, **35A**, pp 21-27 (1985).

[4] Ahmad S.R., Ali I, Rathore H.S., and. Kumari K., IAWPC Technology, Annual **10**,pp75-82 (1993)

[5] Sen A.K., Water Research, 21, 8, pp 885-888 (1987).

[6] Gupta G.S.,Parsad G. and. Singh N.V., Water Research, 24,1,pp 45-50 (1990).

[7] Banerjee K., Cheremisinoff P.N.and Cheng S.L., Water Research, 31,2 pp 249-261 (1997)

[8] El-Geundi M.S., Adsorption Science and Technology; 7, 3, pp124- 132 (1990).

[9] El-Geundi M.S.; Adsorption Science and Tech., 25, 3, pp114-123 (1990).

[10] El-Geundi. M.S., Water Research, 25, 3, pp 271-273 (1991)

[11] Mckay G., El-Geundi M. and Nassar M.M., Water Research, 22, 12 pp1527-1533 (1988).

[12] Mckay G., El-Geundi M. and M.M. Nassar M.M., Water Research, 21, pp1520-1523 (1987).

[13] El-Saiid A.E., Fayed M.S. and Ahmed E.A., Proc. of 2nd Int. Conf., On Environmental Protection is a must, Alexandria. University, Egypt; 24-27 Feb .pp 383-405 (1992).

[14] Rashed I.G.A., Lotfy H. R., El-Komy M. A. and Metwally M.A., Porc. of 2nd Int. Conf., on Environmental protection is a must; Alexandria Univ., Egypt; 24-27 Feb. pp 417-429 (1992).

[15] Rashed I.G.A., El-Komy M.A., Al-Sarawy A.A. , Mostafa R., and Al Bashir S. Journal of Environmental Science, Mansoura University, 8, pp12-18 (1994).

[16] Sarkar M.; Poddar S.; Journal of Anal. Proc. (London), 1, (7), pp 213-215 (1994).

[17] Al-Sarawy. A. A. Ph.D. Thesis, Faculty of Science, Mansoura University, Egypt (1996).

[18] Safari I., Nymburska K. and .Safarikova M, Journal of Chemical & Biotechnology. 69, 1 , pp 1- 4 (1997).

[19] Sankar M, Sekaran G., Sadulla S., and Ramas ami. T., J. Chem Technol Biotechnol ,74,pp337-344 (1999)

[20] Ruey-Shin J., Ru-Ling T., Feng-Chin W.and Shwu-Hwa L., J. Chem. Tech. Biotechnol. , 70, 391È399 (1997).

[21] Attia M.I., Ph.D. Thesis, Faculty of Science (Damietta), Mansoura University, Egypt (1999).

[22] Cheung C.W., PorterJ.F. and Mckay G.; Water Research, 35, 3, pp 605-612 (2001)

[23] Feng-Chin W., Ru-Ling T. and Ruey-Chin J., Water Research, 35, 3, pp613-618 (2001) .

[24] Shawwa R.A., DanielW.S. and C.S. David C.S., Water Research, 35 , 3, pp745-749 (2001).

[25] Langmuir I. J. ; Am. J. Chem. Soc., 40, 1361 (1918).

[26]. Freundlich H.; Colloid and Capillary Chemistry, Metheun, London (1926).

[27] Bruanaur J.; Emmett P. H. and Teller E.; Am J.; Chem. Soc.; 60,309 (1938).

[28] Rashed I. G.; Khalil A. M., El-komy M. A. and Al-Sarawy A. A.,; Journal of Environmental science, Mansoura University, Egypt, 6, pp 121-144 (1994).

[29] Laidler K. J.; Meiser T. H.;"Physical Chemistry"Benjamin/Cummings publishing company; Inc., (1982).

[30] Wali .F. K. M., M.Sc. Thesis, Faculty of Scince (Damietta), Mansoura University, Egypt (2001).

[31] Benfield L.D., Judkins J.F., Weand B.L.,Process Chemistry for Water and Wastewater Treatment, Printice. Hall, Iglewood Cliffs, New Jersy; (1982).

Table 1 : Analysis of Langmuir parameters of different dyes on different adsorbents at different temperatures.

Dye	Temp. (°C)	Granular carbon				Soot				PAC			
		a	b	R_L	R^2	a	b	R_L	R^2	a	b	R_L	R^2
1	25	1.003	0.0090	0.0098	0.860	63.31	0.0130	0.0001	0.893	59.83	0.0133	0.0001	0.975
	40	2.322	0.0120	0.0042	0.962	74.14	0.0150	0.0001	0.973	57.58	0.0165	0.0001	0.911
	50	3.049	0.0130	0.0032	0.974	93.15	0.0190	0.0001	0.895	68.44	0.0199	0.0001	0.885
	60	4.965	0.0188	0.0020	0.950	112.26	0.0210	0.0000	0.954	87.67	0.0212	0.0001	0.791
2	25	1.173	0.0074	0.0084	0.929	28.32	0.0125	0.0003	0.881	33.44	0.0158	0.0003	0.935
	40	1.501	0.0076	0.0066	0.885	27.93	0.0139	0.0003	0.873	44.05	0.0151	0.0002	0.928
	50	1.346	0.0112	0.0073	0.961	31.44	0.0163	0.0003	0.895	85.47	0.0169	0.0001	0.947
	60	1.636	0.0127	0.0060	0.886	36.36	0.0198	0.0002	0.893	38.91	0.0201	0.0013	0.841
3	25	0.394	0.0073	0.0240	0.913	24.13	0.0077	0.0004	0.993	115.56	0.0078	0.0000	0.774
	40	0.388	0.0090	0.0250	0.966	27.20	0.0095	0.0003	0.981	128.66	0.0099	0.0000	0.941
	50	0.325	0.0136	0.0300	0.959	30.18	0.0146	0.0003	0.998	154.75	0.0160	0.0000	0.910
	60	0.680	0.0144	0.0144	0.968	27.17	0.0151	0.0003	0.938	121.61	0.0157	0.0000	0.995
4	25	2.473	0.0097	0.0040	0.959	27.02	0.0271	0.0003	0.924	295.79	0.0298	0.0000	0.995
	40	1.497	0.0110	0.0066	0.999	44.07	0.0301	0.0002	0.972	315.92	0.0337	0.0000	0.708
	50	0.872	0.0150	0.0113	0.974	37.82	0.0309	0.0002	0.673	371.42	0.0376	0.0000	0.790
	60	0.513	0.0190	0.0191	0.837	22.71	0.0430	0.0004	0.822	1021.1	0.0472	0.0000	0.782
5	25	1.005	0.0097	0.0098	0.724	85.34	0.0135	0.0001	0.995	236.74	0.0191	0.0001	0.826
	40	1.116	0.0111	0.0088	0.852	92.99	0.0151	0.0001	0.996	237.12	0.0211	0.0001	0.725
	50	1.211	0.0141	0.0081	0.944	172.07	0.0161	0.0000	0.989	275.31	0.0233	0.0001	0.645
	60	0.594	0.0254	0.0165	0.965	79.60	0.0251	0.0001	0.900	298.08	0.0331	0.0001	0.648

Table 2 : Analysis of Freundlich parameters of different dyes on different adsorbents at different temperatures.

Dye	Temp. (°C)	Granular carbon			Soot			PAC		
		n	K	R^2	n	K	R^2	n	K	R^2
1	25	1.492	1.21	0.621	1.891	1.616	0.994	2.016	1.49	0.840
	40	1.193	1.29	0.735	1.986	2.099	0.983	2.574	1.43	0.986
	50	1.772	1.372	0.863	2.45	3.526	0.991	2.47	2.53	0.965
	60	1.811	1.451	0.998	2.266	5.013	0.976	2.602	4.207	0.955
2	25	1.482	1.015	0.697	2.125	1.164	0.811	2.101	1.235	0.926
	40	1.312	1.018	0.738	1.926	1.26	0.948	2.330	1.343	0.866
	50	1.792	1.041	0.819	1.981	1.32	0.831	1.996	1.39	0.839
	60	1.826	1.142	0.972	2.214	1.384	0.993	2.391	1.495	0.958
3	25	1.748	1.501	0.765	1.295	1.287	0.745	3.074	2.114	0.949
	40	1.111	1.581	0.701	1.508	1.581	0.970	2.381	2.205	0.870
	50	1.169	2.137	0.681	1.861	1.588	0.993	3.037	2.285	0.893
	60	1.971	1.651	0.756	2.491	1.738	0.979	4.859	2.55	0.952
4	25	1.191	8.729	0.528	1.353	1.774	0.756	1.783	2.317	0.697
	40	1.012	1.206	0.726	1.233	1.794	0.811	1.707	3.045	0.655
	50	1.383	1.384	0.807	1.335	2.843	0.891	1.778	3.713	0.846
	60	1.462	1.686	0.928	1.339	4.599	0.842	1.989	5.843	0.847
5	25	1.201	2.331	0.562	1.196	1.23	0.889	2.184	1.699	0.892
	40	1.339	2.603	0.654	1.233	1.87	0.959	2.196	2.137	0.708
	50	1.111	3.306	0.753	1.335	2.744	0.979	2.207	2.71	0.964
	60	1.456	4.018	0.820	1.632	4.639	0.960	2.146	3.398	0.958

Table 3 : Analysis of BET parameters of different dyes on different adsorbents at different temperature.

Dye	Temp. (°C)	Granular carbon			Soot			PAC		
		A	X_m	R^2	A	X_m	R^2	A	X_m	R^2
1	25	0.0083	1.196	0.914	0.052	2.433	0.990	0.125	2.853	0.945
	40	0.0048	1.606	0.954	0.0129	3.87	0.999	0.077	3.307	0.990
	50	0.0017	2.839	0.884	0.0175	4.632	0.994	0.076	4.809	0.896
	60	0.0016	3.314	0.987	0.00716	4.879	0.963	0.032	5.365	0.994
2	25	0.0027	3.239	0.974	0.0304	5.809	0.867	0.853	8.603	0.935
	40	0.002	2.58	0.978	0.007	5.948	0.869	0.021	7.12	0.983
	50	0.0019	4.454	0.903	0.019	7.353	0.835	0.0139	8.588	0.943
	60	0.0013	5.316	0.968	0.0098	8.24	0.938	0.0341	8.987	0.823
3	25	0.00073	4.694	0.974	0.00022	6.39	0.984	0.0002	7.705	0.923
	40	0.00006	5.084	0.978	0.0007[illegible]	6.12	0.993	0.00043	7.866	0.786
	50	0.00005	6.406	0.992	0.00[illegible]15	8.11	0.941	0.00081	5.16	0.990
	60	0.0006	6.375	0.979	0.00081	8.60	0.984	0.0032	8.587	0.991
4	25	0.0161	1.436	0.952	0.256	3.993	0.918	0.302	4.845	0.992
	40	0.00549	1.773	0.961	0.105	3.1033	0.924	0.0405	4.988	0.946
	50	0.0057	3.195	0.993	0.0496	4.518	0.857	0.0275	6.047	0.912
	60	0.0032	4.48	0.993	0.0289	5.919	0.976	0.0205	6.999	0.915
5	25	0.158	1.002	0.994	0.271	1.849	0.995	0.298	1.87	0.990
	40	0.0765	1.78	0.885	0.1053	3.104	0.996	0.0405	3.995	0.991
	50	0.0632	2.005	0.949	0.0496	4.5188	0.999	0.0275	5.050	0.996
	60	0.051	2.6317	0.965	0.0152	5.189	0.999	0.0205	6.999	0.998