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Sorptive removal of color from aqueous coffee and tea infusions

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ABSTRACT

Aqueous coffee and tea infusions were decolorized by adsorption onto activated carbon. The color of the infusions has changed gradually from brown to colorless during the decolorization process. To understand the potentiality of activated carbon, experiments were conducted to determine equilibrium time, optimum dose of adsorbent, intraparticle diffusion, adsorption isotherm, optimum pH, and desorption of color from the coffee and tea infusions. The corresponding results show that around 80–82% of color removal was achieved with 100 mg/L of activated carbon within 2 h. The isothermal equilibrium sorption data fitted well into the Langmuir isotherm. Film diffusion seems to be the rate limiting step for coffee infusions but pore diffusion for tea infusions. The sorption process appears to follow anionic type as the extent of sorption is decreasing with increasing pH. Desorption studies revealed that the sorption interaction was more of chemical nature.

Keywords: Adsorption; Activated carbon; Coffee infusion; Tea infusion; Decolorization

1. Introduction

Coffee and tea ranks among the five most popular beverages worldwide and India is one of the major nations in the world with 302,000 MT of coffee and 451,000 T of tea production in the year 2011 [1]. Appallingly processing of coffee seeds and tea leaves results in generation of large quantities of wastewater heavily loaded with organic matter which is often intensely colored and the disposal of which poses several problems like discoloration of receiving waters, biological oxygen demand (BOD)/dissolved oxygen depletion, toxicity (due to pollutant chemicals constituents such as caffeine, alkaloids, tannins, and so on), odor, etc. [2–8] including regulatory concerns. The chemical oxygen demand of coffee processing wastewater ranges from 2.4 to 9.6 g O_2/L or higher, BOD is of 1.4 g/L depending upon the processing technique and usually the pH is acidic for the wastewaters [2,3]. When the self purification of the wastewater receiving watercourse exceeds, the microbial degradation reduces the level of oxygen to anaerobic conditions under which no higher aquatic life is possible. In brief two major potential problems associated with coffee wastewater effluents are high acidity and depletion of oxygen in the receiving water bodies. Apart from being unesthetic and unacceptable, the discoloration of receiving waters reduces the photosynthetic activity consequently inhibiting the growth of desirable aquatic biota. Color causing compounds also have a tendency to chelate with metal ions and become microtoxic to aquatic biota. Therefore, it is important to remove the color from such effluents prior to its disposal into the environment.

Coffee and tea infusions contain a spectrum of chemical compounds belonging to various chemical

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families that impart color and flavor. The reddish brown color of tea is attributed to phenolics, tannins, flavonoids, catechins, leucoanthocyanins, melanins, etc. [9,10]. In the case of coffee, color is ascribed to the presence of chemical compounds like lignin, caffeine, and nonenzymatic browning of sugars and amino groups in addition to phenols, tannins, and flavonoids [11,12]. Some of these melanoidins that are final products of the Maillard reaction are shown to be dark brown macromolecular materials containing nitrogen [13]. The melanoidins possess antioxidant properties that render them toxic and inhibitory to biological treatment and hence are not removed during the regular and routine wastewater treatment processes.

The coffee industry wastewater needs attention and in regard to its pollutant behavior a cluster of methodologies like chemical flocculation, advanced oxidation processes [11], and electrochemical oxidation method [14] were applied to treat the coffee wastewaters. Recently, dark brown colored model coffee effluent was decolorized by photo-Fenton process [6]. Although coffee and other colored effluents could be decolorized by the methods mentioned so far, it is worth considering their demand for expense and energy. Adsorption process counters to be a most economical method. Although adsorption process cannot mineralize the pollutants, it can effectively remove pollutants remaining in a concentrate which can be incinerated for further destruction. Adsorption process was chosen for this study basically because of its proven potential and is a state of art practice in wastewater treatment plants especially in developing countries like India.

Adsorption is a classical method with wide application and credible competence. Among a plethora of adsorbents, activated carbon is promising in performance due to its superior properties offered by the unique combination of geometrical and chemical properties. Its widespread use as an effective adsorbent can be witnessed from numerous studies on adsorptive removal of color and chemicals like phenols, lignins, melanoidins, and so far from an assortment of industrial wastewaters [8,15,16]. However, literature on adsorption of coffee and tea wastewaters is minimal. Therefore, this current research article is expected to give a handful of results to the relatively less-studied area of color removal from coffee and tea infusions which are expected to create pollution due to their high production and usage rate although there may not be any immediate problem associated with the processing wastewater disposal.

The aim of the present investigation is to study removal of color from aqueous coffee and tea infusions by adsorption onto activated carbon. Included in the scope of the study are kinetics and isothermal equilibrium studies, desorption and interruption studies, and study of effect of adsorption process parameters such as pH, adsorbent dose, etc. This study will be useful for further applications in designing the batch adsorption process for the discoloration of coffee and tea effluents in food industries.

2. Materials and methods

2.1. Adsorbent and chemicals

Activated carbon of mean particle size of 1.5 mm (pore volume about 0.95 ml/g on dry basis) obtained from Aldrich chemicals was used as adsorbent in this study. The activated carbon was used in the adsorption experiments as purchased without any pretreatment. Aqueous infusions of coffee and tea were prepared from two different commercial brands of coffee and tea powders available in the local market as detailed in Table 1. Aqueous infusions of coffee and tea were prepared by adding 1.0 g of powder to 1,000 mL of boiling distilled water and the suspension was brewed for 30 min with occasional stirring. The solid matter was separated by filtration with Advantec 5C quantitative ash less filter paper. Fresh extracts were prepared as and when required and are used in the experiments. The pH of the solution was adjusted using 1.0 M H_2SO_4 or 1.0 M NaOH as per the requirement. All other chemicals were obtained from Acros organics, New Jersey, USA. All the chemicals used were of reagent grade. The glassware used is of Pyrex quality.

Table 1
Commercial brands and some characteristics of aqueous tea and coffee infusions

Commercial brand	Type	Characteristics			
		TDS (mg/L)	Color (Pt-Co units)	EC ($S\,m^{-1}$)	pH
AVT Supreme (AVT)	Black tea	290	1,982	55.6	4.83
YLT	Black tea	287	866	54.8	4.90
DRC	Roasted coffee	210	1,035	60.3	4.66
NCC	Roasted coffee	209	908	–	4.81

2.2. Analysis

Residual color concentration of infusions was analyzed colorimetrically using a UV-vis spectrophotometer (JASCO V- 550) by taking absorbance at wavelength 455 nm and computing concentration from the calibration curve. A wavelength of 455 nm was used since no specific peak was observed within 400–700 nm wavelength range and particularly 455 nm was chosen because it marks the beginning of the visible wavelength range. The pH was measured by Suntex Microprocessor pH meter 2000A. All analyses were done in accordance with standard methods [17]. Some characteristics of coffee and tea infusions like total dissolved solids (TDS), electrical conductivity (EC), and color concentration are given in Table 1.

3. Experimental procedure

All adsorption studies were carried out employing 1.0 g/L concentration of aqueous infusions of coffee and tea at room temperature (25 ± 2˚C). Experiments were conducted to determine the equilibrium time, isothermal equilibrium adsorption, optimum pH, dose of adsorbent, and desorption of adsorbed color.

3.1. Adsorption studies

A bottle- point method was employed in which each point on the graph is obtained by a separate bottle and a number of such identical bottles containing reaction mixtures were employed. The reaction mixture, consisting of 100 mL of 1.0 g/L of test solution and 100 mg of activated carbon was placed in a 250 mL stoppered glass bottle and agitated on a horizontal shaker at a rate of 150 rpm to overcome the diffusive resistance to the boundary layer during the sorption process. Depending on the requirement, a number of such identical bottles were employed for each sorption test. At the end of the desired contact time, bottles were withdrawn from the shaker, the contents filtered through Advantec 5C quantitative ashless (pore size = 0.45 μm) membrane filters and the filtrate was analyzed for the residual color concentration. The presented results are the average of triplicate experiments and the standard deviation was within 15%.

3.2. Kinetic study

The kinetics of the sorption reaction was studied by analyzing the residual color concentration at predetermined time intervals of 0, 5, 10, 20, 40, 60, 90, 120, 240, 360, and 480 min to find the equilibrium time and this equilibrium time was used in all the subsequent batch experiments.

3.3. Isothermal equilibrium adsorption study

The effect of pH on sorption was studied by conducting equilibrium sorption tests at different solution pH values of 2.0, 4.0, 6.0, 8.0, 10.0, and 12.0. Batch isothermal equilibrium studies were conducted by varying the dosage of the adsorbent at 50, 100, 150, and 200 mg/L and by keeping the concentration of the adsorbate constant at 1.0 g/L. The reaction mixture was mixed for equilibrium time; sorbents were separated and the filtrate was analyzed for residual color concentration.

3.4. Desorption study

Desorption studies were performed first by adsorbing the coloring substances onto the activated carbon; sorbent was separated and air dried and then reintroduced into a bottle containing distilled water. The mixture was agitated for equilibrium time and then analyzed for ambient color concentration. To evaluate color removal, color concentrations were measured before and after the experiment.

4. Results and discussion

Results of all the experiments are obtained either as percentage (%) color removal or amount of color sorbed and are presented in tabular and/or graphical form.

4.1. Kinetics of color adsorption

A study of adsorption process kinetics is important as it explains the progression and approach of the sorption process towards the equilibrium. The adsorption process is dependent on contact time and there exists an equilibrium for a given sorbate-sorbent-solute/solvent system. The effect of contact time on adsorptive removal of color of coffee and tea infusions was investigated by measuring the residual color concentration at the designed time intervals (Fig. 1).

It may be observed from the color removal data presented in Fig. 1 that the rate of removal of color from both the coffee and tea infusions is very high initially which gradually decelerated approaching equilibrium beyond which there was no significant increase in the rate of color removal. The initial rapid sorption may be attributed to participation of specific

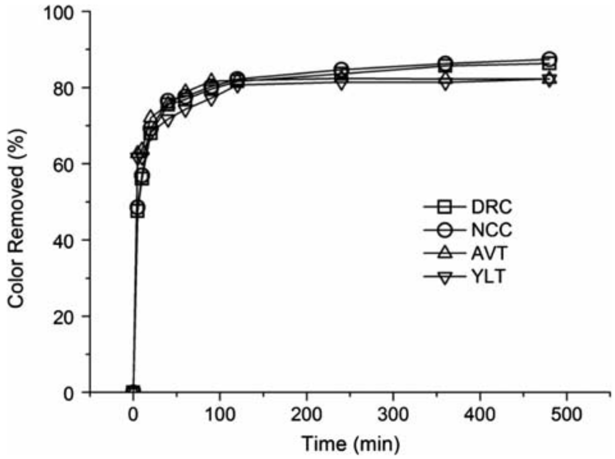

Fig. 1. Effect of contact time on color removal from coffee and tea infusions (temperature 25 ± 2°C, initial concentration of solute 1 g/L, and adsorbent dose 100 mg).

functional groups on activated carbon such as carbonyl, carboxyl, alcoholic, and ether groups [18]; macro pores and active surface sites in the sorptive removal of color molecules. The extent of color removal has increased gradually to 82% at the end of 90 min for AVT and 81% at the end of 120 min of contact time for Yellow Label Tea (YLT) tea infusion and remained more or less constant at around 82% for both the AVT and YLT even after a contact time of 8 h. A large fraction of the color (~70%) was removed within few minutes (20 min) in case of tea infusions. Considering economic and practical aspects, an equilibrium time of 90 and 120 min is employed for AVT and YLT tea infusion, respectively. In case of coffee infusions, nearly 75–77% of color was removed within 40 min; 78–82% in 120 min and 86–87% in 480 min (8 h) beyond which the experiment was terminated. An equilibrium time of 120 min was considered and employed as equilibrium contact time for coffee infusions in all subsequent experiments.

Kinetic models can be used to understand the nature of the sorption process. The sorption process usually depends on physical and chemical characteristics of the adsorbent system and also on the environmental conditions. Although a plethora of kinetic models, pseudo-first and pseudo-second-order kinetic models have been tested for its applicability in this study. Both the pseudo-first and pseudo-second-order models are based on an assumption that the adsorption process is a pseudo-chemical reaction. An equation of the form represented by Eqs. (1) and (2) are applied for finding the reaction rate for pseudo-first and pseudo-second-order, respectively.

$$\mathrm{Log}(q_\mathrm{e} - q_t) = \mathrm{Log}(q_\mathrm{e}) - \left(\frac{k_1}{2.303}\right)t \tag{1}$$

$$\frac{\mathrm{t}}{q_t} = \frac{1}{k_2 q_\mathrm{e}^2} + \frac{t}{q_\mathrm{e}} \tag{2}$$

where q_e (g of color/g of adsorbent) is the solid phase concentration at equilibrium, q_t (g color/g of adsorbent) is the average solid phase concentration at time t (min), and k_1 and k_2 are the pseudo-first and pseudo-second-order rate constants, respectively.

The plots were obtained with "log(q_e–q_t) vs. t" for pseudo-first-order and "t/q_t vs. t" for pseudo-second-order model and are shown in Fig. 2(a) and (b). The values of the rate constants k_1 and k_2 were calculated from the slopes and intercepts of the plots and are shown in Table 2. The pseudo-second-order model seems to explain the sorption process of color better than that of the pseudo-first-order model because of the superior correlation coefficient values,

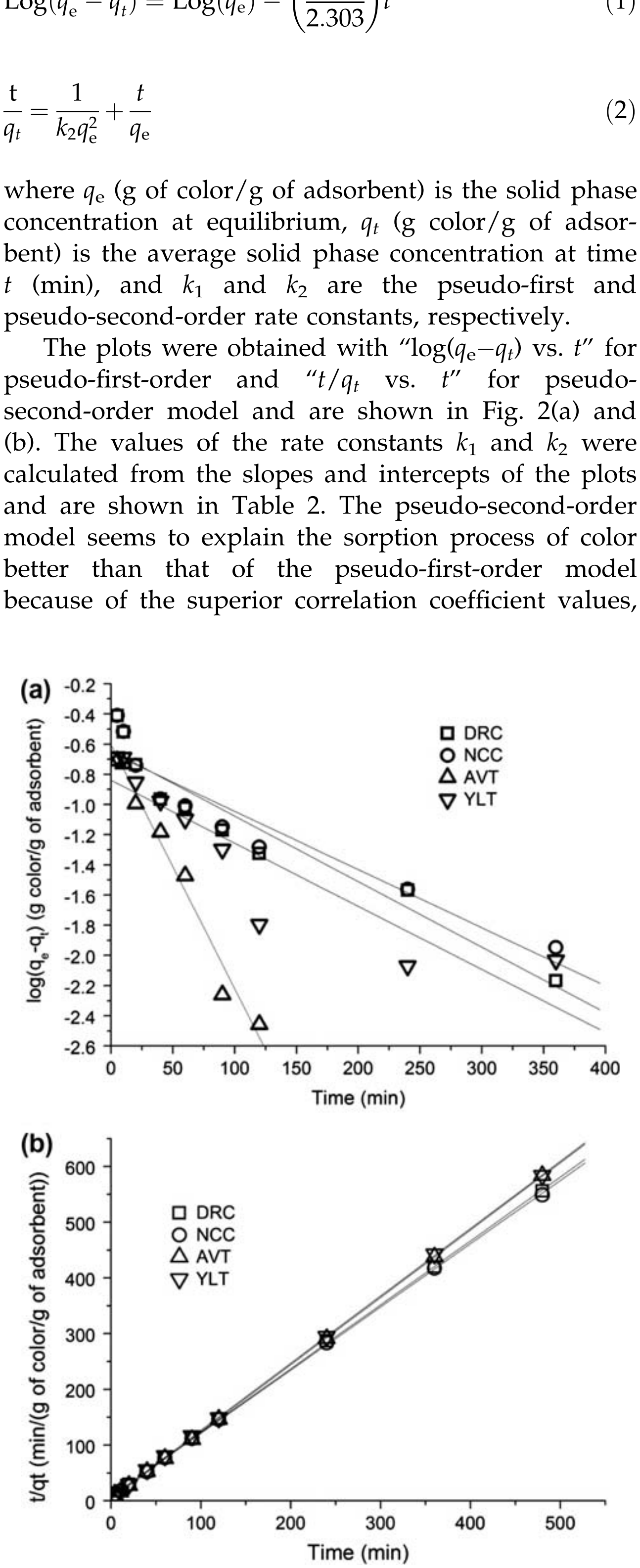

Fig. 2. Linear (a) pseudo-first-order and (b) pseudo-second-order plot for adsorption of color from aqueous coffee and tea infusions onto activated carbon.

Table 2
Kinetic model rate constants for adsorption of color from coffee and tea infusions onto activated carbon

Infusion	q_e (exp^a) $\left(\frac{\text{g of color}}{\text{g of adsorbent}}\right)$	Pseudo-first-order			Pseudo-second-order		
		k_1 (min^{-1})	q_e (cal^b) $\left(\frac{\text{g of color}}{\text{g of adsorbent}}\right)$	R^2	k_2 (min^{-1})	q_e (cal^b) $\left(\frac{\text{g of color}}{\text{g of adsorbent}}\right)$	R^2
DRC	0.863	0.0099	0.977	0.9208	0.157	0.872	0.9999
NCC	0.874	0.0089	0.979	0.8974	0.157	0.741	0.9998
AVT	0.822	0.0370	0.918	0.9768	0.514	0.827	1.0000
YLT	0.822	0.0096	0.978	0.8230	0.261	0.826	0.9999

[a] exp means experimental value.

[b] cal means calculated value.

further the equilibrium values of the experimental data greatly coincides with the calculated values from the theoretical model.

4.2. Rate limiting factors

In order to design any adsorption system, prediction of mechanisms of sorption is as important as understanding the kinetics and equilibrium isotherms. The system dynamics are described by three consecutive steps (i) bulk diffusion: solute transport from bulk solution through surface thin film onto the adsorbent exterior surface, (ii) pore diffusion: diffusion of solute into the pore of adsorbent except for a small quantity of sorption on the external surface, and (iii) capillary diffusion: intraparticle diffusion onto the interior pore and capillary surfaces eventually reaching equilibrium [5]. In general, the last step proceeds very fast and is considered to be negligible. Therefore, the two kinds of diffusion, film and pore diffusions are the major contributing factors that control the rate of adsorption of an adsorbate from the solution by a porous adsorbent [8,15]. Either or both of them may be rate limiting depending upon the system conditions. Rate limiting factor can be determined by plotting the square root of time ($t^{1/2}$) of uptake to amount of color sorbed per gram of adsorbent. The intraparticle rate diffusion coefficient is defined by the equation proposed by Morris and Weber [19]:

$$q_t = k_{\text{id}} t^{1/2} + C \tag{3}$$

where q_t is the amount of color adsorbed per gram of adsorbent, t is the time of uptake, and k_{id} is the intraparticle diffusion rate coefficient.

The time dependence of uptake of color of coffee and tea infusions by activated carbon is portrayed in Fig. 3. The obtained plots were of general characteristic shape, where the initial curved portion may be attributed to boundary layer diffusion effects [20]; while the final linear portion is due to the intraparticle diffusion effects [21]. Since the straight line did not pass through the origin it can be said that the intraparticle diffusion alone is not the rate controlling step. Boundary layer thickness is defined by the intercept obtained by extrapolating the final linear portion of the curve back to the y-axis as shown in Fig. 3. It may thus be inferred from the plots that the boundary layer thickness is greater for Nescafe Coffee (NCC) than Double Roast coffee (DRC) and for YLT than AVT infusions. The amount of the coffee or tea color causing compounds sorbed per gram of sorbent per square root of time was obtained from the slope of the curve according to Eq. (3) which corresponds to k_{id} values (Table 3).

The values of film diffusion coefficient and pore diffusion coefficient are calculated on an assumption that the adsorbent particle is spherical in shape with radius 'a' and the diffusion follows the Fick's law as explained by Arda Serpen et al. [15]. The equations used to determine the diffusion coefficients are

$$\frac{q_t}{q_e} = 6\left(\frac{D_f}{\pi a^2}\right)^{1/2} t^{1/2} \tag{4}$$

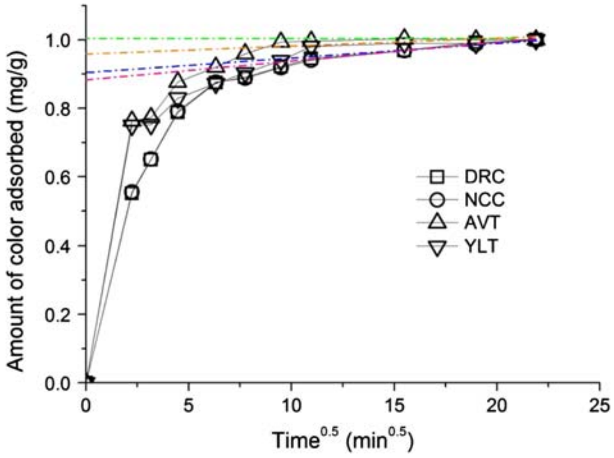

Fig. 3. Intraparticle diffusion plot for DRC, NCC, AVT, and YLT infusions at room temperature (25 ± 2˚C).

Table 3
Diffusion coefficients of adsorption of color from aqueous coffee and tea infusions onto activated carbon at room temperature

Infusion	Diffusion coefficients				
	$k_{id} \times 10^{-3}$ (color/g min$^{1/2}$)	$D_f \times 10^{-8}$ (cm^2/s)	R^2	$D_p \times 10^{-8}$(cm^2/s)	R^2
DRC	12.62	0.12	0.9397	0.38	0.9880
NCC	12.75	0.12	0.9394	0.34	0.9907
AVT	1.62	0.15	0.9018	0.14	0.9468
YLT	2.08	0.16	0.8810	0.08	0.9367

$$\ln\left(1 - \frac{q_t}{q_e}\right) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{D_p \pi^2 t}{a^2}\right) \tag{5}$$

where q_t and q_e are the solid phase concentration at time t and at equilibrium, respectively, D_f is the film diffusion coefficient and D_p is the pore diffusion coefficient.

The plots for diffusion coefficient determination are shown in Fig. 4(a) and (b) with the linear fitting equations and regression coefficients (R^2 values). The diffusion coefficients, D_f was calculated from the slope of the plot of q_t/q_e vs. $t^{1/2}$ (Fig. 4(a)) and D_p from the slope of plot of ln $(1-q_t/q_e)$ vs. t (Fig. 4(b)); the values are shown in Table 3. It can be construed that the film diffusion appears to be rate limiting in the case of coffee infusions by approximately threefold while pore diffusion seems to be the one in case of tea infusions. However, once these resistances are overcome by the coffee and tea infusions, intraparticle diffusion is faster in case of coffee infusions than that of tea infusions by approximately 10-fold. Nevertheless, the intraparticle diffusion is almost consistent in case of coffee and tea infusions individually after the first two diffusive resistances are surmounted.

4.3. Isothermal equilibrium adsorption modeling

Equilibrium adsorption isotherms are useful to understand the sorption interaction as well as to find adsorption capacity of the adsorbent. Isothermal equilibrium adsorption data were observed with two well-known models namely Langmuir and Freundlich isotherms. The Freundlich model is defined by

$$q_e = K_F C_e^{1/n} \tag{6}$$

where K_F is a Freundlich constant that is taken as an indicator of adsorption capacity at given equilibrium concentration C_e and $1/n$ is an empirical constant related to the magnitude and driving force of adsorption.

A linearized form of the Eq. (6) was used to plot the Freundlich isotherm, which explains the heterogeneous nature of the adsorption system. The values of Freundlich constants K_F and $1/n$ values can be obtained from the intercept and slope in linear regression result.

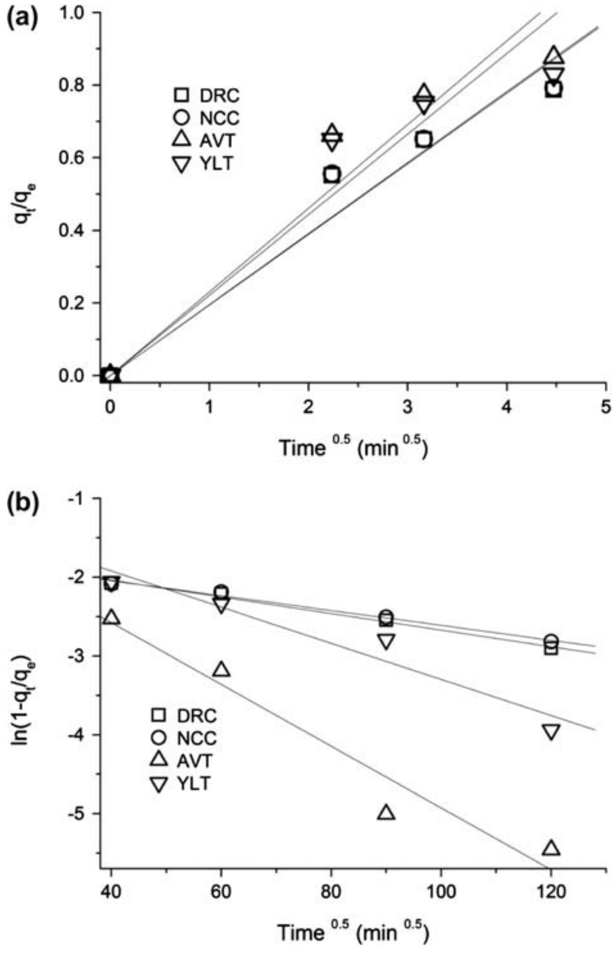

Fig. 4. Plot for the determination of (a) film diffusion coefficient (D_f) and (b) intraparticle diffusion coefficient (D_p).

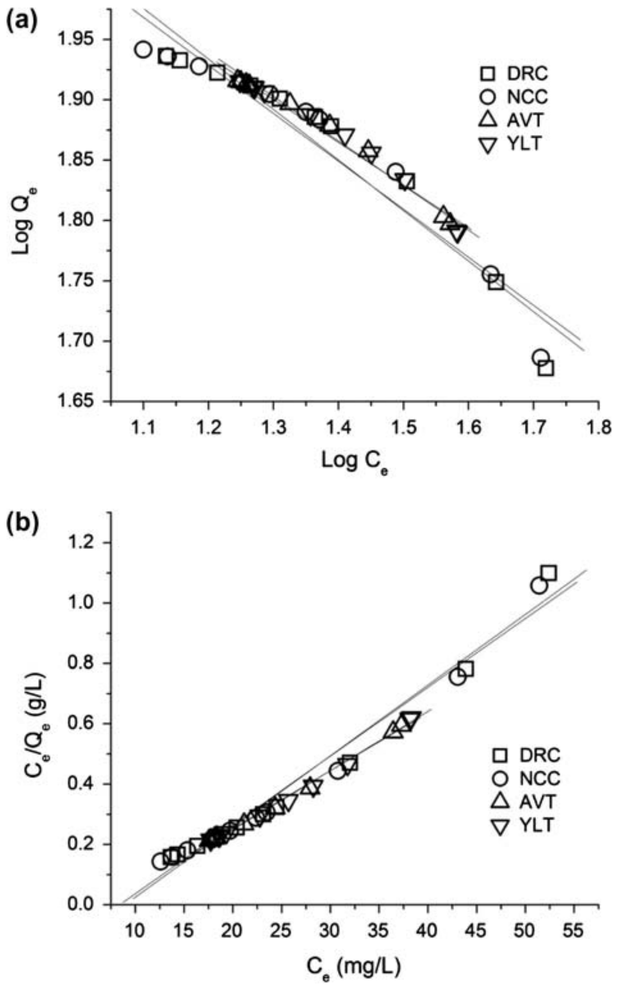

Fig. 5. Linearized (a) Freundlich isotherm and (b) Langmuir isotherm plot for adsorption of color from aqueous coffee infusions and tea infusions onto activated carbon at room temperature.

A quantitative model developed by Langmuir which is based on the assumption that maximum adsorption corresponds to a saturated monolayer of the solute molecule on the adsorbent surface with constant adsorption energy and there is no transmigration of the adsorbate in the plane of the surface was tested for its applicability. The Langmuir adsorption isotherm model used can be represented as

$$\frac{C}{q_e} = \frac{1}{Q^0 b} + \frac{C}{Q^0} \tag{7}$$

where C is the equilibrium concentration of sorbate in mg/L, q_e is the amount of color adsorbed at equilibrium in mg/g, and b is the adsorption energy constant of Langmuir adsorption isotherm (L/mg). Q^0 (mg/g) is the maximum amount of adsorption corresponding to complete monolayer coverage.

The plots of the isotherm models for coffee and tea infusions are shown in Fig. 5(a) and (b) and the data in Table 4. In general, the correlation coefficients are higher for Langmuir model than Freundlich, which support that the sorbent surfaces are of homogeneous nature and additionally it depicts the formation of monolayer coverage of color causing molecules onto the surface of the activated carbon. The values of the Langmuir constants for either of the infusions are not highly variant; but with a standard deviation of 4.48 for Q^0 and 0.01 for adsorption energy constant indicating the similarities of the tea and coffee infusions towards sorption interaction and adsorption capacity.

4.4. Dosage of the adsorbent

Equilibrium adsorption experiments were performed employing varying doses of adsorbent. Fig. 6 depicts the effect of dosage of the adsorbent on the removal of color from coffee and tea infusions. The extent of color removal (Fig. 6) from coffee infusions was very less at a lower level of adsorbent dosage (50 mg/L) with 58.82% for DRC and 51.25% for NCC, which increased dramatically to around 80% for both DRC and NCC infusions at a dosage of 100 mg/L. Further increase in the adsorbent dosage to 150 mg/L (82%) and 200 mg/L (84%) has not shown any significant improvement in color removal except with a slight increase of about 5% for the coffee infusions. The color removal increased from 74 to 82% for AVT

Table 4
Adsorption isotherm constants and correlation coefficients at room temperature (25 ± 2˚C)

Infusion	Freundlich constants			Langmuir constants		
	K_F (mg of color/g of AC)	n	R^2	Q^0 (mg/g)	b (L/mg)	R^2
DRC	272.89	2.38	0.9343	42.74	0.112	0.9766
NCC	254.33	2.51	0.9303	43.85	0.119	0.9775
AVT	229.66	2.82	0.9844	51.02	0.136	0.994
YLT	241.10	2.71	0.9804	51.02	0.136	0.994

tea infusion as dosage of the adsorbent was increased from 50 to 100 mg/L and no significant increase in the removal as the dosage was increased to 200 mg/L (83%); color removal remained constant around 82% beyond 100 mg/L. In the case of YLT tea infusion, color removal varied from 81 to 83% as activated carbon dosage increased from 50 to 200 mg/L. Therefore, in all the subsequent studies 100 mg/L was considered as an appropriate dosage of the adsorbent. A sample photograph of YLT infusion before color removal and after color removal at optimum dose of adsorbent (100 mg/L) and pH 6 is shown in Fig. 7. The increase in the color removal in case of tea infusions with increase in the adsorbent dose from 50 to 100 mg/L more than coffee infusions should have been due to the chemical composition of the infusions. For example, tea contains predominantly phenols while coffee contains Maillard reaction products like melanoidins. Several studies on adsorption of phenols to activated carbon also reported increased adsorption of phenols with increased dose of adsorbent [5,6]. Comparatively, melanoidins or browning enzymes interaction towards adsorbents is slow because of the various rate limiting mechanisms at operation during the adsorption process [15,22].

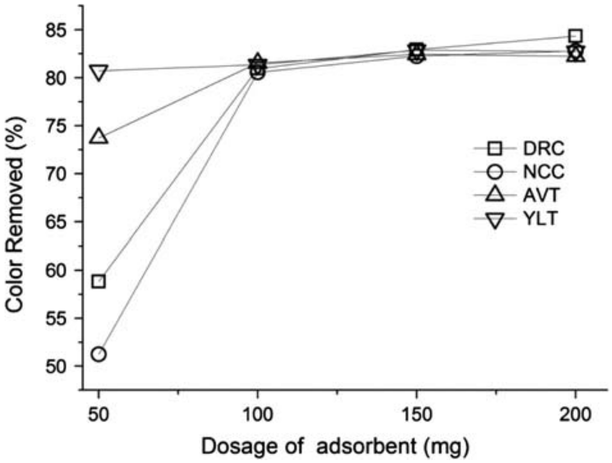

Fig. 6. Effect of dose of adsorbent on coffee and tea infusions (temperature 25 ± 2°C, initial concentration of solute 1 g/L, and at corresponding equilibrium time).

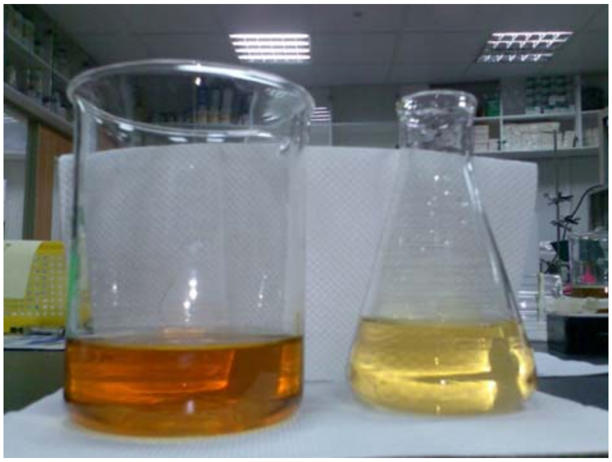

Fig. 7. Color of YLT infusion before and after adsorption onto activated carbon (activated carbon 100 mg/L, pH 6.0, initial concentration of solute 1 g/L, and time of process 90 min).

4.5. Influence of pH

Adsorption process is pH dependent and therefore, dependency of sorptive removal of color of coffee and tea infusions onto activated carbon was studied in the laboratory employing equilibrium batch adsorption tests as outlined earlier and the experimental results are depicted in Fig. 8. The extent of sorption was decreasing with increasing pH; 90% at pH 2.0 to 50% at pH 12.0 for tea infusions. In the case of coffee infusions, the increase in color removal was marginal (1–3%) as pH increased from 2.0 to 4.0 beyond which color removal reduced from around 81% at pH 4.0 to 38% at pH 12.0. In general, the extent of sorption decreased with increasing pH and the decrease was drastic in the pH range 6.0–12.0. Similar trend was observed by Diez et al. [5] when phenols were adsorbed onto allophanic compounds. This pattern of color removal is characteristic of anion sorption. However, in this case, pH-sorption edge is

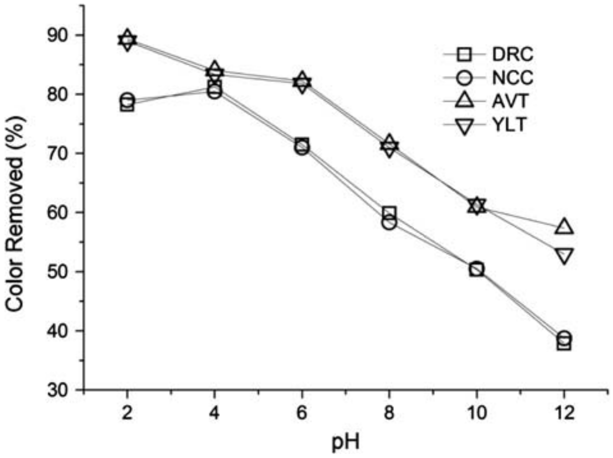

Fig. 8. Effect of pH on color removal from coffee and tea infusions (temperature 25 ± 2°C, initial concentration of solute 1 g/L, adsorbent dose 100 mg and at equilibrium time 90 min for AVT and 120 min for YLT, DRC, and NCC).

wider than the normal 1.0–2.0 pH units. This may perhaps be due to heterogeneous nature of the sorbate. At acidic pH values, the surface of activated carbon becomes positively charged and this facilitates sorption of color cations. Exchange sorption might have facilitated the sorption of color cations to positively charged adsorbent surface. Liverniche [23] has reported that at the lower pH values, decrease in color from the effluent may be due to the precipitation of the chromophoric materials. The reduction of sorption capacity at higher pH values may be attributed to the competition between OH^- and color anions. Also certain chemical compounds in coffee and tea infusions such as phenols and acids that are proton donors become anions when the solution pH reaches the pKa value of the compound, in which case the adsorption decreases with increase in pH [24].

4.6. Desorption studies

Desorption experiments with distilled water on aqueous coffee and tea infusions produced desorption of 10.2, 8.4, 7.1, and 6.9% for DRC, NCC, AVT, and YLT infusions, respectively. It can be inferred from this data that most of the sorbate molecules were bound to the sorbent surface through a chemical interaction resulting in chemisorption while only a small portion (7–10%) was bound by physisorption.

5. Conclusions

As evidenced in this study, tea and coffee infusions can be decolorized by adsorption onto activated carbon. Around 80–82% of color removal from tea and coffee infusions is achieved by adsorption onto 100 mg/L dosage of activated carbon at room temperature within 2 h of time. The color of the infusion gradually changed from brown to colorless. Isothermal equilibrium adsorption data fitted into Langmuir model confirming the formation of monolayer of the color causing substances during the sorption process and that the nature of sorbent surface is homogeneous. Intraparticle diffusion is quite constant once the resistances are overcome with film diffusion being a major rate limiting step for coffee infusions and pore diffusion being the rate limiting factor for tea infusions. Acidic pH is more suitable for better color removal. The variation from one coffee/tea to other may be attributed to the inherent chemical constitutional differences. The present study has limelighted the fact that adsorption is superior to other processes for removal of color from coffee and tea effluents with high efficiency, minimal time, and therefore adsorption appears to be a promising tool to achieve the target of decolorization cost effectively.

List of symbols

q_e — solid phase concentration at equilibrium (g of color/g of adsorbent)
q_t — average solid phase concentration at time t in min (g of color/g of adsorbent)
k_1 — pseudo-first-order rate constant
k_2 — pseudo-second-order rate constant
k_{id} — intraparticle diffusion rate coefficient
D_f — film diffusion coefficient
D_p — pore diffusion coefficient
a — radius of the spherical adsorbent particle
K_F — Freundlich constant
C_e and $1/n$ — empirical constant related to the magnitude and driving force of adsorption
C — equilibrium concentration of sorbate in mg/L
b — adsorption energy constant of Langmuir adsorption isotherm
Q^0 — maximum amount of adsorption corresponding to complete monolayer coverage

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