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Removal of Pathogenic Bacteria from Water Using Pomegranate Peels

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DESPITE expensive treatment procedures designed to eliminate harmful germs from drinkable water supplies and waterborne illnesses, they still pose a threat to public health. The current investigation is concerned with the removal of Gram-positive and Gram-negative pathogenic bacteria from aqueous solutions. The abundant and inexpensive natural resource, pomegranate dry peel (PDP), and its activated carbon (PDPAC) have been used as bio-adsorbents. Phosphoric acid (30%) was used to chemically activate the carbon at 800 ºC. The optimum contact time was 60min for the dry peel and 40min for the activated carbon at a pH range of 7.0 to 7.5 and 30 to 35ºC processing temperature. The adsorption isotherm of different bacteria was determined for both adsorbents and analyzed by three common isotherm models. The equilibrium results have matched well to the Langmuir equation and the maximal monolayer adsorption capacity was 12500, 14286, 20000, 1000 CFU/g with PDP and 25000, 25010, 33343, 20000 CFU/g with PDPAC for *E. coli, S. enterica, S. aureus*, and *E. faecalis,* respectively. This research can be applied in the treatment stages of water treatment plants, sewage treatment plants, and household filters as a low-cost adsorbent material to remove pathogenic bacteria, antibiotic-resistant bacteria, and damaged DNA.

Keywords: Activated carbon, Adsorption, Bacteria, Isotherm, Pomegranate.

Introduction

Antibiotic-resistant bacteria in water supply systems have become a major public health problem (Kumar et al., 2013). Drinking water tainted with bacteria can result in a variety of health issues, including: fever, exhaustion, vomiting, stomach, eye, skin, and intestinal infections, diarrhea, and sometimes leads to death (Odonkor & Addo, 2018). Filtration, sedimentation, centrifugation, coagulation, and adsorption are some techniques used to remove microorganisms from aqueous solutions. All of these techniques have several drawbacks, such as sludge formation, secondary pollution creation, and high running costs (Shah et al., 2020). The most promising technology is adsorption because of its low cost, high removal rate, simplicity, and ease of operation and design. It is also a green technology since there is no sludge formation or secondary pollution creation during water treatment procedures (Isaeva et al., 2021).

Adsorption is the process by which the dissolved and suspended substances (adsorbate) in a liquid or gas phase, accumulate on the surface of a solid phase (adsorbent) under the action of attraction forces i.e., chemisorption (Yadav & Jagadevan, 2021). In the case of physical adsorption, electrostatic interactions and van der Waal are responsible for the adsorption process. Although

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physical adsorption is generally considered a reversible process, chemical adsorption is considered irreversible because of the presence of functional groups on the surface of adsorbents **(**Chen et al., 2022**)**. Because of its huge surface area, high adsorption capacity and numerous surface functional groups, the activated carbon is a microcrystalline form of carbon and is commonly utilized adsorbent to eliminate polar and nonpolar pollutants from liquid and gas streams (Islam et al., 2022; Srikhaow et al., 2022).

Physical and chemical activation procedures can be used to create activated carbon. Carbonization of raw materials, followed by the activation at elevated temperatures using oxidizing gases such as carbon dioxide, steam, air, or their mixes, is a common method of physical activation (Tejada et al., 2017). Otherwise, chemical activation is achieved by soaking the raw material with activating agents (phosphoric acid, zinc chloride, potassium bicarbonate, sodium hydroxide, or potassium hydroxide) to digest the cellulosic materials and prevent shrinkage during carbonization, then heating the mixture to temperatures ranging from 400°C to 800°C (Vimalkumar et al., 2018). The benefits of chemical activation include lower energy and operational costs, higher carbon outputs, and larger surface areas (Varghese et al., 2013).

The production of carbon-based adsorbents from agricultural wastes represents an interesting design strategy because the precursors are cheap, renewable, safe, abundant and readily available (Soffian et al., 2018). Much of agricultural waste has recently been identified as a societal ecological cost (Stenmarck et al., 2016). Fruit processing generates a substantial quantity of waste, accounting for 25-30% of the entire output. Waste fruit peels, on the other hand, as lignocellulosic biomass-rich materials, have sparked new avenues for the development of renewable, low-cost, and long-term adsorbents for water treatment applications (Plazzotta et al., 2017).

The pomegranate (*Punica granatum* L.) is a deciduous shrub that bears fruit and belongs to the subfamily *Punicoideae* of the *Lythraceae* family. Its height ranges from 5 to 10 meters. Pomegranate cultivation is widespread in the Middle East, the Caucasus, tropical North Africa, the Indian subcontinent, Central Asia, the drier portions of Southeast Asia, and the Mediterranean Basin. The fruit is normally in season from October to February in the Northern Hemisphere and from March to May in the Southern Hemisphere, representing a continual supply of the fruits most of the year. Around 1,500,000 tons of pomegranates are produced worldwide each year, with the peels accounting for 60% of the fruit's weight (Kipçak, 2018; Jafar & Mawlood, 2020).

Numerous academics have investigated the production of activated carbons from pomegranate dry peels and use in the adsorption of different contaminants from aqueous solutions, such as methylene blue (Jawad et al., 2018), pharmaceutical residues (Hashem et al., 2016), heavy metals such as Cu (II) ions (Shah et al., 2020). Other researchers have studied the adsorption of pathogenic bacteria by economic and biodegradable magnetic-coated chitosan (Hussain et al., 2016), commercial activated carbon (Yoon et al., 2008), or activated carbon coated by silver particles (Stewart et al., 1990).

The main objective of this work is to use a low-cost material, pomegranate peels, as an adsorbent for antibiotic-resistant bacteria (*Escherichia coli, Salmonella enterica, Staphylococcus aureus,* and *Enterococcus faecalis).* The aim is extended to produce activated carbon from peels to enhance the process efficiency and study the adsorption equilibrium.

Materials and Methods

Preparation of Pomegranate peels

The fresh pomegranate fruits were collected from the local Mansoura city market and then washed and peeled. The collected peels were washed with tap water and then with bi-distilled water. The peels were cut into small pieces and dried in an electrical oven at 100°C for two days, and then divided into two parts. The first was ground into a fine powder using an electric blender (PDP), then stored in a sealed plastic holder until use. The second was soaked in a 30% phosphoric acid solution for 24h. The mixture was put into a cylindrical stainless-steel box and then, subjected to the carbonization process in a muffle furnace at 400ºC for 30min and finally activated at 800°C for 15min. After the processes of dehydration and carbonization, the produced activated carbon (PDPAC) was ground and then stored in a sealed plastic holder for using as has been recommended by Vimalkumar et al. (2018).

Adsorbed organisms

Four strains of pure culture bacteria strains: *Escherichia coli* ATCC 8739, *Salmonella enterica* ATCC 14028/NCTC 12023 (Gram negative bacteria), *Staphylococcus aureus* ATCC 25923/ NCTC 12981, and *Enterococcus faecalis* ATCC 29212/NCTC 12697 (Gram-positive bacteria) from Tody Laboratories Int. (Bucharest, ROMANIA) were examined. Bacterial cultures from solid media were sub-cultivated in tryptic soy broth and incubated at 35°C for 24h.

Experimental procedures

The batch adsorption experiments for the different pathogenic bacteria onto PDP and PDPAC were performed in 250mL borosilicate bottle by adding 3g of adsorbent (PDP or PDPAC) to 50mL of polluted solution. Preliminary tests were conducted to determine the contact time required for the bacteria-PDP and bacteria-PDPAC systems to reach equilibrium as well as the optimum temperature and medium pH; this data may be used to forecast the operating conditions needed to conduct adsorption isotherms later. Adsorption experiments were conducted at different contact times (5-240min), pH range (5.5-8.5), and different temperatures (15-45ºC). The pH was adjusted by adding either 0.1M HCl or 0.2M NaOH for a desired value that was monitored using a pH meter (Symphony SB70P pH Lab, USA). Different initial bacterial concentration (75-3000 CFU/ mL) was used in this investigation. The various bacterial suspension concentrations were made by comparing them to various (0.5, 1, 2, 3, 4) McFarland turbidity standards inoculated on Petri plates using the pour plate technique. The Petri dishes were incubated for 24 hours at 35°C. The method of McFarland (1907**)** is applied in order to determine the number of colonies. The dilution factor was calculated using the following equation:

CFU= (number of colonies × dilution factor)/ (volume of the culture plate) (1)

The removal efficiency was calculated as well as the number of bacteria adsorbed per unit mass of PDP and PDPAC according to the following equations:

% Removal = [C_O - C_t]/C_O x 100 (2)

$Q_t = ((C_O - C_t)\, V)/M$ (3)

$Q_e = ((C_O - C_e)\, V)/M$ (4)

where, C_o is the initial bacterium concentrations in solution (CFU/ml), C_t is the concentrations of bacteria (CFU/ml) at time *t*, C_e is the bacterium concentration (CFU/ml) at equilibrium, M is the mass (g) of the adsorbent, V is the volume (L) of the solution, and Q_t is the adsorption capacity (CFU/g) at time *t*, and Q_e is the adsorption capacity (CFU/g) at equilibrium.

According to the accepted microbiological techniques, all adsorption experiments were carried out in triplicate in a biosafety cabinet. The equilibrium isotherm data obtained in this study were analyzed using three distinct parameter models: Langmuir, Freundlich, and Temkin. The adsorption isotherm model which simulates and fits well the experimental data is judged by the correlation coefficient (R^2).

Results and Discussion

Effect of contact time

The process time is an essential operating condition that must be determined accurately. A set of tests were conducted to determine the contact time required to achieve adsorbate-adsorbent equilibrium. It is observed that with increasing time, the percentage of removal does; however, after reaching the equilibrium time, the increase is not significant. Figure 1 shows the contact time required for the adsorption process to reach equilibrium with an initial bacterial concentration of 300 CFU/mL. Noting that the adsorption rate increased significantly with the increase in the contact time, and that the adsorption balance was achieved with PDP after 60min, and PDPAC after 40min, but the removal percentage differed according to the type of absorbent material and the type of bacteria. This may be since initially all the sites on the surface of the adsorbent were vacant and the bacterial concentration gradient was relatively high, whereas in the later stage, the binding sites became restricted and the remaining sites were not occupied (Omri et al., 2016). The equilibrium time of activated carbon which was lower than the equilibrium time of dry peels may be due to the high variation of activated site between activated carbon and natural dry peels (Cecen & Aktaş, 2011; Wei et al., 2009; Satti et al., 2020). Therefore, a contact time for each adsorbent was chosen to construct equilibrium adsorption isotherms, as longer contact times might have resulted in undesirable bacterial aggregation in the suspensions.

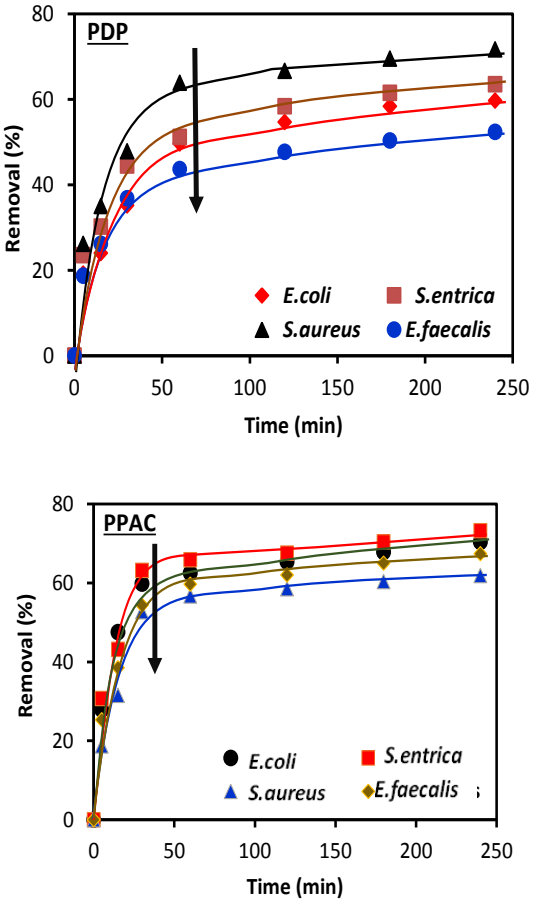


Fig. 1. Equilibrium time for adsorption of *E. coli, S. enterica, S. aureus,* and *E. faecalis* onto PDP and PDPAC

Effect of pH

One of the important factors that can influence on adsorption process, is the pH of the solution. It may be due to the changes in the surface chemistry of the adsorbent as an action of the pH. Thus, it can affect the chemical interaction between the adsorbents and the adsorbates (Pereira et al., 2019). The effect of pH on the adsorption of bacteria onto PDP and PDPAC was studied in the range of 5.5-8.5. Batch experiments were done at an adsorbent dose of 3g, initial bacterial concentration 300 CFU/mL for 2h of contacts at normal temperature (25ºC).

Figure 2 represents the adsorption of the four different bacteria at different values of pH. The results indicate that the adsorption process is highly pH-dependent and at a range of pH 7:7.5, the maximum adsorption capacity was attained. This result may be ascribed to the surface charge of bacteria at natural pH was negative charge due to cell wall peptidoglycans, which make stronger electrostatic interaction between bacteria with PDP and PDPAC, and was the optimum value for a strong bacterial metabolism that facilitates their adsorption capabilities. These results agree with Yee et al. (2000), Guo et al. (2011), Borkowski et al. (2015) and Shah et al. (2020).

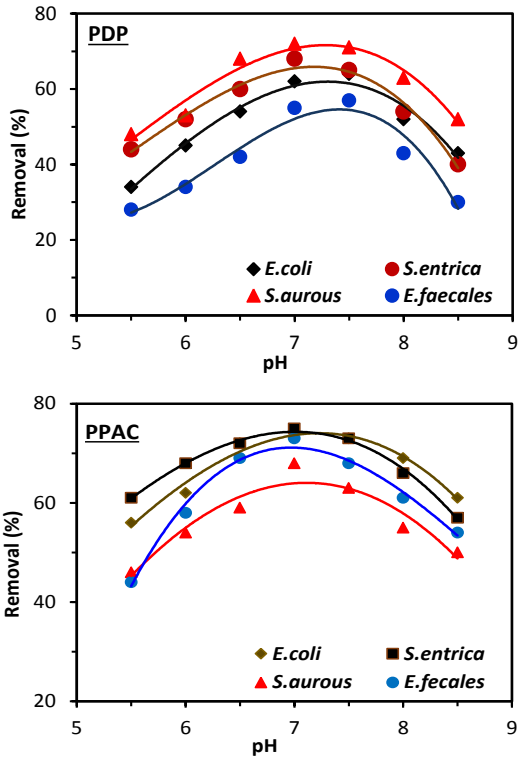


Fig. 2. Effect of pH on removal of *E. coli, S. enterica, S. aureus,* and *E. faecalis* by PDP and PDPAC

Effect of temperature

The physiological state of bacteria governs how much germs adhere to solid surfaces, and a strong bacterial metabolism facilitates their adsorption capabilities (Li et al., 2011). Figure 3 shows the effect of temperature on the adsorption of the four bacteria under investigation. The results indicated that the rate of adsorption enhanced with increasing temperature from 15 to 30°C, Higher temperature has an inverse effect on the removal efficiency. Temperatures between 30 and 35°C exhibited the greatest bacterial adsorption, which means the process's optimum temperature, may be due to it being the optimum temperature range for bacterial growth (Yee et al.,2000; Meng et al., 2001; Guo et al., 2011; Borkowski et al., 2015; Shah et al., 2020).

Equilibrium isotherm

The adsorption isotherm is the most popular way to display the adsorption data and shows how

the adsorbate spreads between the liquid and solid phases in equilibrium (C_e and Q_e), so it is essential for adsorption system design.

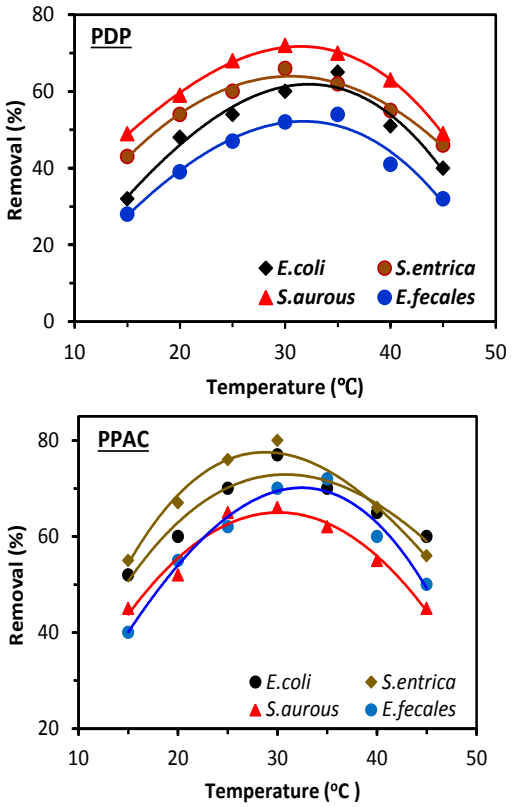


Fig. 3. Effect of Temperature on removal of *E. coli, S. enterica, S. aureus* and *E. faecalis* by PDP and PDPA

Figure 4 shows the isotherms (spreading) of bacteria onto PDP and PDPAC at constant temperature (25ºC) and pH (7.5), whereas the contact time at 60min for PDP and 40min for PDPAC. The plots represent that an isotherm shape can be classified as a relaxed L-shape according to Gilles classification (Jaikaew et al., 2017). It was illustrated that the C_e and Q_e values significantly enhance with the increase of initial bacterial concentration, which indicates the strong effect of the initial concentration of bacteria as a driving force for adsorption, and it may also be due to the surface size and sufficient adsorption sites available for bacteria adsorption. As the available suspended sites decrease, adsorption reduces and the equilibrium occurs (Prachpreecha et al., 2016; Ingole et al., 2017; Satti et al., 2020).

Adsorption models

The validity of the experimental results has been predicted by using a variety of isotherm models. In our work, the adsorption equilibrium data are analyzed by using three of the most popular models, including: the Langmuir, Freundlich, and Temkin isotherms.

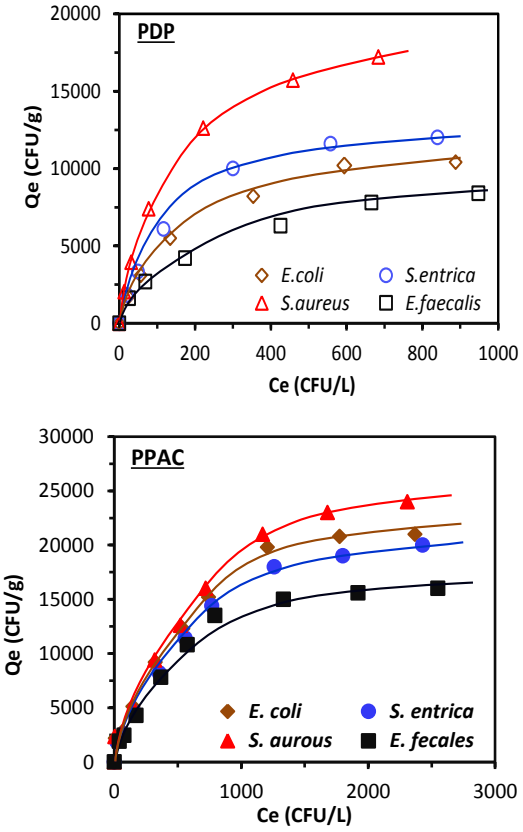


Fig. 4. Equilibrium isotherms for adsorption of *E. coli, S. enterica, S. aureus*, and *E. faecalis* by PDP and PDPAC

Langmuir model

The Langmuir adsorption model suggests that only homogenous, specified spots within the adsorbent can undergo adsorption; once the adsorbate resides, there, no further adsorption can take place, leading to monolayer adsorption on the outer surface of the adsorbent without any interaction between the adsorbed elements (El-Geundi et al., 2005).

One of the linear forms of the Langmuir model is provided by Eq. (5):

$$\frac{C_e}{Q_e} = \frac{1}{Q_{max}\ b} + \frac{C_e}{Q_{max}} \qquad (5)$$

where Ce is the equilibrium concentration (CFU/L), Q_{max} and b are the Langmuir constants

concerned with adsorption capacity and rate of adsorption, respectively. Q_e is the quantity of adsorbate adsorbed per unit mass of adsorbent at equilibrium (CFU/g).

Plotting of C_e/Q_e vis C_e for each bacterium allows for predicting Langmuir constants (Fig. 5). The plots are good straight lines suggesting that the adsorption of pathogenic bacteria onto PDP and PDPAC follows the Langmuir model. The correlation coefficient, R^2, and the Langmuir constants b and Q_{max} have been determined and are given in Table 1. The confirmation of the experimental data into the Langmuir isotherm model shows that the PDP and PDPAC surfaces are homogeneous, meaning that the adsorption activation energies of each bacterium/adsorbent are equivalent. The outcomes also show that bacteria can develop in a monolayer covering on the adsorbent's outer surface. The R^2 values were 0.9969, 0.9977, and 0.9994 for *E. coli, S. enterica*, and *S. aureus,* respectively, that confirms the occurrence of monolayer adsorption on the PDP surface. PDP showed the highest homogenous monolayer adsorption capacity (Q_{max} CFU/gm) with *S. aureus* followed by *S. enterica, E. coli*, and then *E. faecalis.* Moreover, a higher value of surface energy (b CFU/mL) of PDP with *S. aureus, S. enterica, E. coli*, and E. faecalis is 156.3, 97.1, 75.2, and 51.8 CFU/mL, respectively, implied the existence of stronger bonds between bacteria and PDP (Hashem & Amin, 2016; Jawad et al., 2018). In contrast to the value of PDPAC, we discovered that adsorption capacity rose and surface energy reduced, indicating the formation of a strong physisorption link between bacteria and PDPAC and a decrease in Zeta potential.

The essential feature of the Langmuir isotherm can be stated in expressions of dimensionless separation factors and equilibrium parameter (R_L) in order to predict the type of adsorption process defined as presented in Eq. (6):

$$R_L = 1/(1+ Q_{(max)}\ b) \quad (6)$$

The value of R_L indicates the type of isotherm to be irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), linear ($R_L = 1$), or unfavorable ($R_L > 1$) (Wu et al., 2019). The calculated values for R_L for different systems are presented in Table 2 which shows its average values presented in a range of 0:1 confirming the favorability of bacteria uptake by adsorption using both PDP and PDPAC.

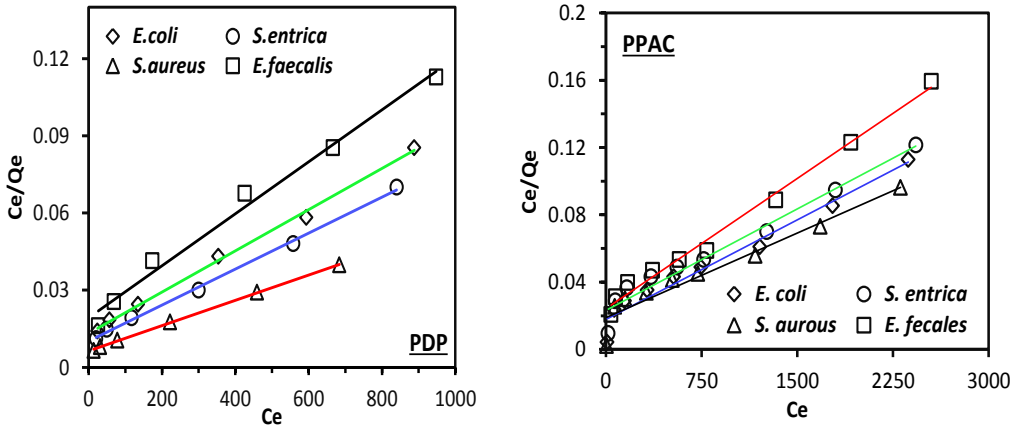


Fig. 5. Langmuir plots for adsorption of *E. coli, S. enterica, S. aureus,* and *E. faecalis* onto PDP and PDPAC

TABLE 1. Langmuir Parameters for adsorption of *E. coli, S. enterica, S. aureus* and *E. faecalis* onto PDP and PDPAC

Strain	PDP			PDPAC		
	Q_{max} (CFU/g)	b (CFU/mL)	R^2	Q_{max} (CFU/g)	b (CFU/mL)	R^2
E. coli	12500	75.2	0.997	25000	56.2	0.996
S. enterica	14286	97.1	0.998	25010	43.3	0.966
S. aureus	20000	156.3	0.999	33343	52.6	0.935
E. faecalis	10000	51.8	0.987	20000	41.3	0.989

TABLE 2. Separation factor (RL) for adsorption of E. coli, S. enterica, S. aureus, and E. faecalis onto PDP and PDPAC

C_0	$R_L = 1/(1+ Q_{(max)}\ b)$							
	E. coli		*S. enterica*		*S. aureus*		*E. faecalis*	
	PDP	**PDPAC**	**PDP**	**PDPAC**	**PDP**	**PDPAC**	**PDP**	**PDPAC**
75	0.6891	0.8558	0.6624	0.9842	0.6305	0.2255	0.7201	0.9641
150	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
300	0.0048	0.0039	0.0050	0.0069	0.0053	0.0009	0.0046	0.0062
600	0.0017	0.0017	0.0017	0.0031	0.0017	0.0001	0.0017	0.0028
900	0.1875	0.2226	0.1816	0.2153	0.1744	0.0856	0.1943	0.2229
1200	0.3337	0.3337	0.3337	0.3040	0.3337	0.3771	0.3337	0.3161
Average	**0.3695**	**0.0025**	**0.3641**	**0.0038**	**0.3576**	**0.0006**	**0.3757**	**0.0035**

Freundlich model

The empirical equation of the Freundlich model is based on adsorption on a heterogeneous surface or surfaces with various affinities (Amer et al., 2017). The relationship between the number of bacteria adsorbed at equilibrium Q_e and equilibrium bacteria concentration C_e was gained from the Freundlich isotherm models as represented in Eq. (7).

$$\ln Q_e = \ln K_F + \frac{1}{\mathrm{n}} \ln C_e \qquad (7)$$

where K_F (CFU/gm) and (1/n) are the Freundlich constants characteristic of the system, where K_F indicating the adsorption equilibrium capacity and (1/n) is the adsorption intensity and indicating the extent of heterogeneity of the sorption system confirming the increases in bond energies with the increases in planar density. Value of (1/n) < 1 indicates normal adsorption and greater heterogeneity, (1/n) > 1 indicates cooperative adsorption (lower heterogeneity), and a favorable sorption process when 1<n>10. Figure 6 shows the plots of ln Q_e vis ln C_e that appears straight lines with a good fitting for all bacteria under investigation.

The model parameters are calculated and reported in Table 3. The estimated values of n are greater than one, indicating that dye adsorption onto both adsorbents is favorable. The K_F values suggest that PDPAC has a high capacity to adsorb *S. aureus* and *E. coli* compared with PDP in contrast PDP has a high capacity to adsorb *S. enterica* and *E. faecalis*.

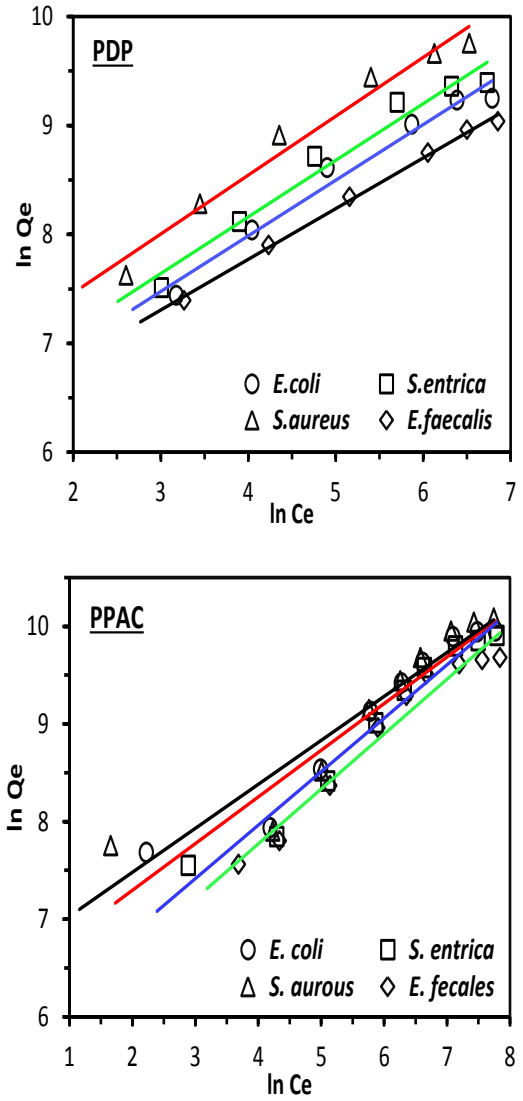


Fig. 6. Freundlich plots for adsorption of *E. coli, S. enterica, S. aureus* and *E. faecalis* onto PDP and PDPAC

TABLE 3. Freundlich parameters for adsorption of *E. coli, S. enterica, S. aureus* and *E. faecalis* onto PDP and PDPAC

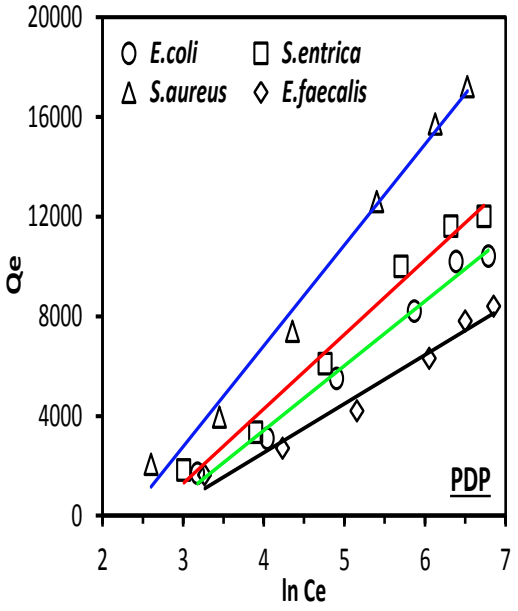
Strain	PDP			PDPAC		
	K_F (CFU/gm)	n	R^2	K_F (CFU/gm)	n	R^2
E. coli	382	1.96	0.9714	568	2.09	0.9445
S. enterica	437	1.92	0.9637	322	1.83	0.9666
S. aureus	590	1.85	0.9714	720	2.22	0.8942
E. faecalis	369	2.15	0.9962	250	1.78	0.9609

Temkin model

The Temkin isotherm model is the third model employed for this study's analysis of equilibrium data. Heat of adsorption of all molecules in the layer decrease linearly with coverage as a result of interactions between the adsorbent and adsorbate; the adsorption is characterized by a uniform binding energy represented by the following linear equation, Eq. (8),

$$Q_e = BlnK_T + BlnC_e \quad (8)$$

where, K_T (CFU/gm) is the equilibrium binding constant corresponding to the maximum binding energy, B=RT/b and b is the Temkin isotherm constant related to the heat of adsorption (kJ/mol) and (1/b) indicates the adsorption potential of the adsorbent. Both K_T and B can be determined from a plot of (Q_e)(CFU/ gm) vs. ln C_e as presented in Fig. 7.



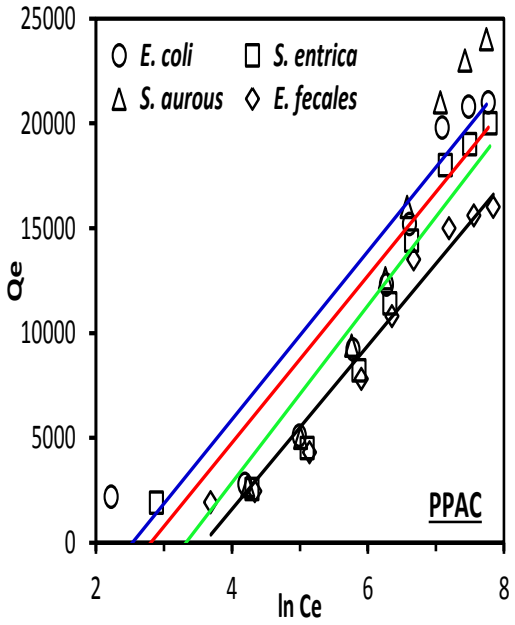


Fig. 7. Temkin plots for adsorption of *E. coli, S. enterica, S. aureus* and *E. faecalis* onto PDP and PDPAC

Table 4 provides a summary of the correlation coefficients and corresponding constants determined for the Temkin model. Comparing data presented in Tables 1, 3 and 4, the Temkin isotherm has a lower correlation coefficient indicating that this model would not be appropriate to describe this process. The Langmuir model's correlation coefficients were nearly one, indicating a better fit to the equilibrium data and a recommendation for the design process. The highest binding energy was found for *E. coli* with PDP as well as for *E. faecalis* with the PDPAC. The lowest heat of sorption was for *S. aureus* in the case of PDP adsorbent while it was for *S. enterica* in the case of PDPAC adsorbent.

TABLE 4. Temkin Parameters for adsorption of *E. coli, S. enterica, S. aureus* and *E. faecalis* onto PDP and PDPAC

Strain	PDP			PDPAC		
	B (kJ /mol)	K_T (CFU/gm)	R^2	B (kJ /mol)	K_T (CFU/gm)	R^2
E. coli	1958.9	14.96	0.9738	3735	13.4	0.8462
S. enterica	2984.3	13.02	0.983	3496	21.2	0.8755
S. aureus	4044.7	10.15	0.9896	4399	14.8	0.878
E. faecalis	2593.3	14.62	0.9875	3572	33.0	0.9017

Models simulation

Using the appropriate constants for the Langmuir, Freundlich and Temkin isotherm models, the theoretical isotherm curves can be predicted using known values of C_e. Figure 8 presents a comparison of experimental data with the used models for *E. coli* as an example to identify which model provides the best fit. The results shown in the figures demonstrate that the Langmuir model greatly outperformed other models in terms of its ability to fit the experimental adsorption data.

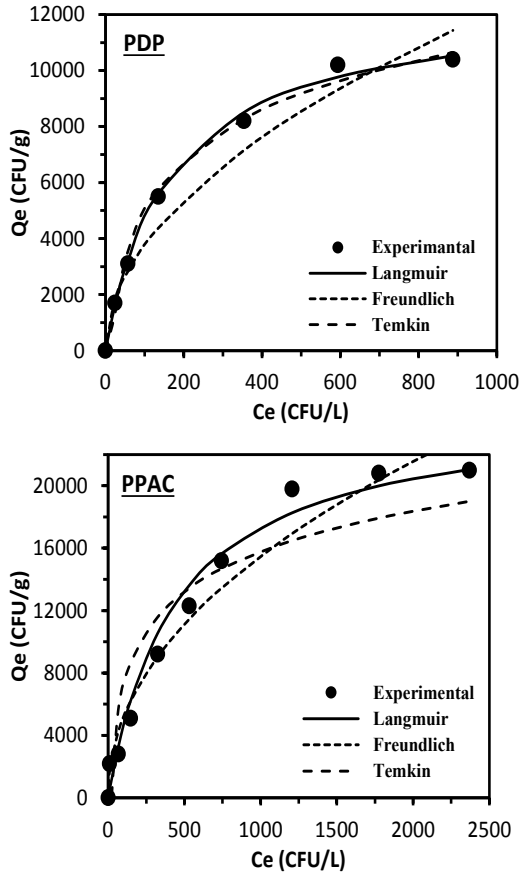


Fig. 8. Comparison of experimental data with theoretical isotherms for the adsorption of *E. coli* onto PDP and PDPAC

Conclusion

PDP and its activated carbon PDPAC are found to be considered efficient low-cost adsorbents to uptake four different Gram-positive and Gram-negative bacteria (*E. coli, S. enterica, S. aureus,* and *E. faecalis*) from the aqueous solutions. The optimum contact time was 60 and 40 min for PDP and PDPAC respectively. High adsorption capabilities were achieved at temperatures between 30 and 35 °C and a pH between 7 and 7.5. The Langmuir, Freundlich, and Temkin adsorption models were used to fit the equilibrium data of related adsorption isotherms, and the associated constants were then determined for the various system conditions. The Langmuir isotherm provided a superior fit where it had the best correlation coefficient when these isotherms were compared with the experimental data. A high affinity of adsorption was found in *S. aureus* compared to other bacteria, being 20000 CFU/g for PDP and 33343 CFU/g for PDPAC.

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Reference

Amer, H., El-Gendy, A., El-Haggar, S. (2017) Removal

of lead (II) from aqueous solutions using rice straw. *Water Science and Technology*, **76**(5), 1011-1021.

Borkowski, A., Szala, M., Cłapa, T. (2015) Adsorption studies of the Gram-negative bacteria onto nanostructured silicon carbide. *Applied Biochemistry and Biotechnology*, **175**(3), 1448-1459.

Cecen, F., Aktaş, Ö. (2011) "*Activated carbon for water and wastewater treatment: Integration of adsorption and biological treatment*". John Wiley & Sons, 306p.

Chen, X., Hossain, M.F., Duan, C., Lu, J., Tsang, Y.F., Islam, M.S., Zhou, Y. (2022) Isotherm models for adsorption of heavy metals from water-a review. *Chemosphere,* **307***,* 135545.

El-Geundi, M.S., Farrag, T.E., El-Ghany, H.A. (2005) Adsorption equilibrium of a herbicide (pendimethalin) onto natural clay. *Adsorption Science & Technology*, **23**(6), 437-453.

Guo, T., Cao, S., Su, R., Li, Z., Hu, P., Xu, Z. (2011) Adsorptive property of Cu2+-loaded montmorillonite clays for Escherichia coli K88 in vitro. *Journal of Environmental Sciences*, **23**(11), 1808-1815.

Hashem, F.S., Amin, M.S. (2016) Adsorption of methylene blue by activated carbon derived from various fruit peels. *Desalination and Water Treatment*, **57**(47), 22573-22584.

Hashem, F.S., Al-Qahtani, K.M., Al-Fawzan, F.F., Alshabanat, M. (2016) Comparative study on activated carbon prepared from various fruit peels. *International Journal of Innovative Research in Science, Engineering and Technology*, **5**(3), 2750-1759.

Hussain, M.A., Al-Ani, M., Al-Khalidi, S. (2016) Adsorption of coliform bacteria from water by activated carbon. *Engineering and Technology Journal*, **34**(9 Part).10.30684 /etj.34.9A.6

Ingole, R.S., Lataye, D.H., Dhorabe, P.T. (2017) Adsorption of phenol onto banana peels activated carbon. *KSCE Journal of Civil Engineering*, **21**(1), 100-110.

Isaeva, V.I., Vedenyapina, M.D., Kurmysheva, A.Y., Weichgrebe, D., Nair, R.R., Nguyen, N.P.T., Kustov, L.M. (2021) Modern carbon–based materials for adsorptive removal of organic and inorganic pollutants from water and wastewater. *Molecules,* **26**(21), 6628.

Islam, M.N., Khatton, A., Sarker, J., Sikder, H.A., Chowdhury, A.S. (2022) Preparation and characterization of activated carbon from Jute Stick by chemical activation: Comparison of different activating agents. *Saudi Journal of Engineering and Technology*, **7**(2), 112-117.

Jafar, S.N., Mawlood, K.A. (2020) Protective role of pomegranate peels and piper longum fruit on the testicular function of thioacetamide-induced reproductive toxicity of male albino rats. *Plant Archives,* **20**(1), 2355-2362.

Jaikaew, P., Malhat, F., Boulange, J., Watanabe, H. (2017) Aspect of the degradation and adsorption kinetics of atrazine and metolachlor in andisol soil. *Hellenic Plant Protection Journal*, **10**(1), 1-14.

Jawad, A.H., Sauodi, M.H., Mastuli, M.S., Aouda, M.A., Radzun, K.A. (2018) Pomegranate peels collected from fresh juice shop as a renewable precursor for high surface area activated carbon with potential application for methylene blue adsorption. *Desalination and Water Treatment,* **124**, 287-296.

Kipçak, A.S. (2018) Investigation of infrared drying of pomegranate by-products. *Journal of Thermal Engineering*, **4**(2), 1821-1827.

Kumar, S., Tripathi, V.R., Garg, S.K. (2013) Antibiotic resistance and genetic diversity in water-borne Enterobacteriaceae isolates from recreational and drinking water sources. *International Journal of Environmental Science and Technology*, **10**(4), 789-798.

Li, L., Gao, M., Liu, J., Guo, X. (2011) Removal of airborne microorganisms emitted from a wastewater treatment oxidation ditch by adsorption on activated carbon. *Journal of Environmental Sciences*, **23**(5), 711-717.

McFarland, J. (1907) The nephelometer: an instrument for estimating the number of bacteria in suspensions used for calculating the opsonic index and for vaccines. *Journal of the American Medical Association*, **49**(14), 1176-1178.

Meng, J., Feng, P., Doyle, M.P. (2001) Pathogenic Escherichia coli. *Compendium of Methods for the Microbiological Examination of Foods*, **4**, 331-341.

Odonkor, S.T., Addo, K.K. (2018) Prevalence of multidrug-resistant *Escherichia coli* isolated from drinking water sources. *International Journal of Microbiology*, 7204013-7. https://doi.org/10.1155/2018/7204013.

Omri, A., Wali, A., Benzina, M. (2016) Adsorption of bentazon on activated carbon prepared from Lawsonia inermis wood: Equilibrium, kinetic and thermodynamic studies. *Arabian Journal of Chemistry*, **9**, S1729-S1739.

Pereira, R.C., Anizelli, P.R., Di Mauro, E., Valezi, D.F., da Costa, A.C.S., Zaia, C.T.B., Zaia, D.A. (2019) The effect of pH and ionic strength on the adsorption of glyphosate onto ferrihydrite. *Geochemical Transactions*, **20**(1), 1-14.

Plazzotta, S., Manzocco, L., Nicoli, M.C. (2017) Fruit and vegetable waste management and the challenge of fresh-cut salad. In: "*Trends in Food Science and Technology*", Vol. 63, Elsevier Ltd, pp. 51–9.

Prachpreecha, O., Pipatpanyanugoon, K., Sawangwong, P. (2016) A study of characterizations and efficiency of activated carbon prepared from peel and bunch of banana for methyl orange dye adsorption. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, **10**, 17-26.

Satti, Z., Akhtar, M., Mazhar, N., Khan, S.U., Ahmed, N., Yasir, Q.M., Ahmad, W. (2020) Adsorption of cadmium from aqueous solution onto untreated gypsum rock material: Equilibrium and kinetics. *Biointerface Research in Applied Chemistry,* **11**, 10755-10764.

Shah, K.H., Yameen, M.A., Yousaf, T., Waseem, M., Fahad, M., Sherazi, T.A., Ahmad, H. (2020) Adsorption of bacteria by highly efficient, economic and biodegradable magnetic coated chitosan adsorbent. *Journal of Solution Chemistry*, **49**(11), 1304-1318.

Soffian, M.S., Halim, F.Z.A., Aziz, F., Rahman, M.A., Amin, M.A.M., Chee, D.N.A. (2022) Carbon-based material derived from biomass waste for wastewater treatment. *Environmental Advances,* 100259. DOI:10.1016/j.envadv.2022.100259

Srikhaow, A., Chaengsawang, W., Kiatsiriroat, T., Kajitvichyanukul, P., Smith, S.M. (2022) Adsorption kinetics of imidacloprid, acetamiprid and methomyl pesticides in aqueous solution onto Eucalyptus Woodchip derived Biochar. *Minerals*, **12**(5), 528.

Stenmarck, A., Jensen, C., Quested, T., Moates, G., Buksti, M., Cseh, B., et al. (2016) "*Estimates of European Food Waste Levels*". IVL Swedish Environmental Research Institute (Sweden), 79p.

Stewart, M.H., Wolfe, R.L., Means, E.G. (1990) Assessment of the bacteriological activity associated with granular activated carbon treatment of drinking water. *Applied and Environmental Microbiology*, **56**(12), 3822-3829.

Tejada, C.N., Almanza, D., Villabona, A., Colpas, F., Granados, C. (2017) Caracterización de carbón activado sintetizado a baja temperatura a partir de cáscara de cacao (*Theobroma cacao*) para la adsorción de amoxicilina. *Ingeniería Y Competitividad*, **19**(2), 45-54.

Varghese, S., Kuriakose, S., Jose, S. (2013) Antimicrobial a`ctivity of carbon nanoparticles isolated from natural sources against pathogenic Gram-negative and Gram-positive bacteria. *Journal of Nanoscience*, ID 457865, 5 pages.

Vimalkumar, A., Thilagan, J., Rajasekaran, K., Raja, C., Flora, M.N. (2018) Preparation of activated carbon from mixed peels of fruits with chemical activation (K2CO3)–application in adsorptive removal of methylene blue from aqueous solution. *International Journal of Environment and Waste Management*, **22**(1-4), 260-271.

Wei, G.U., Sun, C.J., Qi, L.I.U., Cui, H.X. (2009) Adsorption of avermectins on activated carbon: Equilibrium, kinetics, and UV-shielding. *Transactions of Nonferrous Metals Society of China*, **19**, s845-s850.

Wu, Q., Xian, Y., He, Z., Zhang, Q., Wu, J., Yang, G., Long, L. (2019) Adsorption characteristics of Pb (II) using biochar derived from spent mushroom substrate. *Scientific Reports*, **9**(1), 1-11.

Yadav, K., Jagadevan, S. (2021) Adsorbents for removal of fluoride from water. In: "*Green Technologies for the Defluoridation of Water*", pp. 89-118. Elsevier.

Yee, N., Fein, J.B., Daughney, C.J. (2000) Experimental study of the pH, ionic strength, and reversibility behavior of bacteria–mineral adsorption. *Geochimica et Cosmochimica Acta*, **64**(4), 609-617.

Yoon, K.Y., Byeon, J.H., Park, C.W., Hwang, J. (2008) Antimicrobial effect of silver particles on bacterial contamination of activated carbon fibers. *Environmental Science & Technology*, **42**(4), 1251-1255.

إزالة البكتيريا المسببة للأمراض من الماء باستخدام مواد ماصة بيولوجية عالية الكفاءة ومنخفضة التكلفة

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على الرغم من طرق المعالجة الباهظة المصممة للقضاء على الجراثيم الضارة من إمدادات المياه الصالحة للشرب، فإن الأمراض التي تنقلها المياه تشكل مع ذلك تهديدًا للصحة العامة. تعنى هذه الورقة بإزالة البكتيريا الممرضة إيجابية الجرام وسالبة الجرام من المحاليل المائية. باستخدام الموارد الطبيعية الوفيرة وغير المكلفة حيث تم استخدام قشر الرمان الجاف (PDP) والكربون المنشط (PDPAC) كمواد ماصة بيولوجية. تم استخدام حامض الفوسفوريك (30٪) لتنشيط الكربون كيميائيا عند 800 درجة مئوية. كان وقت التلامس الأمثل 60 دقيقة للقشر الجاف و 40 دقيقة للكربون المنشط عند pH تتراوح من 7.0 إلى 7.5 ومن 30 إلى 35 درجة مئوية في درجة حرارة العملية. تم تحديد درجة حرارة الامتزاز للبكتيريا المختلفة لكل من الممتزات وتم تحليلها بواسطة ثلاثة نماذج متساوية الحرارة الشائعة. تمت مطابقة نتائج التوازن بشكل جيد مع معادلة لانجمويير وكانت السعة القصوى لامتصاص الطبقة الأحادية 12500، 14286، 20000 و 1000 CFU/جم مع قشور الرومان الجاف و 25000، 25010، 33343 و20000 CFU/ جم مع *E. Coli* ، *S. enterica* ، *S. aureus* و *E. faecalis*.