Original Article

Adsorption of gas-phase n-hexane and benzene, toluene, ethyl benzene, and xylene onto compost; kinetics and isothermal studies

Mohammad Mehdi Amin, Bijan Bina, Amir Rahimi[1], Mohsen Heidari[2,3]

Environment Research Center, Research Institute for Primordial Prevention of Non-communicable Disease, Isfahan University of Medical Sciences (IUMS), Isfahan, Iran and Department of Environmental Health Engineering, School of Health, IUMS, Isfahan, Iran, [1]Chemical Engineering Department, College of Engineering, University of Isfahan, Isfahan, Iran, [2]Department of Environmental Health Engineering, Student Research Center, School of Health, Isfahan University of Medical Sciences (IUMS), Isfahan, Iran, [3]Department of Environmental Health Engineering, Faculty of Health, Hormozgan University of Medical Sciences, Bandar Abbas, Iran

ABSTRACT

Aims: In this study, the potential capability of compost in the simultaneous adsorption of gas-phase n-hexane and benzene, toluene, ethyl benzene, and xylene (BTEX) was studied.

Materials and Methods: Batch adsorption technique was used to assess the adsorption properties of compost. The pseudo-first and pseudo-second order kinetics were considered in order to identify the possible mechanism of the adsorption process. Moreover, the suitability of the adsorbent was evaluated using Langmuir, Freundlich and The Dubinin-Radushkevich isotherm models.

Results: After 24 h contact time, the adsorption capacity of one g compost was 1.42 mg n-hexane and BTEX for initial concentration of 7.74 mg/l. The adsorption capacities were in order of n-hexane < benzene < toluene < ethylbenzene < xylene. This order is in accordance to the ascending octanol-air partitioning coefficient (K_{OA}) order of the compounds (the lowest for n-hexane and the highest for xylene). The kinetics data proved a closer fit to the pseudo-second order model, while the isotherm experimental data were a good correlation to both Freundlich and Langmuir models.

Conclusion: The experimental data show that a material with an organic matrix, that is, raw compost, has a higher adsorption capacity for the gaseous compounds with higher K_{OA}. Overall look to the results of this study indicates that although the raw compost could adsorb gaseous n-hexane and BTEX, its capacity may not be sufficient for the continuous removal of VOCs from the air in the compost-based biofilters, in which biodegradation play a key role.

Key words: Adsorption, benzene, toluene, ethyl benzene, and xylene, compost, n-hexane

Address for correspondence:
Dr. Mohsen Heidari,
Department of Environmental Health Engineering,
Environment Research Centre, School of Health,
Isfahan University of Medical Sciences, Hezar Jerib Ave, Isfahan, Iran.
E-mail: moheidari84@gmail.com

INTRODUCTION

Volatile organic compounds (VOCs) are considered to be some of the most hazardous air pollutants emitted from a variety of sources including industries and automobiles. These compounds, though in most cases are used in their liquid form, have the potential to vaporize at significant rates

into the ambient atmosphere.[1] Among VOCs, benzene, toluene, ethyl benzene, and xylene (BTEX) and n-hexane are common components of many solvent mixtures and are mainly used in textile, polymer and varnishing industries. They are among the main air pollutants emitted from petrochemical industries.[2-4] BTEX account for up to 59% (w/w) of gasoline pollutants.[5,6] They are well-known VOCs of environmental and health concern. Benzene is a well-known carcinogen that has also been linked to leukemia. Chronic exposure to xylene and toluene has been associated with adverse effects on the nervous system, liver and the kidneys while chronic exposure to ethylbenzene has adverse effects on the respiratory system and the kidneys.[5,7,8] Over-exposure to n-hexane has been related to dizziness and drowsiness and peripheral neuropathy of hands and feet.[9]

Due to the ubiquity of VOCs in the environment and risk to human health, it is necessary to limit and control their emissions. The control techniques are broadly classified into two types: Destruction (thermal oxidation, catalytic oxidation, biofiltration) and recovery (adsorption, membrane separation, condensation).[10,11] Adsorption is a reliable process to remove organic compounds from industrial waste gases and in some applications, to recover recyclable materials from process exhaust streams.[12,13] Besides, adsorption and absorption phenomena are believed to be effective in the performance of biofilters, especially under transient conditions or shock loading since adsorption along with absorption may act as a buffer for biological activity.[14]

Activated carbon is the most common material used extensively for the adsorption of various VOCs from the air.[13] Some studies have been done on the adsorption capacity of other adsorptive materials, including diatomaceous earth (toluene),[15] fibrous peat and ground tire rubber (GTR) (n-butyl acetate, toluene, m-xylene),[16] zeolite (acetone and toluene),[17] porous metal-organic frameworks (VOCs),[18] and polymeric resin (trichloroethylene and benzene).[10] Recently, Mohammadi-Moghadam *et al.* reported that Glycyrrhiza glabra Root (GGR) could adsorb around 2.2 mg/g toluene from the air under batch tests.[19] Compost has also been used for the adsorption of different gas-phase pollutants.[20,21] Moreover, it is a well-known packing material in biofiltration process, in which adsorption may play a role in the removal of VOCs.

To help evaluate the performance of a sorbent in the removal of gaseous-phase pollutants, it is important to understand the isotherm and kinetic characteristics between the adsorbent used and adsorbate.[13] The sorption of a gas-phase adsorbate onto a solid adsorbent is typically studied through three methods; namely: (a) Static volumetric method, (b) dynamic column method, and (c) gravimetric method.[22] Moreover, there are some studies that evaluate the adsorptive properties of packing material, usually used in biofiltration system, through simple batch tests.[16,19,23] This test is basically similar to static volumetric method. In this method, sorbent media are placed in an airtight chamber/reactor with an initial gas concentration inside. As adsorption occurs, the gas-phase concentration decreases until an equilibrium state is reached. In static volumetric method, the gas-phase adsorbate concentration calculated through appropriate pressure-volume-temperature measurement,[22] while in batch test the gaseous concentration is measured through direct sampling.

To the best of our knowledge, there appears to be relatively little information in the literature concerning multicomponent adsorption of VOCs on compost through batch test. Compost is a common filter media in the biofiltration of VOCs. In the other hand, adsorption phenomenon may have a significant role in the removal of gas-phase VOCs along with biodegradation within biofilm. Therefore, in this study, the potential capability of raw compost in simultaneous adsorption of common VOCs, including n-hexane and BTEX was explored. This may illustrate the scale of adsorption in compost-based biofilters treating the tested pollutants. Moreover, the effects of parameters such as contact time and adsorbate concentration on adsorption capacity were investigated. To describe the adsorption of n-hexane and BTEX onto compost, different adsorption kinetic and isotherm models fitted to the experimental data.

MATERIALS AND METHODS

Materials
Compost was provided from Isfahan Compost Company. Benzene (≥99%), toluene (99.5%), ethylbenzene (≥99%), xylene (99.5%) and n-hexane were purchased from Merck Co. The physicochemical properties of n-hexane and BTEX are presented in Table 1.[24-28]

Preparation of the adsorbent
Compost was sieved through a 2-mm sieve to remove large particles and then sieved through a 1-mm sieve. Undesirable components such as glass and plastic were then removed manually. The sieved compost was presterilized at 120°C for 15 min in an autoclave and dried at 100°C for 24 h in the oven and subsequently cooled at room temperature in desiccators for 1 h.

Analytical methods
The concentrations of gaseous n-hexane and BTEX were analyzed by a gas chromatograph equipped with flame ionization detector (GC-FID) (Agilent GC, 7890A). The column used was an Agilent 19091S-433 capillary column, 30 m × 250 μm × 0.25 μm. The GC-FID method for the determination of BTEX and n-hexane was optimized as follows:

- Injected sample volume: 100 μl,
- Carrier gas: Helium (purity 99.995%) with flow of 1.11 ml/min,
- Fuel gas: H$_2$ (30 ml/min),
- Detector temperature: 250°C,
- Oven temperature: 50°C for 1 min and increased with the rate of 10°C/min to 150°C for 10 min (total run time: 11 min).

To achieve calibration curve, known amounts of the compounds were injected into a glass bottle sealed with Teflon septum according to the standard procedure.[29] Then, air samples were drawn from the bottles with a 1 ml gas tight syringe (Hamilton, USA), and directly injected into the GC.

Adsorption experiments

Batch adsorption experiments were carried out to determine the effect of parameters such as contact time and adsorbate concentration on the adsorption of gas-phase n-hexane and BTEX onto compost. All of the adsorption experiments were carried out in sterilized 250 ml glass bottles with PTFE airtight cap contained 1 g adsorbent. For the determination of isotherm properties, liquid compounds were injected into the bottles to obtain overall gas-phase concentrations of 1.68-16.12 mg/l and maintained at 25°C ± 1°C. The bottles were shaken by a rotary shaker at 300 rpm. After given time intervals, an aliquot of polluted gas was analyzed for the organic pollutants by GC-FID. The experiments were duplicated, and their average values were calculated. Blank samples (BTEX and n-hexane mixture without the adsorbent) were also used to determine the value of the components loss. The blank recoveries were calculated (80-93%) and the data were adjusted for them. The amount of the gaseous compounds that are adsorbed on the adsorbent can be expressed as follows:

$$q_e = \frac{(C_o - C_e)\ V}{m} \tag{1}$$

where q$_e$ (mg/g) is the adsorption capacity of compost for the compounds, C$_0$ (mg/l) is the initial gas-phase concentration of compounds, C$_e$ (mg/l) is the equilibrium gas-phase concentration of the compounds, *m* (g) is the mass of the compost, and V (l) is the volume of the gas (or volume of the bottle, the adsorbent volume is negligible).

RESULTS

Effects of contact time

The adsorbed mass of n-hexane and BTEX per mass of compost (mg/g) in relation to the adsorbent-adsorbate contact time (t in hours) is presented in Figure 1. In general, the adsorption of the tested pollutants on the adsorbent was increased over time.

Adsorption kinetics

In this study, the experimental data obtained for the simultaneous adsorption of gaseous n-hexane and BTEX onto compost were fitted through two kinetic models including pseudo-first order and pseudo-second order models. The general form of the pseudo-first order kinetic is shown by the following equation:[30]

$$q_t = q_e\left(1 - e^{-k_1 t}\right) \tag{2}$$

With a linear form of

$$\ln\left(q_e - q_t\right) = \ln q_e - k_1 t \tag{3}$$

where q$_e$ (mg/g) and q$_t$ (mg/g) are the adsorbed quantity of n-hexane and BTEX at equilibrium and at time (t),
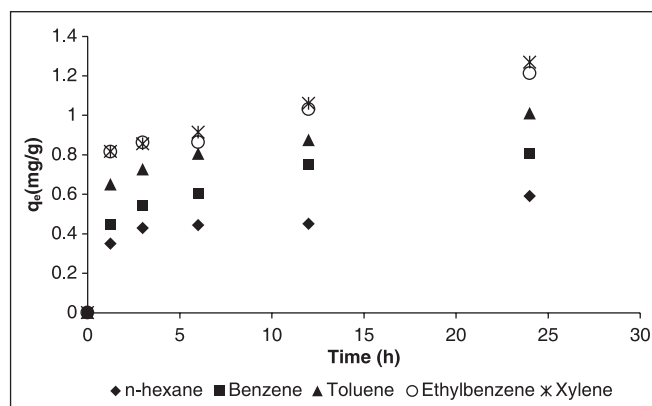

Figure 1: The effects of contact time on n-hexane and benzene, toluene, ethyl benzene, and xylene adsorption by the compost (compost weight = 1 g, initial concentration = 24.4 mg/l)

Table 1: Physiochemical properties of n-hexane and BTEX compounds

Characteristics	n-hexane	Benzene	Toluene	Ethylbenzene	Xylene
Formula	CH$_3$ (CH$_2$)$_4$CH$_3$	C$_6$H$_6$	C$_6$H$_5$CH$_3$	C$_6$H$_5$CH$_2$CH$_3$	C$_6$H$_4$(CH$_3$)$_2$
Molecular weight (g/mol)	86.17	78.11	92.14	106.16	106.16
Water solubility at 20°C (mg/l)	9.5	1790	526	169	162
Boiling point (°C)	68.5	80	111	136	138
Vapor pressure at 25°C (mmHg)	124	75	21	7	9
Log octanol-water partition coefficient, log K$_{OW}$ (K$_{OW}$)	3.90 (7943.3)	2.13 (134.7)	2.73 (537.03)	3.15 (1412.5)	3.15 (1412.5)
Log air-water partition coefficient, log K$_{AW}$ (K$_{AW}$)	1.867 (73.62)	−0.644 (0.227)	−0.566 (0.272)	−0.492 (0.322)	−0.550 (0.282)
Log octanol-air partition coefficient, log K$_{OA}$ (K$_{OA}$)	2.033 (107.9)	2.774 (594.3)	3.296 (1977.3)	3.642 (4386.6)	3.700 (5008.9)

BTEX: Benzene, toluene, ethyl benzene, and xylene

respectively. k_1 (1/h) is the pseudo-first order rate constant. k_1 and q_e values can be obtained by plotting $\ln(q_e - q_t)$ against t.

The experiment data were also analyzed by pseudo-second order model. This adsorption kinetic is shown by the following equation:[30]

$$q_t = \frac{q_e^2 k_2 t}{1 + q_e k_2 t} \tag{4}$$

With a linear form of

$$t/q_t = 1/(k_2 q_e^2) + t/q_e \tag{5}$$

where q_e and q_t defined already for the pseudo-first order model. k_2 (g/mg/h) is the pseudo-second order rate constant. k_2 and q_e can be obtained by plotting t/q_t versus t in Eq (5).

The experimental data obtained for the adsorption of gas-phase n-hexane and BTEX by compost at different time intervals were correlated with the above mentioned kinetics, which are presented in Figure 2. The values of regression coefficients obtained from the fitting the experimental data to the pseudo-first order and pseudo-second order kinetic models were in the range of 0.513-0.944 and 0.976-0.995, respectively. Furthermore, the pseudo-first and pseudo-second order kinetics presented overall equilibrium adsorption capacities of 2.88 mg and 5.10 mg n-hexane and BTEX per g dry compost, respectively [Table 2].

Adsorption capacity

In order to determine the adsorption isotherm (next section), it is necessary to evaluate the adsorption capacity of the adsorbent at various initial concentrations of adsorbate. The adsorption capacity of compost was assessed for initial n-hexane and BTEX concentrations ranged from 1.68 to 16.12 mg/l at 25°C after 24 h contact time. The overall adsorption capacities (q_e) of the pollutants are presented in Table 3.

Adsorption isotherms

The Langmuir adsorption isotherm, the Freundlich model and the Dubinin-Radushkevich (D-R) isotherm model are evaluated for the results of the adsorption

experiments.

The general form of this isotherm is given by[30]

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \tag{6}$$

The linearized form of the Langmuir isotherm equation is written as

$$\frac{1}{q_e} = \frac{1}{K_L q_m C_e} + \frac{1}{q_m} \tag{7}$$

where q_e is quantity of n-hexane and BTEX adsorbed onto the dry support (mg/g), C_e is the equilibrium gas-phase concentration (mg/l), q_m is the monolayer or maximum adsorption capacity of the adsorbent (mg/g), and K_L is the Langmuir adsorption constant (l/mg) and is related to the free energy of adsorption.
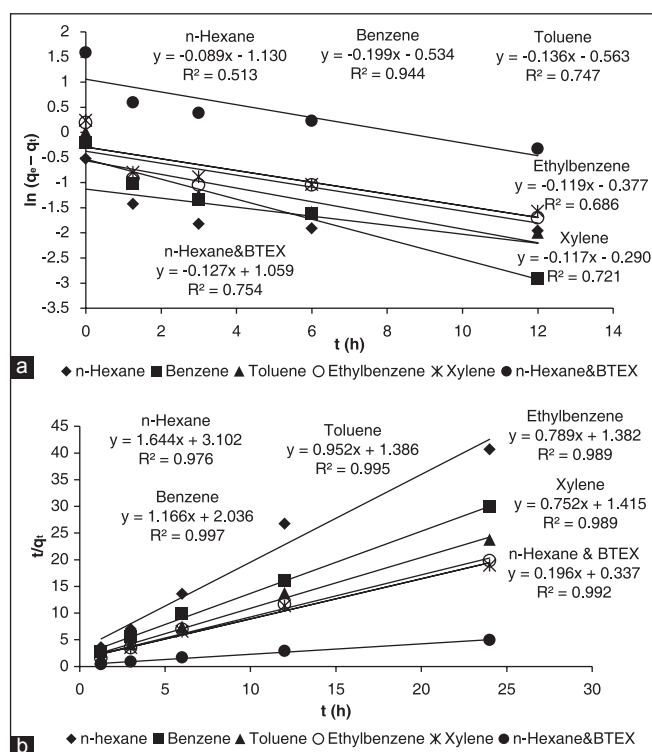

Figure 2: (a) The pseudo-first order and (b) pseudo-second order kinetic fitted to the experimental data

Table 2: Parameters of pseudo-first order and pseudo-second order kinetics obtained from this study						
Adsorbate	**Pseudo-first order**			**Pseudo-second order**		
	k_1	q_e	R^2	k_2 (g/mg/h)	$q_{e,\,calculated}$ (mg/g)	R^2
n-hexane	0.09	0.32	0.513	0.87	0.61	0.976
Benzene	0.20	0.59	0.944	0.67	0.86	0.997
Toluene	0.14	0.57	0.747	0.65	1.05	0.995
Ethylbenzene	0.12	0.69	0.686	0.45	1.27	0.989
Xylene	0.12	0.75	0.721	0.40	1.33	0.989
n-hexane and BTEX	0.13	2.88	0.754	0.11	5.10	0.992

BTEX: Benzene, toluene, ethyl benzene, and xylene

The general form of Freundlich isotherm can be written as:[30]

$$q_e = K_F C_e^{1/n} \tag{8}$$

With a linearized form of

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \tag{9}$$

where K_F (mg/g [l/mg]$^{1/n}$) and n are parameters characteristic of the adsorbent-sorbate system, which must be determined by data fitting. They are indicative of the extent of adsorption and the degree of nonlinearity between gaseous concentration and adsorption and show the capacity and intensity of the adsorption, respectively.

The linear form of D-R isotherm can be shown as:[19]

$$in q_e = in q_m - \beta \grave{O}^2 \tag{10}$$

where q_m (mg/g) is the theoretical saturation sorption capacity, β (kJ/mol) related to mean adsorption energy and ε is the Polanyi potential which is related to the equilibrium concentration as follows:

$$RT \ln(1 + 1/C_e) \tag{11}$$

where R is the gas constant (0.008314 kJ/mol/K) and T is the absolute temperature.

The experimental data for various equilibrium gaseous adsorbate concentrations were fitted to the linear Langmuir, Freundlich and D-R models through plotting $1/q_e$ versus $1/C_e$ [Figure 3a], C_e/q_e versus C_e [Figure 3b] and $\ln q_e$ versus ε^2 [Figure 3c], respectively. The regression coefficients obtained from the fitting the experimental data to the Langmuir, Freundlich and D-R isotherm equations were in the ranges of 0.970-0.981, 0.975-0.988, and 0.733-0.853, respectively. The isotherm constants and correlation coefficients of the adsorption of n-hexane and BTEX onto compost are calculated and presented in Table 4.

DISCUSSION

The effect of contact time

Figure 1 shows that the adsorption of n-hexane and BTEX was rapidly increased during first 75 min (n-hexane = 59%, Benzene = 55%, toluene = 64%, ethylbenzene = 67% and xylene = 64%) and then they continue to increase at a relatively low speed with contact time up to 24 h. The higher rate of adsorption at the beginning of the adsorption time may be due to the availability of abundant adsorption sites, which are reduced as the time goes forward.[19] It must also consider that the available adsorbate concentration is reduced over time.

Adsorption kinetics

Adsorption kinetic models are used generally to determine the controlling mechanism of adsorption and the efficiency of the adsorbents for the removal of pollutants.[4,31] As is evident in

Table 3: The capacity of various materials in the adsorption of VOCs

Gas-phase adsorbate	Adsorbent	Contact time (h)	Initial concentration (mg/l)	Adsorption capacity (mg/g)	Study
n-hexane and BTEX	Compost	24	1.68	0.40	This study
			3.36	0.66	
			7.74	1.43	
			11.2	2.21	
			16.12	3.51	
Toluene	Fibrous peat	48	10	4.3	[16]
Toluene	GTR**	48	10	22.1	[16]
m-xylene	Fibrous peat	48	10	12.6	[16]
m-xylene	GTR	48	10	95.5	[16]
Toluene	GGR*	12	6.93	2.2	[20]
Hexane	perlite	72	10	0.19	[24]

*Glycyrrhiza glabra root, **Ground tire rubber. BTEX: Benzene, toluene, ethyl benzene, and xylene, VOCs: Volatile organic compounds

Table 4: Langmuir, Freundlich and D-R isotherm parameters for the simultaneous adsorption of n-hexane and BTEX onto compost

Adsorbate	Langmuir isotherm			Freundlich isotherm		D-R isotherm	
	q_m (mg/g)	K_L (l/mg)	R_L	K_F (l/g)	n	q_m (mg/g)	E (kj/mol)
n-hexane	0.84	0.24	0.51	0.16	1.07	0.35	1.82
Benzene	1.03	0.26	0.50	0.21	1.09	0.43	1.88
Toluene	1.23	0.28	0.48	0.27	1.09	0.50	2.02
Ethylbenzene	1.63	0.26	0.50	0.35	1.05	0.59	2.10
Xylene	1.70	0.26	0.50	0.36	1.05	0.60	2.11
n-hexane and BTEX	6.41	0.05	0.51	0.29	1.07	2.08	0.75

BTEX: Benzene, toluene, ethyl benzene, and xylene, D-R: Dubinin-Radushkevich
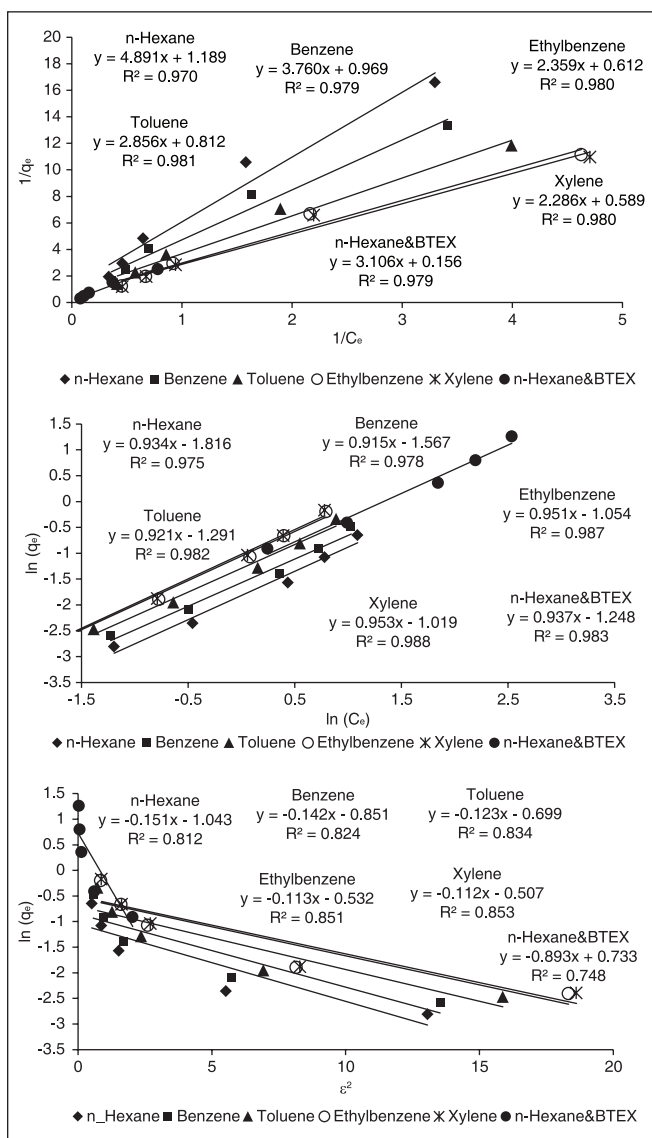
Figure 3: (a) Langmuir isotherm model, (b) Freundlich isotherm model, and (c) Dubinin-Radushkevich isotherm model for the simultaneous adsorption of n-hexane and benzene, toluene, ethyl benzene, and xylene onto compost

the Figure 2a and b, the experimental data for each of adsorbates examined best fit the pseudo-second order kinetics model, providing correlation coefficient (R^2) values higher than that of pseudo-first order. The comparison between the experimental adsorption capacity obtained from the contact time effect experiments (q_{exp}: 4.88 mg/g) and the calculated adsorption capacity (q_{cal}: 5.1 mg/g) [Table 2] shows that the q_{cal} value is close to q_{exp} value for the pseudo-second order kinetics. Also, the q_e values obtained by pseudo-second order model were in order of n-hexane < benzene < toluene < ethylbenzene < xylene which is in agreement with that obtained experimentally.

Adsorption capacity

The adsorption capacity of the compost was increased by the increasing gas-phase n-hexane and BTEX concentrations.

This may be due to an increase in driving forces including van der Waal's force to the active sites of the adsorbent that originated from high concentrations of the compounds.[19] In this study, the initial concentrations ranged from 1.68 to 16.12 mg/l was selected to evaluate adsorption capacity of compost at various concentrations and to determine the adsorption isotherm. Hernández-Meléndez *et al.* applied the gas-phase hexane concentrations ranged from 4 to 24.8 mg/l to determine adsorption isotherm of this compound onto various biofilter bed materials. They selected the initial concentration of 10 mg/l to compare adsorption capacity of various filter bed materials.[23] Moreover initial concentration of 6.93 mg/l and 10 mg/l VOCs have been used to evaluate adsorption capacity of various filter bed materials.[16,19] The ranges of applicable inlet concentration of VOCs for biological air treatment and adsorption systems are usually up to 5 and 10 mg/l, respectively.[32] Therefore, the initial concentration of 7.74 mg/l is a conservative measure to evaluate the adsorption capacity of compost as a biofilter bed material. At this concentration, the adsorption capacities were in the order of n-hexane (0.21 mg) < benzene (0.25 mg) < toluene (0.28 mg) < ethylbenzene (0.34 mg) < xylene (0.35 mg). This order may be related to the different affinity of the gaseous species to the organic matter (based on K_{OA}) and approximately molecular weight [Table 1].

The octanol-air partition coefficient (K_{OA}) is the ratio of a chemical concentration in octanol to that in air at equilibrium. It is useful for predicting the partitioning behavior between air and solid matrices. It is possible to estimate K_{OA} from the octanol-water partition coefficient (K_{OW}) and air-water partition coefficient (K_{AW}) as:[33]

$$K_{OA} = K_{OW}/K_{AW} \tag{12}$$

As shown from Table 1, the K_{OA} values for the subjected compounds are in the order of n-hexane (2.033) < benzene (2.774) < toluene (3.296) < ethylbenzene (3.642) < xylene (3.700). The higher K_{OA}, the higher tendency of gas-phase species to the organic matrices.[33]

According to Table 3, for initial gas-phase n-hexane and BTEX concentration of 7.74 g/m³, the overall adsorption capacity of compost was 1.43 mg/g. With respect to the initial concentration of gaseous adsorbates, contact time and adsorbate type reported in other studies, it is approximately concluded that the capacity of compost for the adsorption of VOCs is lower than GTR, GGR, and fibrous peat and higher than perlite [Table 3].[16,19,23] Oh *et al.* in a study focused on the adsorptive properties of biofilter packing materials on toluene removal reported that the compost adsorbs lower gaseous toluene than that of the GTR and significantly lower than that of the GAC.[20] However, compost is a well-known and good media in the biofiltration of VOCs, in which the elimination capacities as high as 180 g VOCs/m³/h have been reported.[34] In general, this adsorption capacity of compost

does not guarantee the effective continuous and long-term removal of VOCs in compost-based biofilters, in which biological degradation play a key role. In Oh *et al.* study, it was concluded that the adsorption capacity of the packing materials would have been exhausted within a day and the removal of toluene relied primarily on biological degradation after the 1st day of operations.[20]

Adsorption isotherms

The equilibrium adsorption isotherm is fundamental to describe the interactive behavior between the adsorbate and the adsorbent and is useful for designing any sorption system.[4,35] For the interpretation of the isotherm determination experimental data, three yet very frequently applied isothermal models were used in their linear form: (1) The Freundlich model, (2) the Langmuir model and (3) the (D-R) isotherm. The Langmuir adsorption isotherm is fundamentally used for the sorption of gases on a solid surface. This isotherm assumes that the adsorption occurs at specific homogeneous sites within the adsorbent and has found successful application in many studies of monolayer adsorption.[36] This isotherm predicts the maximum monolayer adsorption capacity of the adsorbent.[4,19] The Freundlich model is an empirical expression that assumes a heterogeneous adsorbent surface with sites that have different energies of adsorption and are not equally available. The Freundlich isotherm model is usually explained for multilayer adsorption on a heterogeneous adsorbent surface. It is more widely used but provides no information on the monolayer adsorption capacity, in contrast to the Langmuir model.[36,37] The D-R is more generally used to distinguish between physical and chemical adsorption.

With respect to the regression coefficients presented in Figure 3, both Freundlich and Langmuir isotherms were well adapted to the description of n-hexane and BTEX adsorption on compost. It is reported in some studies that the adsorption of toluene, m-xylene and n-butyl acetate onto fibrous peat and GTR,[16] toluene onto GGR,[19] and hexane onto peat moss and pine sawdust[23] are described well by the freundlich equation. Delhomenie *et al.* in a study conducted on the adsorption of toluene on the compost-based pellets in a bench-scale biofilter (i.e., dynamic column method) reported that both Langmuir and frundlich models are valid to describe the adsorption equilibrium.[21]

The essential characteristic of the Langmuir isotherm can be described by the equilibrium parameter, R_L, calculated by:

$$R_L = \frac{1}{(1 + K_L C_0)} \qquad (13)$$

where K_L is the Langmuir constant and C_0 is the initial gaseous compound concentrations (mg/l). R_L is a dimensionless factor

used to determine whether the adsorption process is favorable or unfavorable. The adsorption process for $0 < R_L < 1$, $R_L > 1$, $R_L = 1$, and $R_L = 0$ are favorable, unfavorable, linear, and irreversible, respectively.[36]

Moreover, the extent of Freundlich isotherm exponent, n, specify the intensity of the adsorption process; the higher values of n (more than 1) the stronger adsorption bond between adsorbent and adsorbate.[4] The n and R_L values calculated to be >1 and between 0 and 1, respectively, for the adsorption of all gaseous compounds onto compost [Table 4], indicating that the adsorption of the n-hexane and BTEX onto compost is favorable.

In order to determine the type of adsorption process, it is necessary to determine the mean adsorption energy, E (kJ/mol) that is related to the β constant obtained from D-R isotherm as

$$E = \frac{1}{\sqrt{2\beta}} \qquad (14)$$

The value of E determines the type of adsorption process, as the physical and chemical adsorptions are occurred at E < 8 kJ/mol and E > 16 kJ/mol, respectively. The chemical ion exchange generally occurred at E values between 8 and 16 kJ/mol.[4,19] As seen from Table 4, the E values are below 2.11 kJ/mol, indicate that the adsorption of gaseous n-hexane and BTEX onto compost has physical nature. The E value reported by Mohammadi-Moghadam *et al.* for the adsorption of gaseous toluene onto GGR was 1.38 kJ/mol, that is, physical adsorption was occurred.[19]

CONCLUSION

In this study, simultaneous adsorption of gas-phase n-hexane and BTEX onto the raw compost was explored. The adsorption capacity decreases in the following order: xylene → ethylbenzene → toluene → benzene → n-hexane with an overall adsorption capacity of 1.43 mg n-hexane and BTEX per g dry compost (initial concentration = 7.74 mg/l). The adsorption of gaseous n-hexane and BTEX onto the raw compost was well described by the pseudo-second order kinetic. The Freundlich and Langmuir models well fitted to the experimental data, providing n and R_L values slightly more than one and between 0 and 1, respectively, indicating the adsorption process is favorable. Generally compost is a relatively potential adsorbent for the removal of gas-phase n-hexane and BTEX. Its capacity increase as the octanol-air partitioning coefficient (K_{OA}) of adsorbates increases. It may be also concluded that the adsorption capacity provided by compost may not be sufficient for the continuous removal of VOCs from air in compost-based biofilters compared to biological degradation.

ACKNOWLEDGMENTS

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