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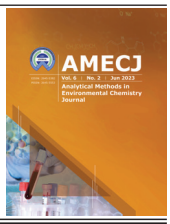

Analysis of Toluene: Removal of toluene from the air stream using a bed made of metal-organic frameworks adsorbent

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ABSTRACT

Toluene is one of the most dangerous and, simultaneously, the most consumed substances in various factories. Toluene strongly affects the central nervous system. The numerous side effects caused by exposure to toluene indicate the removal of toluene vapours from the air in the workplace. This study aims to use the removal of toluene vapours from the air using a Fe-MOFs metal-organic substrate for the first time in the world and to investigate efficient methods to increase the efficiency of removing toluene vapours from the air. This experimental study was carried out on a laboratory scale. After the iron metal-organic framework (Fe-MOFs) was synthesized, the components affecting the adsorption rate, such as reaction time (5-20 min), initial concentration (100-400 mg L^{-1}), adsorbent amount, and temperature (25-80°C) were analyzed and optimized. Then, the efficiency of removing toluene vapours from the air was determined using a gas chromatography device. The absorption capacity of toluene was obtained by the desired adsorbent, 337.2 mg g^{-1}. Also, the effect of different parameters on toluene absorption was investigated and optimized. The maximum absorption for concentration (300 mg L^{-1}), temperature (75°C), and contact time (160s) were obtained as 340 mg g^{-1}, 331 mg g^{-1}, and 325 mg g^{-1}, respectively. The obtained results indicate the suitability of the Fe-MOFs for the absorption of toluene vapours from the air before being determined by gas chromatography (GC-FID).

1. Introduction

The growth of industry, along with its important tools for humans, leads to overproduction and subsequent problems such as global warming, the ozone layer, acid rain, ultraviolet radiation, and its consumption. And it has become dust [1, 2]. The diversity of work and profession increases day by day the number of health-threatening factors and, following that, occupational diseases and professional risks. Achieving a healthy environment for doing work will not be possible except by knowing the factors and causes that endanger the health of the environment and occupational safety and trying to neutralize the effects of these factors [3]. The development of the urban population and rapid economic growth has created serious challenges in maintaining clean air. Since the sources of air pollution are increasing daily, the air quality of cities has become a public concern [4]. Today, toluene, as one of the main air pollutants in indoor and outdoor environments, is considered

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one of the important environmental and occupational concerns that can come from mobile sources (for example, cars and trucks) and stationary sources (such as industrial facilities) to be released [5]. Indoor air quality (IAQ) is one of the important issues in the field of health that has received attention in recent years with changes in life patterns. Today, we spend more than 70 to 90% of our time in indoor environments such as homes, offices, industrial workplaces, subways, cars, etc.. The air quality in such environments has an important impact on health. IAQ is affected by various gaseous and particulate pollutants, among which volatile organic compounds (VOC) have a special place [6,7]. Recently, many adsorbents such as ionic liquids (ILs), TerphApm@ MWCNTs as a novel heterogeneous sorbent, bismuth oxide-fullerene nanoparticles (Bi_2O_3-Cf NPs), task-specific ionic liquid coated on MWCNTs (IL-MWCNTs), bismuth oxide coupled to heterogeneous graphene/graphene oxide by UV photo-catalectic degradation-adsorption process (Bi_2O_3-NG/NGO/UV), hydroxyethylnmethylimidazolium tetrafluoroborate immobilized on MWCNTs(TSIL-MWCNTs), nano-palladium embedded on the mesoporous silica nanoparticles (Pd-MSN), magnetic nanoparticles coated with nickel-doped silica (Fe_3O_4-Ni-SiO_2), Thiol modified bimodal mesoporous silica nanoparticles (SH-MSN), and functionalized bimodal mesoporous silica nanoparticles (UVM7) were used for the adsorption /removal of VOCs, BTEX, and organic compounds, in different matrixes such as air, water, and human samples [8-17]. These compounds are associated with a wide range of health effects due to their high vapour pressure, diffusion capacity, and respiratory exposure to volatile organic compounds; Therefore, it is important to control respiratory exposure to these compounds in indoor environments [18]. Volatile organic compounds form a major group of pollutants released from various sources. They include more than 300 types of different chemical compounds, among which benzene, toluene, ethylbenzene, and xylene (BTEX) are the most important and common compounds of air pollutants and, as representative Volatile organic compounds, have been considered in experimental studies. These compounds are found in different quantities in the workplace, cities' air, and industrial areas. The presence of these pollutants in the air has created a toxic atmosphere that allows the occurrence of many diseases and cancers. Toluene (methylbenzene) is an aromatic compound with a benzene ring, a benzene branch, and a methyl branch with properties similar to benzene but less volatile [19,20,21,22,23]. One of the important pathogenic effects of toluene (C_7H_8) is the effect on the central nervous system, which is in the form of anesthesia, stimulation with a feeling of euphoria and happiness, followed by loss of balance, tremors, feeling Ringing in the ears, blurring of vision, delirium, inability to control voluntary muscles and convulsions and finally coma [24]. In some scientific sources, it is stated that toluene does not cause blood toxicity [25], or there is no definitive evidence of permanent blood injuries and diseases due to exposure to toluene [26,27]; But in other sources, the hematological toxicity of toluene has been mentioned and blood effects such as reduction of white blood cells, lymphocytosis, macro-cytosis, eosinophilia, hypochromic and in severe cases, aplastic anemia. It has been reported due to exposure to toluene [28,29]. Toluene is widely used in the military, chemical, and automotive fuel industries. Most air purification studies consider it a representative of volatile organic compounds [30]. This compound is produced in a significant amount due to the consumption of fossil fuels. It is also used in industries as a solvent in preparing paints, glue, rubber, and plastic or in producing various chemical compounds. Toluene is also widely used in the pharmaceutical industry as feed in chemical processes, wall paint production, sprays and antifreeze production [31]. Human data on the absorption of toluene through the gastrointestinal tract are unavailable. However, studies on toluene in rats have shown complete absorption in the body; however, it is slower than absorption through the gastrointestinal tract Inhalation. In general, organic solvents enter the

body through inhalation. At the same time, their exposure to the skin only slightly helps their transfer and entry into the body of living organisms. The liver carries out the metabolism of many organic solvents. At normal occupational exposure levels, the hepatic clearance of many solvents is related to the hepatic blood flow, which is caused by the hepatic extraction ratio (the ratio between the amount metabolized and delivered to the liver). Considering the effects of toluene on human health and the environment, various methods such as chemical and physical absorption, thermal and catalytic oxidation, and advanced oxidation process are used to remove it from polluted air, many of which are used in The field of chemical agents of the work environment in occupational health as well as environmental health is carried out in the form of laboratory and experimental research [32]. In many studies that have been conducted so far in connection with the measurement of pollutants such as toluene, benzene, xylene, and ethylbenzene, the method provided by the American National Occupational Safety and Health Organization (NIOSH 1501) has been used. In general, this instruction comprehensively describes the sampling methods of volatile organic compounds such as toluene, benzene, ethylbenzene, and xylene [33]. Additive control methods are broadly divided into two categories: chemical decomposition and physical recovery to control the emission of volatile organic compounds, which can be used according to the conditions of the pollutant and the fluid containing the pollutant, the available facilities, and the required control efficiency. Each pollutant control method has the most efficiency and application according to the pollutant-carrying air flow rate and pollutant density for a specific range, which should be considered in the selection stage of the control method. Among the control methods, condensation, thermal and catalytic oxidation, surface absorption, deep absorption, and biological methods are more common [34]. Surface adsorption is a phenomenon carried out by physical or chemical methods in the active adsorption sites on the absorbent surface. The efficiency of the adsorption process depends on the special surface of the absorbent and the possibility of creating a strong and stable reaction between the chemical substance and the absorbent surface. In physical adsorption, molecules are held on the absorbent surface based on weak van der Waals forces; While in chemical adsorption, the relatively strong forces between the molecule and the adsorption site are responsible for the absorption and maintenance of the molecule on the surface of the adsorbent [35]. Metal-organic frameworks (MOFs), as a broad class of crystalline materials with extremely high porosity (up to 90% free volume) and large internal surface areas exceeding 6000 m^2 g^{-1}. These properties, together with the great variability of their structure's organic and inorganic components, have been shown to make organometallic frameworks for potential applications in clean energy, as important storage devices for gases such as hydrogen and methane, and as capacitive adsorbents. Above, favours. Adsorbents are becoming increasingly important to meet various needs such as separation, additional applications in membranes, thin film devices, catalysis, and biomedical imaging. At a fundamental level, metal-organic frameworks show the beauty of chemical structures and the power of organic and inorganic chemistry [36]. Among the organometallic framework (MOF) applications, we can mention energy storage, separation, catalytic role, and application in sensor devices. This study used the Fe-MOFs adsorbent to evaluate toluene adsorption from the air before being determined by GC-FID.

2. Material and Methods

2.1. Chemicals and equipment

The desired goals in this research were done after collecting the required information and reviewing the texts. Also, the necessary arrangements were made with the tools and materials needed to perform the various steps. All materials used in this research were purchased from Merck, Germany. The toluene liquid (CAS Number: 108-88-3, Sigma Aldrich, Germany) was used as a standard solution. Standard toluene solutions were prepared with concentrations of 0.1, 0.5, 5.0, 10, 20, 50,200,

and 500 µg L-1 for the calibration curve. The other reagents, such as acids, bases, acetone, and ethanol, were purchased from Sigma (Germany). The Zabol University laboratory synthesized the Fe-MOFs. The nitric acid (HNO_3; CAS Number: 7697-37-2), H_2SO_4 (CAS Number: 7664-93-9), and acetone (CAS Number: 67-64-1) were purchased from Sigma, Germany. Toluene standard curves were prepared daily. The residual measurement of toluene was performed by a GC-3800 gas chromatography made by Shimadzu, Japan, using a 1000 microliter Hamilton injection syringe (GC-FID, made in America).

2.2. Research implementation method

This study was conducted on samples of airflow contaminated with toluene in several phases as follows:

2.2.1. Preparation of absorbent

The adsorbent used in this research was synthesized and prepared by the following solvothermal method: A 1:1 molar ratio of Fe $(NO_3)_3.9H_2O$ and terephthalic acid were mixed in 40 ml DMF under vigorous stirring for 1 hour. Then 2.0 ml of trimethylamine was added with stirring for 1hrs. These mixtures were stirred for 2 hrs and then transferred into an autoclave at 120°C for 4 hrs. The formed precipitate was filtered by centrifuge at 3000 rmp, washed, then added to 100 ml chloroform and stood overnight. Finally, the Fe-MOFs were filtered and dried at 60° C in a vacuum oven for 6 hrs. (Schema 1).

2.2.2. Absorption study

The experiment method was similar to the technique used in the research of Rezaei et al. In this way, to check the adsorbent's efficiency in removing toluene from the air, the experiments were designed and performed by changing one variable at any time. Three variables, residence time (20-5 minutes), toluene concentration (400-100 parts per million), and air temperature (25-100 degrees Celsius), were investigated as practical, functional components in the absorption process. A Pyrex cylindrical reactor with a continuous flow from the bottom to the top, 50 cm high and 1 cm in diameter, in which a grid plate was installed 10 cm from the bottom of the reactor, was

Schema 1. Preparation of Fe-MOFs by solvothermal method

used for the experiments. The absorber is placed on this mesh screen. An air pump generates airflow. Two heating elements surround the reactor and regulate the airflow temperature. A 500 ml Erlenmeyer flask was used to produce the desired concentrations. To adjust the temperature of the Arlene solution, it is placed inside a container of water. A thermometer measured the water temperature. The air stream entered this Erlen with a flow rate of 1.5 litres per minute, and the mixture of air and toluene exited from another pipe towards the reactor. To ensure the complete mixing of the pollutant with the airflow before the reactor, a glass chamber was installed where the mixture of air and toluene entered this chamber.

A valve that allows the passage of air and toluene mixture is placed after the chamber. A rotameter was used to adjust the airflow rate. Airflow was sampled before and after entering and exiting the mix of air and toluene in the reactor. NIOSH standard method was used for toluene sampling. In this way, a sampling pump with a flow rate of 100 mL min^{-1} and for 30 seconds using a charcoal tube made by SKC was used. 2.0 ml of CS_2 solution was used to extract the samples. The percentage of toluene removal was obtained by Equation 1. The adsorption capacity of the adsorbent was determined from Equation 2.

$$\%R = (C0 - CI) / C0 \times 100 \quad \textbf{(Eq.1)}$$

$$Q = (C0 - Ci) \times V / m \quad \textbf{(Eq.2)}$$

Co is the initial concentration, and ***Ci*** is the final concentration of toluene. ***V*** indicates the volume of the solution in litres, and ***m*** indicates the amount of adsorbent in grams.

2.2.3.Measuring with GC

First, the toluene calibration curve was drawn. Different concentrations of toluene between 50 and 500 parts per million were made to illustrate the calibration curve. To analyze the samples, a Shimadzu gas chromatography device with a flame ionization detector with a column length of 30 meters and a diameter of 0.32 meters and helium carrier gas was used according to method 6220 according to the standard. The temperature of the injection site was 200°C, and the column temperature in this device increased from 35°C to 120°C at a rate of 20°C per minute. Finally, the calibration curve is drawn according to the area under the peaks obtained from the GC device and the concentration of the standards (Fig.1).

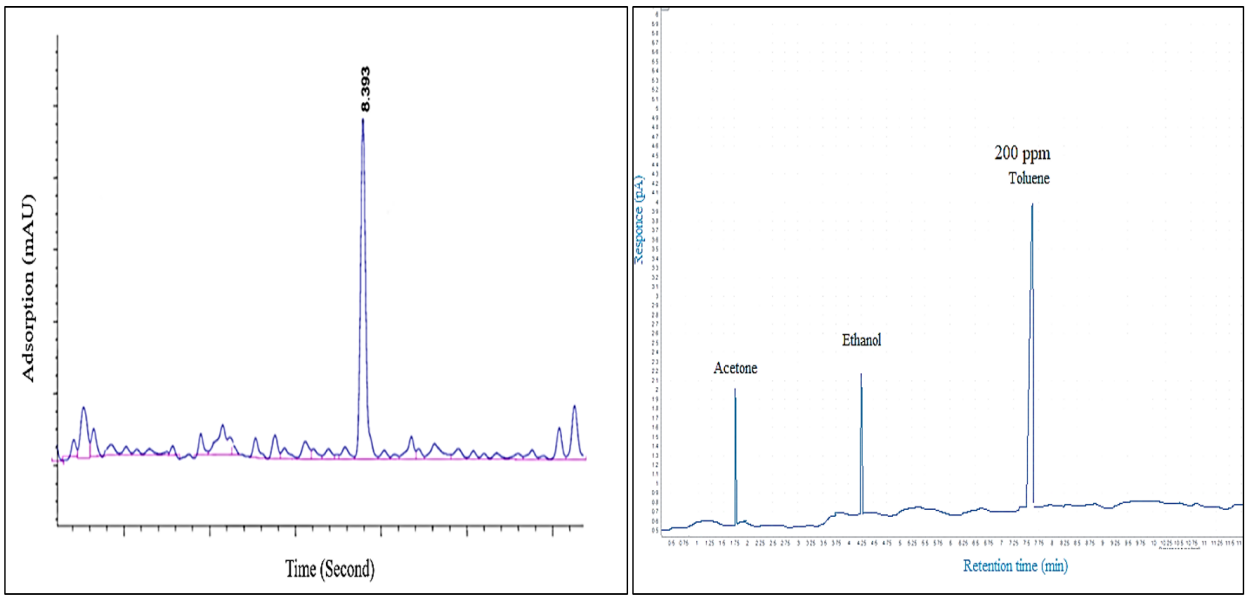

Fig. 1. Chromatogram diagram resulting from injection of 200 parts per million for toluene

3. Results and Discussion

3.1. Characteristics of organometallic framework absorber

The electron microscope image of the iron-based organometallic framework absorber can be seen in Figure 2. The SEM can see the regular structure of the obtained iron-based organometallic framework. In addition, the sample has an average particle size of 32 nm. Figure 3 shows the image of the absorber structure's X-ray diffraction (XRD) spectrum. Some peaks of Fe-MOFs sorbent appeared at 2θ = 5.34, 6.73, 9.63, 11.60,12.88,13.67, 14.80, 20.30 and 23.34°which indicate that the Fe-MOFs were formed. These patterns agree with simulated patterns (JCPDS 087-0453), which show the cubic crystal system of the final product.

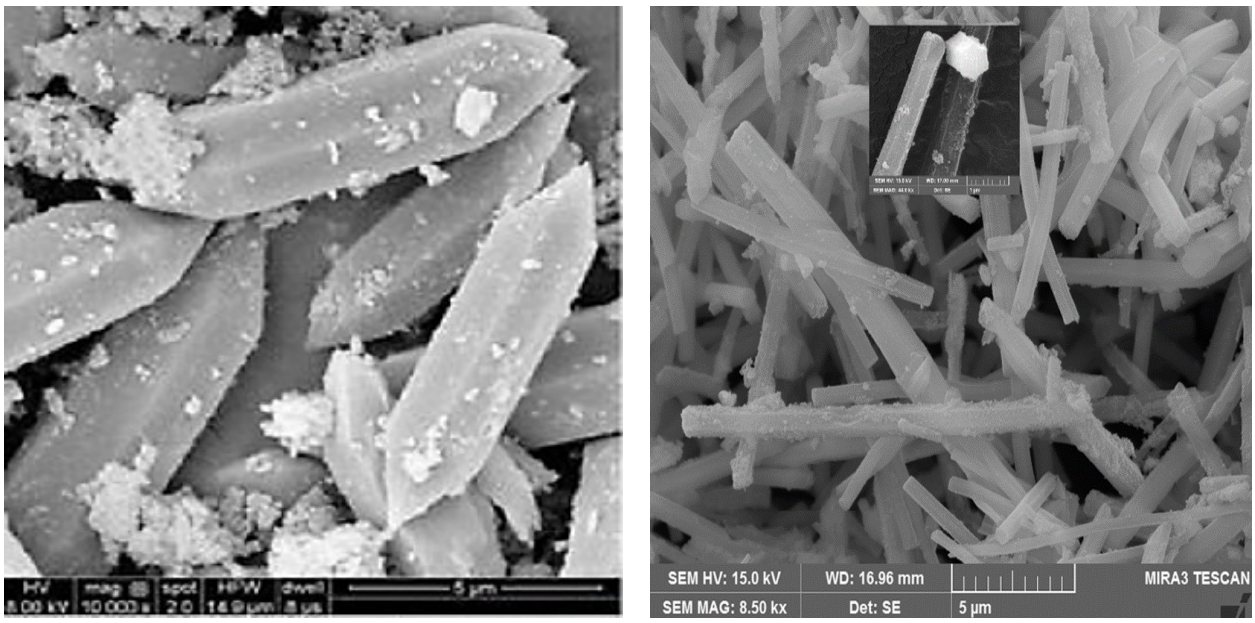

Fig. 2: Image of absorbent surface morphology by SEM

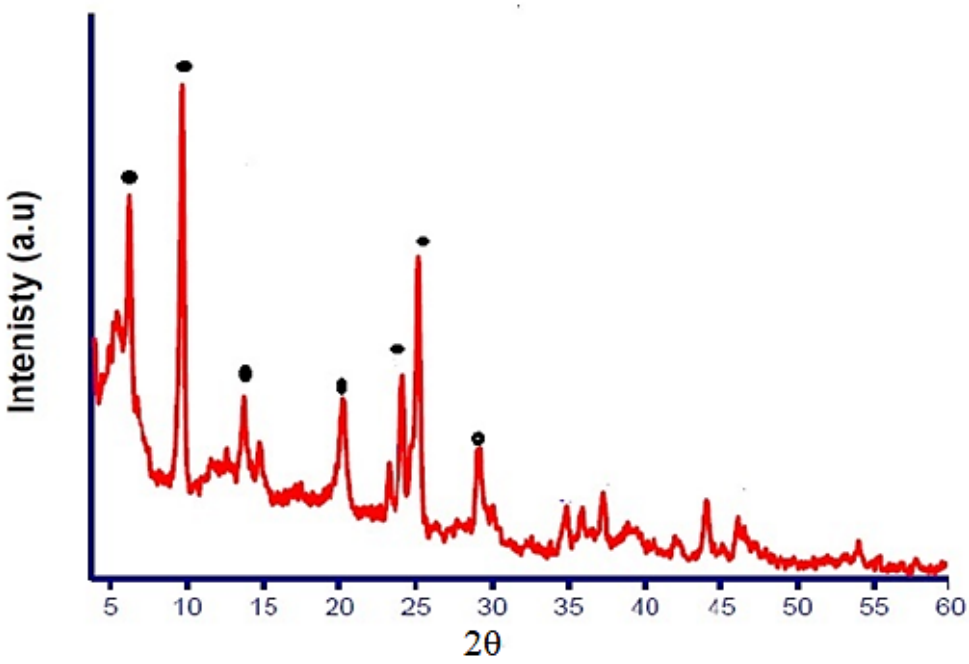

Fig.3. X-ray diffraction spectrum of the absorber structure

3.2. Toluene calibration curve

Different concentrations between 50 and 500 parts per million (ppm; mg L^{-1}) of toluene were made to plot the toluene calibration curve.

3.3. Investigating the components affecting the absorption of toluene

3.3.1. The effect of the initial concentration of toluene on the absorption capacity

Figure 4 shows the impact of the initial concentration of toluene on the adsorption capacity of the iron-based organometallic framework adsorbent. In all the experiments, the reactor's temperature was 25°C, and the airflow time was one minute. As the number of absorbents increases, the amount of absorption also increases. As can be seen from the figures, the maximum absorption of toluene was obtained at 300 mg L^{-1}(ppm). After that, the adsorbent is saturated.

3.3.2. Effect of reaction time on absorption efficiency

The effect of reaction time on the absorption efficiency of toluene by iron-based organometallic framework adsorbent can be seen in Figure 5. In all experiments, the reactor's temperature was 25 °C, and the initial concentration of toluene was 300 parts per million (ppm; mg L^{-1}). The maximum absorption of toluene is obtained in 150 seconds.

3.3.3. Effect of temperature on absorption efficiency

The effect of temperature on the amount of toluene absorption can be seen in Figure 6. The maximum amount of absorption is obtained at a temperature of 75 degrees Celsius.

3.3.4. Investigating the kinetics of toluene absorption on the adsorbent

Adsorption kinetics is used to determine the control mechanism of surface adsorption processes such as surface adsorption, chemical reaction, or permeation mechanisms (Fig.7). In the first-order kinetic model, it is assumed that the rate of change of the solute extraction with time is directly proportional to the changes in the saturation concentration and the amount of absorption of the absorbent with time. The linear form of the first-order kinetics is shown in Equation 3.

$$\mathrm{Ln}\,(q_{eq} - q) = \ln q_{eq} \frac{k1\,t}{2.303} \qquad \textbf{(Eq.3)}$$

q and $\mathbf{q_{eq}}$ (mg g^{-1}) is the amount of toluene absorbed per gram of adsorbent at time **t** and in the equilibrium state. $\boldsymbol{K_1}$ is the first-order kinetic constant (min^{-1}). Assuming that the changes are linear, $\boldsymbol{K_1}$ is determined from the slope of the graph of ln (q_{eq} – q) versus t.

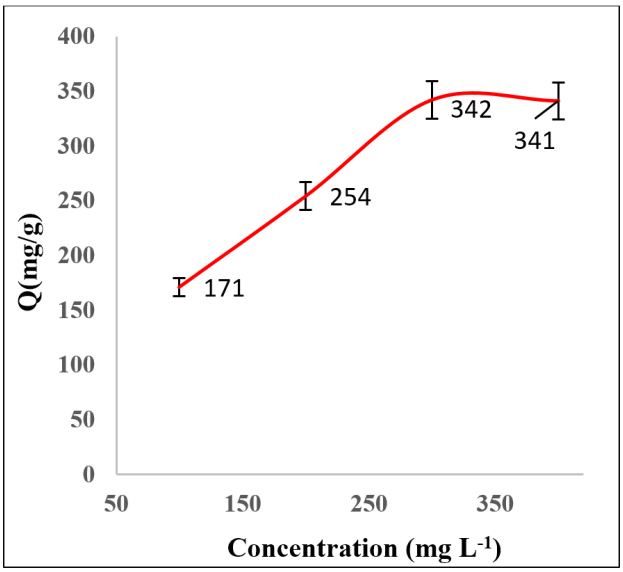

Fig. 4. The effect of the initial concentration of on the absorption efficiency of toluene

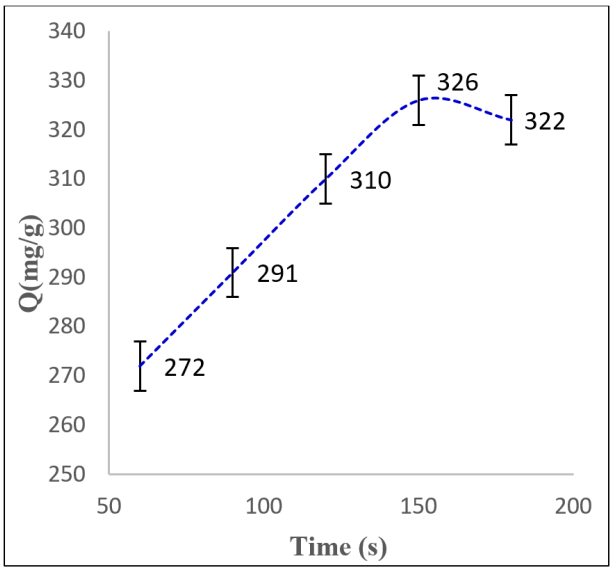

Fig. 5. The effect of reaction time on the absorption efficiency of toluene

In the second-order kinetic model, it is assumed that the adsorption process can be controlled by chemical adsorption. The linear form of second-order kinetics for toluene adsorption on iron-based organometallic framework adsorbents is as Equation 4 [37].

$$\frac{t}{q} = \frac{1}{K_2 q_{eq}^2} + \frac{1}{q_{eq}} t \qquad \textbf{(Eq.4)}$$

K_2 is the kinetic constant of the second order (g (mg min)$^{-1}$). q_{eq} and K_2 are determined from the slope and intersection point of the graph. If we draw the diagram of t/q_{eq} against t, a straight line is obtained if the absorption reaction follows this equation. Also, the absorption kinetics was investigated for first-order kinetics and second-order kinetic models and R^2, K1, K2 and qe were calculated in Table 1.

3.3.5. Examining the adsorption isotherm

Adsorption isotherms are adsorption properties and equilibrium data that describe how pollutants react with adsorbent materials and play an essential role in optimizing adsorbent consumption. It is necessary to establish a cooperative relationship for the equilibrium curve and to optimize the design of a surface adsorption system for toluene removal. Equilibrium adsorption isotherms are expressed by plotting the concentration of toluene in the solid phase against the concentration of these compounds in the solution phase. The distribution of the adsorbed molecule between the solution phase and the adsorbent measures the equilibrium position in the adsorption process. One or more adsorption isotherm models generally express it. There are many isotherm models for analyzing

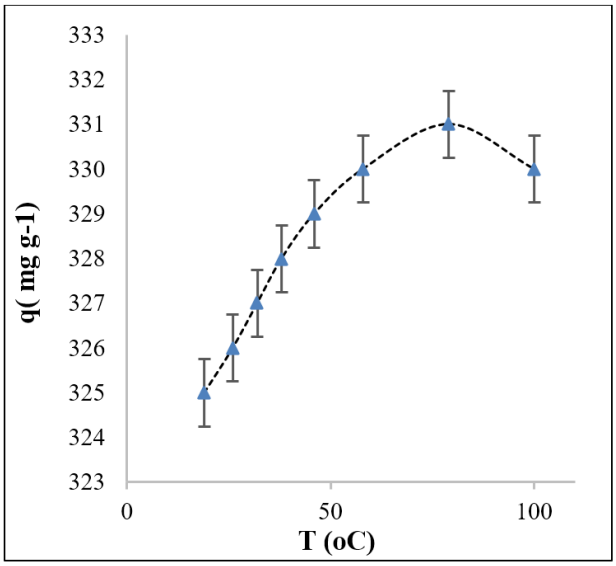

Fig. 6. Effect of temperature on toluene absorption

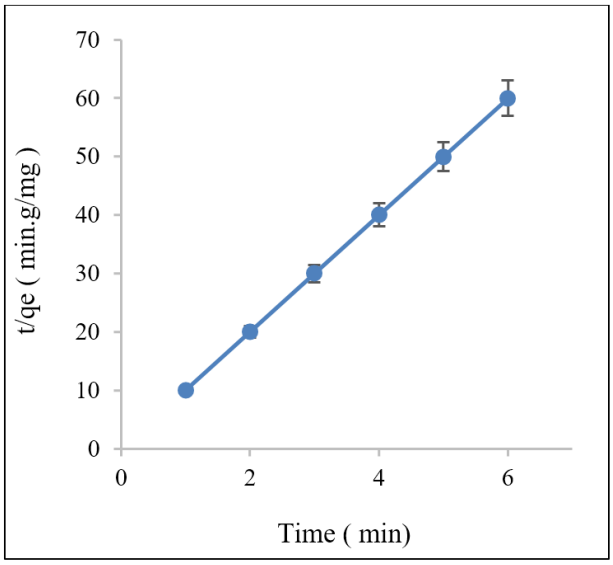

Fig. 7. Kinetics Study on toluene absorption

Table 1. The adsorption kinetics for first-order kinetics and second-order kinetic models

Pollutant	Pseudo-first-order kinetic model			Pseudo-second-order kinetic model		
Toluene	q_e	K_1	R^2	q_e	K_2	R^2
	230	0.103	0.912	320	2.104	0.825

experimental data and describing adsorption equilibrium, such as Langmuir, Freundlich, and Temkin. These models provide a perspective on the adsorption mechanism, surface properties, and adsorption tendency and describe the experimental data of adsorption. Therefore, creating a proper relationship between the balance charts to optimize the conditions and design the absorption systems is very important. Freundlich isotherm is obtained by assuming a heterogeneous surface with a non-uniform distribution of the absorption heat on the surface. According to the Freundlich model, the absorption process is defined by Equation 5.

$$\log(q_{eq}) = \log(K_f) + \frac{1}{n}\log(C_{eq}) \qquad \textbf{(Eq. 5)}$$

Kf is the absorption capacity in unit concentration, 1/n surface absorption intensity, Ceq is the equilibrium concentration in mg L^{-1}, and qe is the amount of toluene absorbed in the equilibrium state in mg g^{-1}. From the linear graph $\log(q_{eq})$ versus log (Ceq), Kf and (1) / n can be determined. 1/n represents the type of isotherm, favorable if 0<1/n < 1 and unfavorable otherwise.

Due to the Langmuir model, assumptions include single-layer absorption, surface uniformity, and elimination of the mutual effects of absorbed molecules. For single-layer absorption, the Langmuir equation is followed by Equation 6 and Figure 8.

$$\frac{C_{eq}}{q_{eq}} = \frac{1}{Q^{\circ}b} + \frac{C_{eq}}{Q^{\circ}} \qquad \textbf{(Eq. 6)}$$

Where q_{eq} (g mg^{-1}) is the amount of toluene absorbed per gram of absorbent, and C_{eq} (mg L^{-1}) is the equilibrium concentration of the pollutant in the equilibrium state. Q° and b are the Langmuir parameters, which are related to the maximum adsorption capacity and adsorption correlation energy, respectively. A plot of C_{eq}/Q_{eq} vs. Ceq shows a straight line with a slope of 1/Q° and an intersection of 1/ bQ°. The fundamental characteristic of the Langmuir isotherm is the dimensionless constant called the equilibrium parameter (RL), which is defined by the Equation 7:

$$R_L = \frac{1}{1 + bC_0} \qquad \textbf{(Eq.7)}$$

C (°) is the initial concentration of toluene, which was considered here as 300 mgL^{-1}. RL represents the type of isotherm. 0<RL<1 for favorable absorption, RL>1 for unfavorable absorption, RL=1 for linear absorption and RL=0 for irreversible absorption.

The maximum toluene absorption (Q_{max}) for the Fe-MOFs adsorbent was calculated with Langmuir and Freundlich isotherms (Table 2). According to the results, the best kinetics is of second order type, and the isotherm is of Freundlich type. The maximum amount of toluene absorption was finally 337.2 mg g^{-1}.

The Equation 8 is one of the adsorption isotherms obtained experimentally. This isotherm was first presented in 1926 by Herbert Freundlich:

$$\theta = a \cdot p^{1/n} \qquad \textbf{(Eq.8)}$$

Where θ is the surface coverage fraction (the ratio of the covered surface to the total surface available for absorption), p is the pressure or concentration of the desired gas, n is a number greater than unity, and a is a constant number. Unlike the Langmuir adsorption model in which (changes in) the adsorption enthalpy is independent of the coverage fraction, in the region where the Freundlich isotherm is used, the adsorption enthalpy is a linear function of ln θ. Freundlich isotherm is obtained by assuming a heterogeneous surface with a non-uniform distribution of heat of absorption on the surface. According to the Freundlich model, the absorption process is defined by the Equation 9.

$$\text{Log}\,(q_{eq}) = \log\,(K_f) + 1/n \log\,(C_{eq}) \qquad \textbf{(Eq.9)}$$

Kf is the absorption capacity in unit concentration, 1/n surface absorption intensity, C_{eq} is the equilibrium concentration in mg L^{-1}, and qeq is the amount of xylene and toluene absorbed in the equilibrium state in mg g^{-1}. From the linear graph of $\log(q_{eq})$ versus log (C_{eq}), K_f and 1/n can be determined. 1/n represents the type of isotherm, which is favourable if 0<1/n < 1 and unfavorable otherwise.

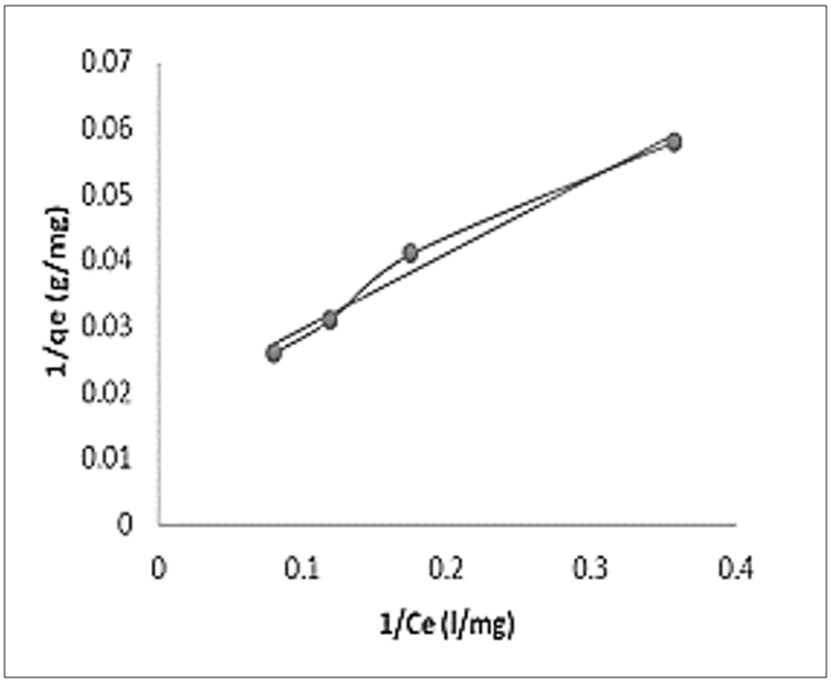

Fig. 8. Results of adsorption isotherm

Table 2. Comparing Langmuir and Freundlich isotherms for the Fe-MOFs adsorbent

Maximum Toluene Absorption	Langmuir isotherm			Freundlich isotherm		
Q_{max}	K_L	R^2	R_L	N	K_f	R^2
337.2	0.8	0.996	0.024	1.012	25.11	0.998

3.4. Effect of parameters on the absorption capacity

3.4.1. The effect of toluene concentration on the absorption capacity of Fe-MOFs adsorbent

The effect of the initial concentration of toluene in the concentration range of 100 to 400 mg L^{-1} (ppm) was studied on the organic iron framework adsorbent. The results showed that the iron adsorbent reached the saturation limit at a concentration of 300 mg L^{-1}.

3.4.2. Effect of contact time on absorbent capacity

The effect of contact time between 60 and 180 seconds on the absorption capacity of toluene by iron organometallic framework adsorbent in various concentrations between 270 and 330 mg of toluene was studied. This study observed that increasing the contact time positively affects the adsorption capacity of the Fe-MOFs adsorbent. It means that absorption increases up to 150 seconds and then decreases.

3.4.3. The effect of temperature on the absorption capacity of Fe-MOFs

To show the effect of temperature on the absorption capacity of the adsorbent, various concentrations of toluene in the range of 326 to 331 mg L^{-1} of toluene were investigated in the temperature range of 25 to 100°C. In general, it was found that first, the temperature increases directly with the increase in the concentration of toluene. After reaching the temperature of 75 °C, we will see a decrease in the concentration of toluene. The one-way ANOVA of time, concentration, and temperature was calculated for the absorption capacity in Table 3 and had no significant difference ($p<0.05$).

T = 140 (s)	T = 120 (s)	T = 160 (s)	p = 0.21
321	308	325	
320.5	307.5	324.5	
322.5	305	326	
C = 200 ppm	C = 250 ppm	C = 300 ppm	p = 0.06
244	285	340	
243	287	342	
246	284	337	
Temp = 40 C	Temp = 60 C	Temp = 75 C	p = 0.16
327.5	329.8	330.5	
327.9	329.7	329	
328	329.65	331	

Table 3. The results of absorption capacity based on One-Way ANOVA for time, concentration, and temperature parameters

3.5. Discussions

Metal-organic framework sorbent is one of the most powerful adsorbents for removing volatile substances from the air. This study investigated and researched the effect of iron organometallic framework adsorbent (Fe-MOFs) on removing toluene vapours. In a survey conducted by Rezaei et al. in 2015 to examine the absorption of toluene from polluted air flow using activated carbon covered with metal oxides of manganese and magnesium, with the increase of toluene concentration from 100 to 400 ppm, the absorption capacity for MgO respectively /GAC increased by 39% and for MnO/GAC by 61.1%. Also, by increasing the temperature from 25 to 100 °C, the absorption capacity increased by 78% for MgO/ GAC and 23% for MnO/GAC, respectively [38]. Also, in a research conducted by Jafari et al. in 2016 to investigate the efficiency of photocatalytic removal of toluene vapour in zeolite Y bed impregnated with titanium dioxide nanoparticles, with the increase of toluene input density from 50 to 300 ppm, the photocatalytic removal efficiency of the bed decreases, and at concentrations of 50, 150 and 300 ppm, the removal efficiency is 50, 48 and 20%, respectively [39, 40]. Meanwhile, in the present study, with the increase of toluene concentration from 100 to 400 ppm, the absorption capacity for Fe-MOFs adsorbent has increased by 42%. Also, by increasing the temperature from 25 to 100 °C, the absorption capacity for Fe-MOFs has increased by 98.48%. By increasing the contact time with the Fe-MOFs absorber, we have seen an increase in absorption by 81.81%.

4. Conclusion

The new adsorbent Fe-MOFs was used to remove toluene from the air stream at a flow rate of 1.5 litres per minute in the present study. To evaluate the absorbent capacity, the effect of three independent components of concentration, temperature, and contact time on the amount of toluene absorption was used, and it was found that the maximum absorption capacity for the three mentioned components is 340 mg g^{-1}, 331 mg g^{-1}, and 325 mg g^{-1}, respectively, which indicates the higher absorption capacity of this the adsorbent is compared to other adsorbents. In addition, the maximum adsorption (Q_{max}) capacity was obtained at 337.2 mg $g^{-1,}$ and the best kinetics and isotherm types were achieved in the second order and the Freundlich model, respectively. In one-way ANOVA for time, concentration, and temperature components, the average responses in none of the investigated components have no significant difference ($p<0.05$). The high recovery for toluene removal from the air was obtained in optimized conditions (more than 95%).

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