A new kinetic models analysis for CO adsorption on palladium zeolite nanostructure by roll-coating technique

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ABSTRACT

The aim of this article was the fabrication of zeolite@Pd/Al2O3 nanostructure through roll-coating technique for CO gas adsorption from air. Transmission electron microscopy (TEM), field-emission scanning electron microscopy (FESEM), X-ray diffraction (XRD), and energy-dispersive x-ray spectroscopy (EDX) were performed to investigate the morphological, structural, and elemental properties of zeolite@Pd/Al2O3 adsorbent. A continues carbon monoxide gas analyzer KIGAZ 210 was applied for analyzing of CO gas adsorption on as-present adsorbent in an experimental set-up. The adsorption capacity at equilibrium time for CO molecules was studied by zeolite@Pd/Al2O3 adsorbent. The Elovich, Avrami, and Fractional power kinetic models were used for this study. The equal value of experimental and theoretical adsorption capacity at equilibrium time as well as the unit value of regression coefficient was indicated that the Avrami kinetic model was the suitable model to describe CO removal from air through zeolite@Pd/Al2O3 nanostructure. The results showed us, the CO molecules were efficiently removed by catalytic zeolite adsorbent more than 95% from air at optimized conditions.

Keywords: Carbon monoxide (CO), Toxic gas analysis, Adsorption, Alumina palladium zeolite composite films, Kinetic models

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1. Introduction

The clean and high quality air is essential for human health. The main contributors to climate change belong to emission of toxic gases CO, CO2, NOx, Sox [1, 2]. Operations of industries and factories, transportation, agricultural activities and post/pre combustion of fuels are major reasons behind the emissions of CO and CO2 in environment air. Carbon Monoxide (CO) as a main ecological pollutant, can be formed by incomplete burning of industrial fuels, automobiles and caused to a serious of symptoms including dizziness, naupathia and dyspnea [3, 4]. The acceptable limit of CO exposure has reported by ACGIH chemical substances [5]. The development of efficient and robust techniques for air purification has been boosting attention over the past few decades [6]. Among these techniques, the process of adsorption shows a fundamental surface phenomenon in which the attachment of solute (adsorbate) into a solid surface (adsorbent) can remove pollutants selectively from air atmosphere [6, 7]. According to the previous studies, some of toxic gases such as CO, CO2, SO2, O3, VOCs, etc., have more concentration in air [3]. Nowadays, excellent properties of nanomaterials such as high surface area and high adsorption
caused to use for air purification [8-10]. According to the most valence of equilibrium cycle, the cycle of adsorption/desorption process can be identified approximately when the adsorbent is started that the model of isotherm as fluctuation of temperature and or pressure can be applied for appraising of the maximum capacity of equilibrium axle. Moreover, the regeneration procedure can be estimated through adsorbents’ recognizable characteristic like thermal behavior of electricity. Electric swing adsorption (ESA), moisture swing adsorption (MSA), temperature swing adsorption (TSA), and pressure swing adsorption (PSA), or techniques like temperature vacuum-pressure swing adsorption (TVPSA) that can be made by compilation of these above methods [11]. Pressure/Vacuum swing adsorption (PSA/VSA) and temperature swing adsorption (TSA) techniques was used for trapping of gas pollutions by above methods [12-15]. Carbon-based adsorbents such as activated carbons are commercially cheaper than other adsorbents, and also have known for toxic gas removal because of its useful properties such as eco-dependence, consistency of thermic and chemic, conductance of heat and electricity, or high resistance [16-19]. However, its disadvantages such as lack of low thermal and mechanical stability rather than other materials should not be ignored [6]. Recently, varieties of nonporous including metal-organic frameworks (MOFs) [20-23], mesoporous alumina (MA) [24, 25], and mesoporous silica (MS) [26,27] have been used for detection and adsorption of toxic gases, and are regarded as alternatives to commercial adsorbents [28,29]. Metal-organic frameworks (MOFs) are confirmed to be a significant adsorbent due to its unique properties such as large specific surface area, ultra-high porosities, controllable architectures, and low density [30, 31]. As an important factor, the porosity of MOFs can help to adsorb and desorbs micro molecules by providing a fast and handy path [32,33]. Although considerable fabricated and natural adsorbents such as activated carbon [26], fly ash [25], natural/modified clays [24], biomaterials [4], metal-organic-frameworks (MOFs) [23], zeolites [22,21], and nanomaterials [27] have been studied for a long period of time, there is still needs for advancements of adsorption technology and developing recyclable, cost-effective, high efficient adsorbents that have high capacity. Mesoporous alumina and other alumina-based substances have high adsorption capacity because of their interconnected channels, uniformed porous structures, and united pore size [34,35]. In particular, γ-Phase nano-Al₂O₃ is the best candidate for gas molecules capturing rather than other alumina phases known as “transition alumina” owing to its pore-volume, large surface area, and great catalytic activity [36, 37, 38]. The properties with high surface area and acidic surface make the gamma-alumina (γ-Al₂O₃) a unique material with extensive application ranging from adsorbents to heterogeneous catalysis [39-42]. The phases including δ-, η-, θ-, and γ - Al₂O₃ indicates one of various metastable stages (polymorphs) of alumina [39, 43, 44]. A higher CO adsorption and great capacity of adsorbents can be occurred by covering of the small particle size of Pd clusters on the Al₂O₃ surface [45]. The application of palladium is restricted due to its high material cost, even though there has been extensive investigation of nanopalladium or its alloy groups [46]. Therefore, in this study, nano-scale palladium II nitrate has used due to its similar unique and useful characteristics with palladium nanoparticles, and because of being cost-effective and easy to access compared to palladium. The mesoporous silicates are one of the promising kinds of nanoscale materials that become well-known for researchers due to their potential abilities and utilizations [47-53]. Several researchers have been reported the advantages of applying nanoscale zeolite (NPs) over micro-scale zeolite (MPs). [54-58] For example, according to results of comparing nano-scale (30-40 nm) and micro-scale (2000 nm) of H-ZSM-5 for its catalytic performance, it has found that the catalyst lifetime for H-ZSM-5 in nano-scale particles is longer than itself in micro-scale particles [58]. Synthesizing and utilizing nanosized zeolite attract great interests compared to zeolite with micron size, recently [54-62]. The properties of high external surface
area and high availability of active sites have been made nanoscale zeolites better catalytic proficiency and age of catalyst. Either a particular type of nanoadsorbents like CNTs [63,64], or some kinds of pollutants including heavy metal, antibiotic and so on [65, 66], or organic and inorganic pollutants removal [67] have totally been focused by most of recent review articles even though over 500 technical papers published between 2000 to 2019 indicate the rapid growth of interest in this research area. Hence, the current study concentrates on the adsorption of carbon monoxide as a toxic gas by nanomaterial based composite films. The present study’s aim is firstly loading three nanoparticles γ-Al$_2$O$_3$, Pd(NO$_3$)$_2$ and zeolite on glass substrates through the roll-coating method, in order to enhance the span of reactions between CO gas molecules and adsorbents surface, and improve the ability of adsorbents for CO capturing. Then, the Elovich, the Avrami, and the Fractional power kinetic models for CO adsorption by zeolite@Pd/Al$_2$O$_3$ nanoadsorbent were studied and analyzed.

2. Experimental

2.1. Materials

Nanoshel chemicals was provided alumina nanoparticles (CASN: 1344-28-1, Molar mass: 101.96 g mol$^{-1}$ γ-Al$_2$O$_3$ with purity >99.9%) and zeolite nanoparticles (CASN: 1318-02-01, Al$_2$O$_3$·4SiO$_2$·H$_2$O with purity 99%). Merck chemicals and Sigma-Aldrich were two sources that 1-methyl-2-pyrrolidone and palladium nitrate (Pd(NO$_3$)$_2$) were bought from them, respectively. There were no needs for purification of received chemicals in order to use them.

2.2. Preparation of Adsorbent

The roll-coating technique has been used to deposit zeolite@Pd/Al$_2$O$_3$ as composite films on glass substrates. Four glass substrates (2 cm × 8 cm) were used in this study. Disinfectant materials such as acetone, ethanol and deionized water were consumed for washing glass substrates three times in an ultrasonic device. Then, the washed substrates dried at room temperature. As the process of samples preparation, firstly 1 g of Al$_2$O$_3$, 1 g of zeolite and 1 g of Pd(NO$_3$)$_2$ were mixed in a container, then 1-methyl-2-pyrrolidone was added dropwise into it as 10 mL in order to make the adhesion of materials on the substrates easy and stronger. After 1 day, the prepared coated substrates were desiccated at room temperature. Finally, a hollow cubic container was fabricated through attaching these four Al$_2$O$_3$/Pd(NO$_3$)$_2$/Zeolite coated substrates to each other whereby this tunnel-like shape helps CO gas molecules to be channeled and trapped readily [68]. In this case, the adsorption capacity and efficiency will be greatly affected by enhancing the rate of interaction between gas molecules and adsorbents.

2.3. Characterization

Transmission Electron Microscopy (TEM) was used in order to determine the shape and grain distribution of nanoparticles with high resolution. X-ray diffraction (XRD, STOE STADI MP) was applied for extracting the crystalline structure of pure initial materials. Topography and morphology of as-present adsorbent (before and after adsorption process) were determined through field emission scanning electron microscope (FESEM, MIRA3 TESCAN), while energy-dispersive X-ray spectroscopy (EDX) analysis was used in order to specify and measure chemical elemental contents of the sample.

2.4. Adsorption of CO

The schematic of designed experimental setup for testing CO adsorption consists of main three sections as a CO gas capsule, a compartment (20 cm length and 7 cm internal diameter) where an adsorbent is placed, and a carbon monoxide gas analyzer KIGAZ 210 (Sauermann Co, CO sensor protection by solenoid valve) based on tunable diode laser (TDL, LOD=1 ppm) for CO Measurement for detection of 1-120 ppm CO and evaluation of target gas (CO 99,999%) concentration [68]. The temperature of 0-250 °C (23-482 °F); optional (for probe installation) 0-600 °C (0-1112 °F) with additional thermal barrier was used. The constant pressure 1.5 bar was applied in this study. The
concentration of inlet CO gas and the saturation level of CO gas concentration were 150 mg L\(^{-1}\) and 5 mg L\(^{-1}\), respectively.

2.5. Adsorption mechanism of CO by Zeolite@Pd/Al\(_2\)O\(_3\)

Generally, movable and fixed bed are two types as classification of the adsorption/desorption by Al\(_2\)O\(_3\)/Pd(NO\(_3\))\(_2\)/Zeolite. The molecules of gases like CO can attach to the adsorbent surface of Al\(_2\)O\(_3\)/Pd(NO\(_3\))\(_2\)/Zeolite when the molecules of these gases achieve decreased free energy while the molecules come towards the surface of adsorbent. The value of CO molecules that come close to the surface of Al\(_2\)O\(_3\)/Pd(NO\(_3\))\(_2\)/Zeolite adsorbent will be increased by decreasing of entropy that occurs by interplay between solid surface and CO molecules. The adsorption process based on van der Waals forces called physically adsorption, while chemical bond formation obtained between surface of Al\(_2\)O\(_3\)/Pd(NO\(_3\))\(_2\)/Zeolite adsorbent and adsorbate. So, there are different mechanisms of physio-chemisorption for adsorption procedure which must be optimized. The MOFs’ surface has several functional groups caused to act chemical reaction in mechanism adsorption [16]. In Order to achieve efficient elimination of CO, the adsorbent substance should possess some essential properties which are demonstrated as follow: 1) Since the proficiency of adsorption can specify how many adsorbents are required whereby the adsorption column’s volume can be measured, it possesses high importance for determining the main cost of the adsorption mechanism. However, the value of adsorbent and size of equipment for adsorption process must be minimized due to high CO concentration. 2) The ratio of CO to another gas capacity shows the selectivity CO gas. 3) Another parameter for grading the adsorbents’ efficiency is the kinetics of adsorption/desorption that the fast rate of adsorption/desorption kinetics for CO will be required by the adsorbents. The cycle of time will be controlled by processes of regeneration and the adsorption’s kinetics that can form two types of curves that are a fast kinetics, and a bugged breakthrough curve occurs if there is slow kinetics for CO. The transfer of mass through the surface of adsorbent, the functional group on the surface of adsorbent, and carbon monoxide’s reaction kinetics can together influence on the kinetics of CO adsorption on the porous substances. 4) In order to keep high kinetics, it is necessary to have a property of the mechanical stability for adsorbent. 5) The demanded energy for regeneration of adsorbents should be measured. The range of -25 to -50 kJ mol\(^{-1}\) is allocated to heat of physisorption and chemisorption cases possess the heat of -60 to -90 kJ mol\(^{-1}\) [17]. Regarding the chemical adsorbents, physical adsorbents such as carbonaceous and non-carbonaceous substances need low energy desire for CO removal due to the no generation of new bonds between these gases and the adsorbents’ surface whereby the regeneration of these gases requires less energy (Fig.1).

![Fig.1. The adsorption mechanism of CO by zeolite@Pd/Al\(_2\)O\(_3\) adsorbent](image)

3. Results and discussion

3.1. TEM analysis

Figure 2a demonstrates the results of TEM analysis of pure Al\(_2\)O\(_3\) nanoparticles (\(\gamma\)-Al\(_2\)O\(_3\)) that three dimensional porous structure are made up by interconnected rod-like particles [69]. It is obviously shown that the shape of nanoparticles does not look accurately spherical [70]. The TEM for nanoparticles of zeolite and zeolite@Pd/Al\(_2\)O\(_3\) was shown in Figure 2b and 2C, respectively.
3.2. XRD spectra

Figure 3 shows the XRD patterns of pure initial materials which are Al₂O₃, Pd(NO₃)₂, and zeolite. An X-ray diffractometer with Cu Kα source (λ = 1.5405 Å) and a scan step size of 0.01° was used for recording XRD patterns. The range of scanning (2θ) was recorded between 10° and 90°. As it is shown, the structure of pure zeolite nanoparticles is more crystalline than pure Al₂O₃, and Pd(NO₃)₂ nanoparticles that confirm an appropriate property of zeolite to have a high adsorption capacity due to its porosity. The diffraction peaks of the pure Al₂O₃ appeared at 2θ of 31.93°, 39.49°, 45.49° and 66.76° which are well distributed to the crystalline preferred orientation of 220, 222, 400 and 440, respectively. The peak positions of Pd(NO₃)₂ were considered as 24.079 and 68.08, which are corresponding to 011 and 220, respectively. The diffraction peaks 10.34, 16.56, 21.79, 29.39 and 31.58, corresponding to the reflection from 220, 212, 203, 451 and 002 are observed in zeolite nanoparticles. The characteristic peaks of pure zeolite are well matched and consistent with the corresponding peaks of all samples, and there are no other observed phases. [71] According to XRD patterns of pure zeolite, there is no considerable alteration in the framework and no lost in solid pure zeolite’s crystallinity as well as the host frame stays intact at the end of the mechanism. [72] Al₂O₃ nanoparticles (Ref 00-029-0063), Pd(NO₃)₂ (Ref 00-005-0681 and 01-087-0643) and zeolite (Ref 01-080-0922) are in good agreement with the candidate references (Table 1). Regarding the fact that available commercial nanomaterials of γ-Al₂O₃ produced through boehmite thermal dehydration, thus determining the crystal structure of γ-Al₂O₃ is difficult as well as it indicates poor crystallinity and impurities. Also, this fact can include other alumina polymorphs that have similar crystal formations. The appropriate structure for analysis belongs to large, clean γ-Al₂O₃ single-crystals that typically cannot produced commercially. Oxidizing single-crystal NiAl (110) under appropriate-controlled conditions would make single-crystal γ-Al₂O₃ films with more than 80 nm thick able to be grown.
which is demonstrated by Zhang et al which were worked on $\text{Al}_2\text{O}_3$ with $\gamma$-shape structure on Ni-Al. Since $\gamma$-$\text{Al}_2\text{O}_3$ fabricated by this technique is well crystalline and does not possess hydrogen or water in bulk structure, it is suitable for considered structural analysis, unlike the material boehmite-originated $\gamma$-$\text{Al}_2\text{O}_3$ [73].

### Table 1. The obtained crystalline regions and peaks of the zeolite@Pd/$\text{Al}_2\text{O}_3$ composite film

| Material       | hkl | 011 | 220 | 222 | 400 | 440 |
|----------------|-----|-----|-----|-----|-----|-----|
| $\text{Al}_2\text{O}_3$ | $2\theta$ (Degree) | 31.93° | 39.49° | 45.49° | 66.76° |
| $\text{Pd(NO}_3\text{)}_2$ | $2\theta$ (Degree) | 24.079° | ----- | ----- | 68.08° |
| Zeolite        | $2\theta$ (Degree) | 10.34° | 16.56° | 21.79° | 29.39° | 31.58° |

**Fig. 3.** The results of XRD analysis for pure initial materials including a) $\text{Al}_2\text{O}_3$/Pd(NO$_3$)$_2$/zeolite b) zeolite, c) Pd(NO$_3$)$_2$ and d) $\text{Al}_2\text{O}_3$ nanoparticles

### 3.3. **FESEM spectra**

The surface morphology, microstructure, particle size and distribution of the as-prepared product are determined by field emission scanning electron microscope (FESEM). Figure 4 indicates the FESEM images of the $\text{Al}_2\text{O}_3$/Pd(NO$_3$)$_2$/Zeolite sample at a 1 µm scale of magnification before
and after CO gas adsorption. The FESEM results revealed that the united porous structures along with regular interlinked channels are developed throughout the adsorbents after adsorption. Also, homogenous dispersion and well particle size repartition of adsorbent after the adsorption process make it incomparable than its virgin version. Hence, a high surface area and whereby a very high CO adsorption is noticed because of these properties.

3.4. Energy-dispersive X-ray spectroscopy

The percentage of elemental content was determined by energy-dispersive X-ray spectroscopy (EDX). Figure 5 illustrates the existence of Al, O, Si, Pd, and N in the sample before the adsorption process that was utilized to fabricate as-present adsorbent. Since Al₂O₃ and zeolite (aluminum silicates) nanoparticles were used in this study, a notable increase in the spectral position of Al EDX peak is observed. The weight and atomic percentages of ingredients are extracted from EDX patterns of virgin adsorbent that include Al, O, Pd, N, and Si at wt.% for each element. (Table 2) The peak of Ca corresponds to glass substrates.

3.5. Kinetic models analysis

The inlet CO gas concentration into an experimental set-up considered as 150 mg L⁻¹. The evaluation of various concentrations of adsorbed CO versus time for Al₂O₃/Pd(NO₃)₂/Zeolite adsorbent’s results indicates the increase of adsorbed CO concentration (mg L⁻¹) with passing time until reaching saturation levels [68]. The relation between adsorbed CO gas concentration and contact time was illustrated in Figure 6. This diagram indicated the effect of passing time on the speed of CO adsorption that becomes slower while time is reaching saturation level. As it is obvious, the adsorbed CO gas concentration is decreased as range of 150-70, 69-11 and 10-5 mg L⁻¹ at rate of 1 s, 2 s and 3 s, respectively.

Table 2. Statistical analysis EDX results of Al₂O₃/Pd(NO₃)₂/zeolite with its atomic and weight values.

| Elements | Al Kα | O Kα | Pd Kα | N Kα | Si Kα | Ca Kα |
|----------|-------|------|-------|------|-------|-------|
| wt.%     | 8.21  | 26.46| 45.01 | 0.53 | 1.62  | 0.48  |
| at%      | 7.78  | 42.33| 10.83 | 0.59 | 1.47  | 0.31  |

Fig. 4. Obtained images from FESEM of Al₂O₃/Pd(NO₃)₂/zeolite adsorbent
a) Before b) after CO gas adsorption at 1 μm scales of magnification.
To explore the chemisorption kinetic of gases onto a solid surface, Elovich kinetic model is describe [74, 75]. The Elovich kinetic introduced in Equation 1 [76].

\[ q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \quad \text{(Eq. 1)} \]

Where \( q_t \) is adsorption capacity at time \( t \) (mg g\(^{-1}\)), the Elovich coefficient \( \alpha \) in the primary rate of adsorption (mg g\(^{-1}\) min\(^{-1}\)), and the Elovich coefficient \( \beta \) is desorption rate constant (g mg\(^{-1}\)) that is associated to the extent of energy activation as well as surface covering for chemisorption process.

**Fig. 5.** EDX patterns of the made Al\(_2\)O\(_3\)/Pd(NO\(_3\))\(_2\)/zeolite adsorbent

**Fig. 6.** The diagram of relation between adsorbed CO gas concentration and contact time (mg L\(^{-1}\), sec)
The amount of $\alpha$ and $\beta$ are obtained from intercept ($\beta^{-1} \ln(\alpha \beta)$) and slope ($\beta^{-1}$) of $q_t$ vs. $\ln t$ linear plot (Fig. 7). It should be noted that the number of remained sites after adsorption process can be specified by the value of $\beta^{-1}$, and adsorption quantity in $\ln t = 0$. It can be shown by $\beta^{-1} \ln(\alpha \beta)$ value that the closeness of this value with experimental value indicates the best fitting of kinetic data to the Elovich model [77], however, in this research work, the values have significant difference.

The obtained parameters were listed in Table 3. Regarding Mozaffari et al. 2020 [68], the amount of experimental equilibrium adsorption capacity at 216 s is 111.16 mg $\cdot$ g$^{-1}$ that is not in agreement with the theoretical adsorption capacity at equilibrium time calculated through this model. The low regression coefficient ($R^2$) value and unequal value of $q_{e,exp}$ as well as $q_{e,cal}$ demonstrate the scantiness Elovich model of for description of CO removal by Al$_2$O$_3$/Pd(NO$_3$)$_2$/Zeolite nano-adsorbent.

![Fig. 7. The Elovich kinetic model for carbon monoxide adsorption by Al$_2$O$_3$/Pd(NO$_3$)$_2$/Zeolite nano-adsorbent](image)

| $q_{e,exp}$ (mg·g$^{-1}$) | 111.16 | [99]   |
|--------------------------|--------|--------|
| **Elovich Model**        |        |        |
| $q_{e,cal}$              | 91.94  |        |
| $\alpha$                 | $r$    |        |
| $\beta$                  | $r$    |        |
| $\beta^{-1}$             | 28.096 |        |
| $\beta^{-1} \ln(\alpha \beta)$ | 58.29  |        |
| $R^2$                    | 0.85   |        |
| **Avrami Model**         |        |        |
| $q_{e,cal}$              | 111.16 |        |
| $k_{AV}$                 | 4.54   |        |
| $n_{AV}$                 | 1.12   |        |
| $R^2$                    | 0.99   |        |
| **Fractional Power Model** |       |        |
| $q_{e,cal}$              | 129.93 |        |
| $k$                      | 1.048  |        |
| $\nu$                    | 0.896  |        |
| $R^2$                    | 0.98   |        |

Table 3. The calculated parameters of the Elovich, Avrami, and Fractional power kinetic models
For simulation of phase transition as well as the growth of crystallite in adsorbent, Avrami kinetic model is investigated [78]. The Avrami kinetic is expressed in equation 2 [79]:

$$\ln \left[ \ln \left( 1 - \frac{q_t}{q_e} \right) \right] = n_{AV} \ln k_{AV} + n_{AV} \ln t$$  \hspace{1cm} (Eq. 2)

Where $K_{AV}$ is the Avrami kinetic constant, the $n_{AV}$ is the Avrami exponent to hypothesize the mechanism of alteration during the process of adsorption [109]. The amount of $K_{AV}$ and $n_{AV}$ are acquired from intercept and slope of $\ln[\ln \left( 1 - \frac{q_t}{q_e} \right)]$ vs. $\ln t$ linear plot.

Figure 8 demonstrates the plot of $\ln \left[ \ln \left( 1 - \frac{q_t}{q_e} \right) \right]$ versus. The regression coefficient ($R^2$) is close to unity that shows the best fit of data. The value of theoretical adsorption capacity at equilibrium time was obtained as 111.16 mg g$^{-1}$ that is match with the experimental equilibrium adsorption capacity which was reported by Mozaffari et al 2020 [68]. Table 3 gives the calculated parameters of this model. Therefore, the unit value of $R^2$ and identical value of $n$ and indicate the best applicability of Avrami kinetic model to describe carbon monoxide adsorption through $\text{Al}_2\text{O}_3/\text{Pd(NO}_3\text{)}_2/\text{Zeolite nano-adsorbent}$.

The modified form of the Freundlich equation is Fractional power model [80]. Fractional power kinetic model is defined as equation 3 [110].

$$\ln q_t = \ln k + \nu \ln t$$  \hspace{1cm} (Eq. 3)

Where $k$ and $\nu$ are constants and $\nu$ should be less than unity. The sorption rate at is defined as $kv$ [80]. The plot of $\ln q_t$ versus $\ln t$ is demonstrated in Figure 9. The amount of $k$ and $\nu$ are obtained from intercept (Ln k) and slope (v) of vs. linear plot.

The calculated constants are tabulated in Table 3. The value of $\nu$ was obtained as 0.89 that is positive and less than unity and regression coefficient ($R^2$)
is almost close to unity. However, experimental adsorption capacity at equilibrium time that was obtained by [99] is not in a good agreement with calculated adsorption capacity. Thus, this model is not sufficient to describe carbon monoxide by Al$_2$O$_3$/Pd(NO$_3$)$_2$/Zeolite nano-adsorbent.

4. Conclusions
In this article, Al$_2$O$_3$/Pd(NO$_3$)$_2$/zeolite adsorbent was prepared by roll coating method to investigate its ability to remove CO gas. It was shown that the effect of passing time on the speed of CO adsorption that becomes slower while time is reaching saturation level. To study the kinetic models for CO removal through this adsorbent, the Elovich, Avrami, and Fractional power kinetic models were explored. The investigation of Avrami kinetic model illustrated that the experimental and theoretical adsorption capacity value at equilibrium time was identical. Furthermore, the regression coefficient value ($R^2$) was close to unity. Therefore, the Avrami kinetic model was the best model to describe CO removal through Al$_2$O$_3$/Pd(NO$_3$)$_2$/zeolite adsorbent. The porous structure of Al$_2$O$_3$/Pd(NO$_3$)$_2$/zeolite adsorbent which was obtained from FESEM analysis is responsible for high values of adsorption efficiency and adsorption capacity. The result of XRD patterns of pure initial materials was applied to confirm their purity and crystalline structures. Elemental content of materials of adsorbent before adsorption was specified by EDX analysis to show the existence of Al, O, Pd, Si, N and Ca that the last one was referred to glass substrates.

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