POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

CO_2 capture performance of graphene oxide synthesized under ultrasound irradiation

Ultrason ışınlaması altında sentezlenen grafen oksitin CO_2 yakalama performansı

***Yazar(lar) (Author(s))**: Deniz SEZGİN[1], Müge SARI YILMAZ[2]*

ORCID[1]: 0000-0001-8243-730X

ORCID[2]: 0000-0003-0441-7586

To cite to this article: Sezgin D. ve Sari Yilmaz M., “CO2 capture performance of graphene oxide synthesized under ultrasound irradiation”, ***Journal of Polytechnic***, 27(2): 681-687, (2024).

Bu makaleye şu şekilde atıfta bulunabilirsiniz: Sezgin D. ve Sari Yilmaz M., “CO2 capture performance of graphene oxide synthesized under ultrasound irradiation”, ***Politeknik Dergisi***, 27(2): 681-687, (2024).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.1179735

CO_2 Capture Performance of Graphene Oxide Synthesized Under Ultrasound Irradiation

Highlights

- *Graphene oxide (GrO) was synthesized under ultrasound irradiation.*
- *The CO_2 capture capacity of GrO decreased with the increase in temperature.*
- *The CO_2 capture capacity of GrO was reached up to 1.04 mmol.g^{-1} at 25°C.*
- *The Avrami (Ar) model better described the CO_2 capture process.*

Graphical Abstract

The CO_2 uptake performance of the sample significantly reduced as the temperature rises, showing the exothermic character of capture. The analysis performed at 25 °C presented a much better capture capacity compared to other temperatures.

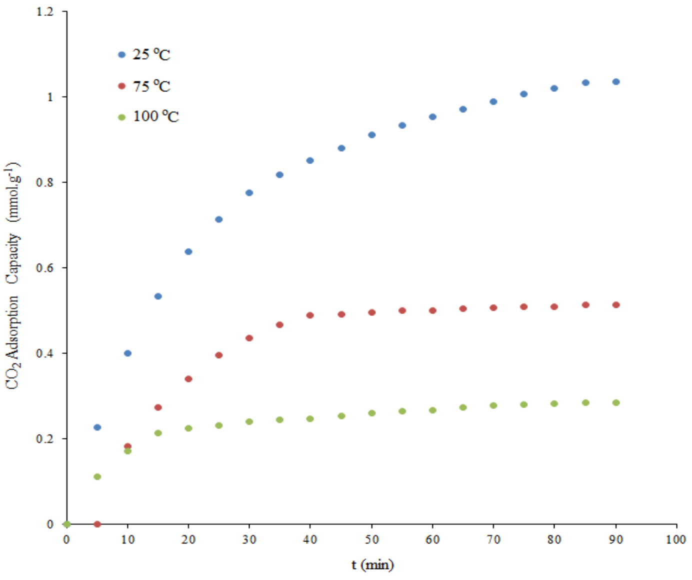


Figure. *The CO_2 adsorption curves at different temperatures*

Aim

The aim of this study is to determine the CO_2 capture performance of synthesized GrO under ultrasonic irradiation.

Design & Methodology

The CO_2 capture studies were applied at 25 °C, 75 °C, and 100 °C. Pf, Ps, and Ar kinetics models were used to describe the kinetic mechanism of CO_2 capture on GrO.

Originality

The originality of this study is the investigation of the CO_2 capture capacity of GrO synthesized by ultrasonic irradiation.

Findings

The CO_2 uptake performance of the sample significantly reduced as the temperature rises, showing the exothermic character of capture.

Conclusion

GrO exhibited the best CO_2 adsorption capacity at 25°C (1.04 mmol g^{-1}).

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

CO_2 Capture Performance of Graphene Oxide Synthesized Under Ultrasound Irradiation

Araştırma Makalesi / Research Article

Deniz SEZGİN, Müge SARI YILMAZ[*]
Department of Chemical Engineering, Yıldız Technical University, Turkey

(Geliş/Received : 24.09.2022 ; Kabul/Accepted : 15.10.2022 ; Erken Görünüm/Early View : 16.12.2022)

ABSTRACT

Nowadays, CO_2 capture is a vital technology to notably reduce the uncontrolled released CO_2 emissions. CO_2 capture using graphene oxide, a derivative of graphene, has become of tremendous interest due to its unique morphology. In this present work, graphene oxide (GrO) was synthesized under ultrasound irradiation according to the modified Hummers' method and its CO_2 capture performance was examined. The X-ray powder diffraction (XRD) and Fourier transform infrared (FTIR) analyses were applied to explore the structure of the sample. CO_2 capture performance of GrO was examined by performing TG analysis under different temperatures. The CO_2 adsorption capacity of GrO was reached up to 1.04 mmol g-1 at 25°C. The experimental data getting from the kinetic study revealed that the Avrami model better described the CO_2 adsorption.

Keywords: Graphene oxide, ultrasound, CO_2 capture, kinetics.

Ultrasonik Işıma Altında Sentezlenen Grafen Oksitin CO_2 Yakalama Performansı

ÖZ

Günümüzde CO_2 yakalama, kontrolsüz salınan CO_2 emisyonlarını önemli ölçüde azaltmak için önemli bir teknoloji olarak görülmektedir. CO_2 yakalamada grafenin bir türevi olan grafen oksitin kullanılması, grafen oksitin benzersiz morfolojisi nedeniyle büyük ilgi görmektedir. Bu çalışmada, modifiye Hummers yöntemine göre ultrason ışıması altında grafen oksit (GrO) sentezlenmiş ve CO_2 yakalama performansı incelenmiştir. Numunenin yapısal özelliklerinin belirlenmesi için X-ışını toz kırınımı (XRD) ve Fourier dönüşümü kızılötesi (FTIR) analizleri uygulanmıştır. GrO'nun CO_2 tutma performansı farklı sıcaklıklar altında TG analiziyle incelenmiştir. GrO'nun CO_2 adsorpsiyon kapasitesi 25°C'de 1,04 mmol g^{-1}'e ulaştı. Kinetik çalışmadan elde edilen deneysel veriler, Avrami modelinin CO_2 adsorpsiyonunu daha iyi tanımladığını ortaya koydu.

Anahtar kelimeler: Grafen oksit, ultrasonik, CO_2 yakalama, kinetic.

1. INTRODUCTION

CO_2 is one of the major atmospheric greenhouse gases resulting from the increase in energy demand and several industrial activities. The dramatic increase in CO_2 emissions has become a widespread concern [1, 2]. The excessive release of CO_2 into the earth's atmosphere is identified as one of the primary causes of climate change and global warming [3, 4]. Regarding this information, to improve the living conditions for the coming years and to take decisions about the reduction of CO_2 emissions, the most emitting CO_2 sources should be determined and required measures should be taken regarding these sources [5, 6]. CO_2 capture, storage, and using technology is a promising option to attain notable reductions in anthropogenic CO_2 emissions. Considering the entire operation, CO_2 capture is seen as the most critical step, as it accounts for a high part of the total cost [7–9]. For this reason, it is expected that the preferred technology for CO_2 capture should be economical [10]. Among the CO_2 capture techniques, adsorption has garnered interest in recent studies because of its advantages, including low operating cost, environmental friendliness with minimal energy consumption, effectiveness, excellent selectivity, and a large variety of adsorbents [11, 12]. For this purpose, considerable classes of solid materials have been evaluated as adsorbents such as metal-organic frameworks (MOFs) [11, 13], silica-based materials [14–18], calcium-based materials [5, 19, 20], zeolite [21], and carbon-based materials. Among carbon class materials, activated carbon [22, 23], CMK [24], carbon nanotubes [25] and graphene oxide [26, 27] are extensively used as solid adsorbents.

GrO, a functionalized oxidized derivative of graphene, is a two-dimensional hydrophilic material consisting of a sp^2-bonded regular lattice structure. Recently, it has emerged as a possible candidate for CO_2 capture because of its significant and multifunctional morphology such as high porosity, high surface area, and thermal stability. Moreover, GrO surface possesses advantageous epoxy, carboxyl, and hydroxyl groups. These oxygen-contained functional groups make the GrO basic and it reaches a high CO_2 capture capacity by interacting with the acidic

---

**Sorumlu Yazar (Corresponding Author)*
e-posta : mugesari@yildiz.edu.tr

CO_2 [28–30]. Apart from CO_2 capture, GrO has attention to various fields such as adsorption [31, 32], fuel cells [33], gas storage [34], electrode material for energy devices [35], and supercapacitor [36].

To the best of the authors' knowledge, any study on the evaluation of pure GrO synthesized under ultrasonic irradiation in CO_2 adsorption is not available in the literature. In this study, GrO was synthesized under ultrasound irradiation to determine the CO_2 capture capacity at various temperatures. The pseudo-first order, pseudo-second order, and Avrami kinetic models were utilized to test the fit of experimental results of CO_2 capture by GrO on the kinetics equations.

2. MATERIAL and METHOD

Graphite powder with a purity of 99.9995% was bought from the Alfa Aesar. Other chemicals used in the experimental studies were bought from Sigma Aldrich.

XRD analyses were applied in a PANalytical X'Pert-Pro XRD instrument using CuKα radiation ($\lambda = 0.15406$ nm), operating at 40 mA and 45 kV. FTIR spectrum of the sample was taken on Perkin Elmer Spectrum One FT-IR spectrometer. The CO_2 capture analyses of the sample were carried out on a Perkin Elmer Pyris Diamond thermogravimetric analyzer (TGA).

2.1 Preparation of GrO

GrO powders were prepared based on the Hummers' method explained in the previous reports, applying modifications. Firstly, H_2SO_4 was added to defined amounts of graphite and $NaNO_3$ mixture and all materials were stirred for 1 h. Then, $KMnO_4$ was added slowly to the stirred mixture in the ice bath. During this process, the temperature was kept below 5˚C. After the mixture was removed from the ice bath, it was taken to an ultrasonic bath for a while, and a determined quantity of deionized water was added to the reaction mixture under ultrasound. Then, H_2O_2 was introduced to the solution, and ultrasound-assisted mixing was continued until a color change was observed. The reaction was stopped when the mixture's color changed from black to brown. The resulting mixture was carefully filtered and rinsed with deionized water until it had a neutral pH. The resultant powder was dried in an oven for 24 hr and named as GrO.

2.2 CO_2 Capture

The CO_2 uptake behavior of the GrO was investigated by the TGA using high-purity CO_2 gas (> 99.99%) under atmospheric pressure. The CO_2 capture studies were applied at 25 °C, 75 °C, and 100 °C. Firstly, 10 mg GrO added in an aluminum crucible was heated in N_2 gas for 60 min with a 100 mL/min flow rate until the temperature reached 105 °C to dehumidify, and then, it was cooled to the specific temperature. In the next step, the gas flow was changed to ensure a constant flow of CO_2 gas and the GrO sample was kept under this constant flow for 1.5 h. The CO_2 capture capacity was determined based on the change in mass of the adsorbent later the initiation of the flow of CO_2 gas.

3. RESULTS and DISCUSSION

3.1 Characterization

Figure 1 indicates the XRD pattern of GrO synthesized under ultrasonic irradiation. The XRD pattern of GrO revealed a wide peak at $2\theta = 11°$, representing the (001) crystal face of GrO. This single characteristic peak proves the formation of graphite to graphene oxide [37, 38].

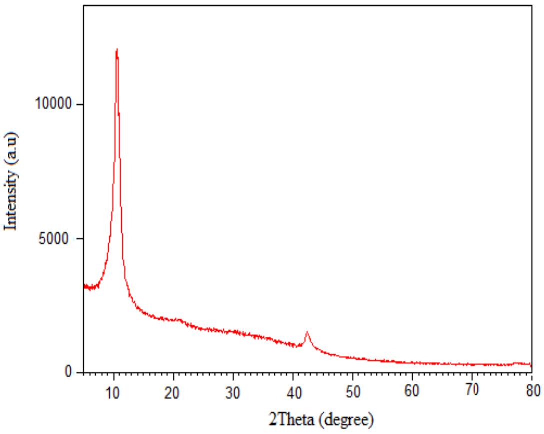


Figure 1. XRD pattern of GrO

The FTIR spectrum of the GrO was presented in Figure 2. The typical wide peak at 3412 cm^{-1} was related to O-H stretching vibration in carboxyl groups due to H_2O molecule absorption. The peak appearing at 1728 cm^{-1} resulted from the C=O stretching of carboxyl and/or carbonyl groups. The unchanged C=C bond in graphite structure was signified at 1626 cm^{-1}. The bands at 1054 cm^{-1} and 1226 cm^{-1} indicated the C-O stretching vibration of alkoxy and epoxy groups, respectively. The band at 1404 cm^{-1} represented the deformation of the O-H bond [29, 37, 39].

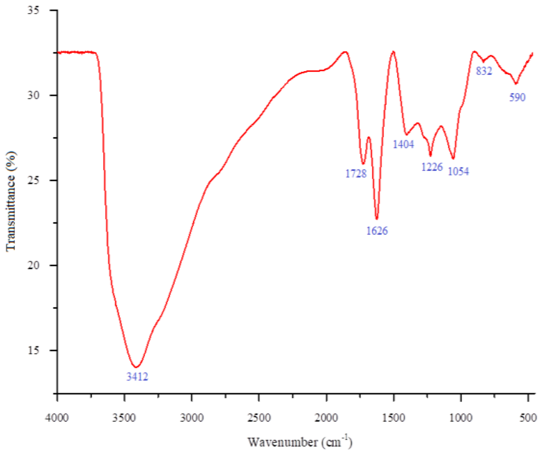


Figure 2. FTIR spectrum of the synthesized GrO under ultrasonic irradiation

3.2 CO_2 Capture

Figure 3 displays the CO_2 adsorption capacity curves of GrO at 25°C, 75°C, and 100°C. The CO_2 uptake performance of the sample significantly reduced as the temperature rises, showing the exothermic character of capture. The analysis performed at 25 °C presented a much better capture capacity compared to other temperatures. The increase in contact time enhanced the CO_2 adsorption performance of the adsorbent. The GrO indicated the best capacity as 1.04 mmol.g^{-1} in 90 min at 25 °C.

To determine the CO_2 uptake capacity of GrO, the performance of other GrO-based samples conducted included in previous works in the literature is listed in Table 1. According to the reported studies, it can be stated that GrO synthesized under ultrasonic irradiation is a convenient option for CO_2 capture.

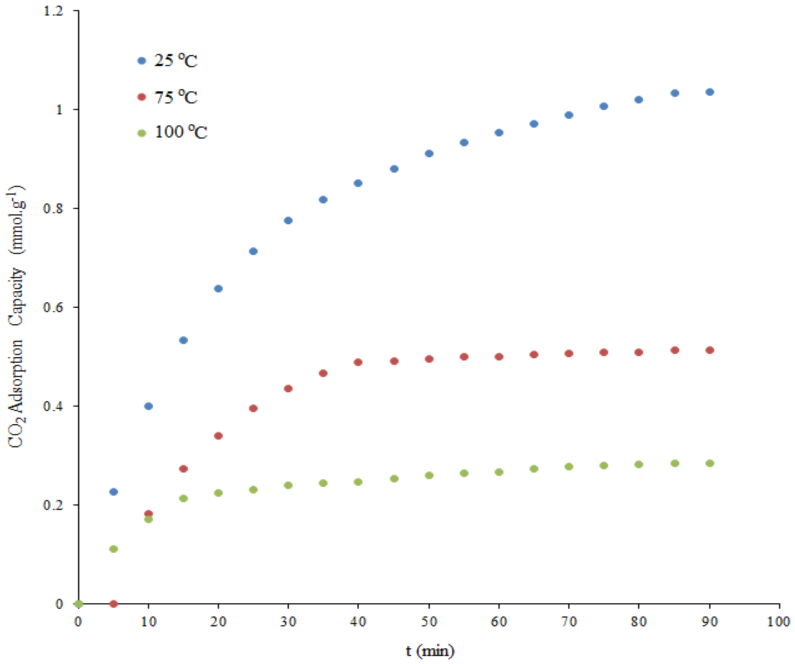


Figure 3. The CO_2 adsorption curves at different temperatures

Table 1. CO_2 uptake capacities of some GrO and GrO-based materials reported in the literature

Sample	T (°C)	P (bar)	Capacity (mmol g^{-1})	Ref.
Mg-Al-NO_3 LDH-NS/GrO	200	1	0.47	[24]
GrO/MWCNT(1:1)50-LDH	300	1	0.49	[25]
Amine-functionalized GrO	65	0.1	1.2	[26]
GrO − LDO-SA	200	1	0.83	[38]
Amine-functionalized GrO	25	1	0.91	[39]
GrO/ZIF-8@ZIF-67	25	1	1.12	[40]
APTES-GrO	70	1	1.5	[41]
Chitosan grafted GrO aerogel	25	1	0.26	[42]
GrO	30	1	1.1	[43]
GrO	25	1	1.04	In this study

3.3 Kinetic Analysis

To describe the kinetic mechanism of GrO, the obtained kinetic data at 25 °C were fitted to pseudo-first order (Pf), pseudo-second-order (Ps), and Avrami (Ar) kinetics models. The Pf model identifies the proportionality between the adsorption rate and the number of vacant sites present on the adsorbent surface [40]. The Ps model assumes a linear ratio between the square of the number of unoccupied adsorption sites and the rate [41]. The Ar factionary kinetic model was proposed to explain the CO_2 gas uptake rate of some solid adsorbents [44]. The Pf, Ps, and Ar kinetic models were represented by the following equations, respectively;

$$q_t = q_e \left[1 - \exp(-k_f\, t)\right] \tag{1}$$

$$q_t = \frac{q_e^2\, k_s\, t}{1 + q_e\, k_s\, t} \tag{2}$$

$$q_t = q_e \left[1 - \exp(-(k_a\, t)^{n_a}\right] \tag{3}$$

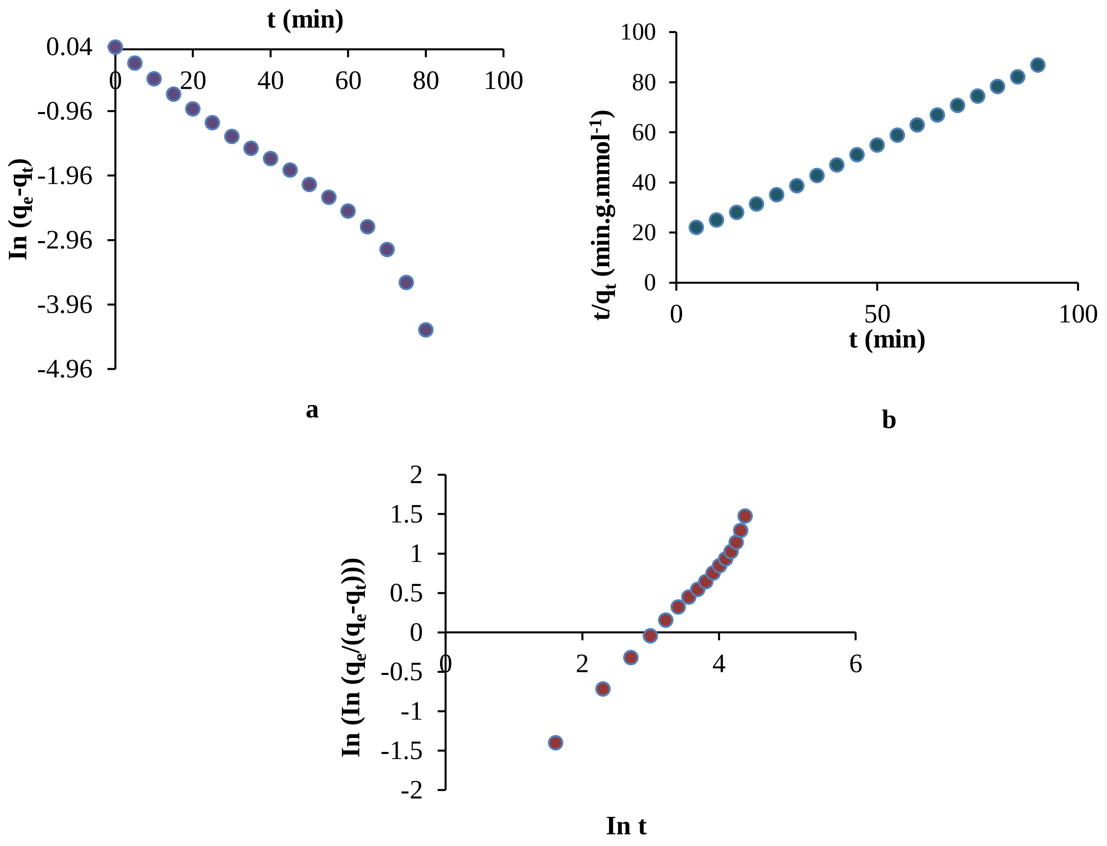
where q_e and q_t are the adsorption capacity at equilibrium and at a given time (mmol g^{-1}). k_f, k_s, and k_a are the rate constants of Pf, Ps, and Ar kinetic models, respectively, and n_a is the order of the equation.

To determine the accuracy of the applied kinetic models, an error function *(Δq%)* was calculated. This error function was defined as;

$$\Delta q(\%) = \sqrt{\frac{\Sigma\left[\frac{q_{e(exp)} - q_{e(pre)}}{q_{e(exp)}}\right]^2}{n-1}} \text{ x } 100\% \tag{4}$$

where the values of the experimental and predicted CO_2 adsorption capacities, respectively, are represented by $q_{e(exp)}$ and $q_{e(pre)}$. The number of the kinetic data points was demonstrated as n.

The kinetic plots and calculated parameters along with these three models were given in Figure 4 and Table 2.



a

b

c

Figure 4. Kinetics plots for the CO_2 capture on GrO a) Pf, b) Ps, and c) Ar

Table 2. The calculated kinetic parameters for CO_2 adsorption on GrO at 25 (°C)

Kinetic Model	Parameter	Value
Pf	$q_{e,exp}$ (mmol.g^{-1})	1.1037
	k_f	0.0474
	R^2	0.9695
	Δq(%)	0.5964
Ps	$q_{e,cal}$ (mmol.g^{-1})	1.293
	k_s	0.036
	R^2	0.999
	Δq(%)	6.09
Ar	$q_{e,cal}$ (mmol.g^{-1})	1.057
	k_a	0.046
	n_a	0.9682
	R^2	0.9917
	Δq(%)	0.596

Among all of the studied kinetics, Ar factionary model presented a much lower *Δq(%)* value. As a result, the q_e value obtained with the Ar model has a value closer to the experimental q_e than the values obtained with the Pf and Ps models. The Ar kinetic model identified well the CO_2 adsorption mechanism on GrO, and this demonstrates the appearance of a complex mechanism or multiple reactions [45].

To estimate the activation energy of the CO_2 adsorption on GrO, the Arrhenius equation was used as given in Eq. (4). The kinetic coefficients at various temperatures (25 ˚C, 75 ˚C, 100 ˚C) may be evaluated by this equation.

$$k = Ae^{\frac{-E_a}{RT}} \quad (5)$$

The linear form of the Arrhenius equation was given by following equation;

$$In\ k = In\ A - \frac{E_a}{R\ T} \quad (6)$$

where *A* refers to Arrhenius pre-exponential factor, E_a is a term related with activation energy and *R* is ideal gas constant.

The activation energy (E_a) of CO_2 adsorption was obtained from the plot of ln *k* versus inverse temperature (*1/T*) (Fig 5). The correlation coefficient R^2 of the plot was found as 0.99 (more than 0.95) and this proves the linearity between ln *k* and *1/T*. According to Figure 5, the E_a of the study was calculated as 8.54 kJ.

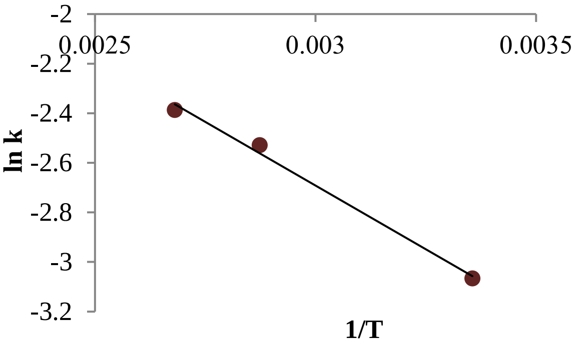


Figure 5. The Arrhenius plot used for the estimation of E_a

4. CONCLUSION

In this paper, GrO was synthesized under ultrasound irradiation following Hummers' method and its CO_2 capture performance was evaluated with TG analysis under 25°C, 75°C, and 100°C. The CO_2 capture performance of GrO decreased with increasing temperature due to the exothermic nature of the adsorption. The CO_2 uptake capacity of GrO was revealed as 1.04 mmol g^{-1} for 90 min at 25 °C. The CO_2 adsorption kinetics of GrO were described by applying to obtain kinetic data for three different kinetic models. The Ar kinetic model has the best fit for CO_2 capture kinetic data.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Deniz SEZGİN: Performed the experiments and wrote the manuscript.

Müge SARI YILMAZ: Performed the experiments, analyzed the results and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Ghanbari T., Abnisa F., Wan Daud WMA., A review on production of metal organic frameworks (MOF) for CO_2 adsorption, ***Science of the Total Environment***, 707 (2020).

[2] Jiménez V., Ramírez-Lucas A., Díaz JA., CO_2 capture in different carbon materials, ***Environ Sci Technol,*** 46:7407–7414 (2012).

[3] Hu Y., Lu H., Liu W., Incorporation of CaO into inert supports for enhanced CO_2 capture: A review, ***Chemical Engineering Journal,*** 396 (2020).

[4] Sun H., Wu C., Shen B., Progress in the development and application of CaO-based adsorbents for CO_2 capture—a review, ***Materials Today Sustainability,*** 1–2:1–27 (2018).

[5] Gao N., Chen K., Quan C., Development of CaO-based adsorbents loaded on charcoal for CO_2 capture at high temperature, ***Fuel***, 260, (2020).

[6] Guo H., Xu Z., Jiang T., The effect of incorporation Mg ions into the crystal lattice of CaO on the high temperature CO_2capture, ***Journal of CO2 Utilization***, 37:335–345 (2020).

[7] Bhatta LKG., Subramanyam S., Chengala MD., Progress in hydrotalcite like compounds and metal-based oxides for CO_2 capture: A review, ***J Clean Prod,*** 103:171–196 (2015).

[8] Tan C., Guo Y., Sun J., Structurally improved MgO adsorbents derived from magnesium oxalate precursor for enhanced CO_2 capture, ***Fuel,*** 278 (2020).

[9] Geng YQ., Guo YX., Fan B., Research progress of calcium-based adsorbents for CO_2 capture and anti-sintering modification, ***Ranliao Huaxue Xuebao/Journal of Fuel Chemistry and Technology,*** 49:998–1013 (2021).

[10] Huang CH., Chang KP., Yu CT., Development of high-temperature CO_2 sorbents made of CaO-based mesoporous silica, ***Chemical Engineering Journal,*** 161:129–135 (2010).

[11] Granados-Pichardo A., Granados-Correa F., Sánchez-Mendieta V., Hernández-Mendoza H., New CaO-based adsorbents prepared by solution combustion and high-energy ball-milling processes for CO2 adsorption: Textural and structural influences, ***Arabian Journal of Chemistry***, 13:171–183 (2020).

[12] Tan YL., Islam MA., Asif M., Hameed BH., Adsorption of carbon dioxide by sodium hydroxide-modified granular coconut shell activated carbon in a fixed bed, ***Energy,*** 77:926–931 (2014).

[13] Zhao Y., Ding H., Zhong Q., Synthesis, and characterization of MOF-aminated graphite oxide composites for CO_2 capture, ***Appl Surf Sci,*** 284:138–144 (2013).

[14] Sari Yilmaz M., Karakas SB., Low-Cost Synthesis of Organic–Inorganic Hybrid MSU-3 from Gold Mine Waste for CO_2 Adsorption, ***Water Air Soil Pollut,*** 229 (2018).

[15] Chen C., Yang ST., Ahn WS., Ryoo R., Amine-impregnated silica monolith with a hierarchical pore structure: Enhancement of CO_2 capture capacity, ***Chemical Communications,*** 3627–3629 (2009).

[16] Li K., Jiang J., Tian S., Polyethyleneimine-nano silica composites: A low-cost and promising adsorbent for CO_2 capture, ***J Mater Chem A Mater,*** 3:2166–2175 (2015).

[17] Sari Yilmaz M., Synthesis of novel amine modified hollow mesoporous silica@Mg-Al layered double hydroxide composite and its application in CO_2 adsorption, ***Microporous and Mesoporous Materials,*** 245:109–117 (2017).

[18] Sari Yilmaz M., The CO_2 adsorption performance of aminosilane-modified mesoporous silicas, ***J Therm Anal Calorim,*** 146:2241–2251 (2021).

[19] Broda M., Kierzkowska AM., Müller CR., Influence of the calcination and carbonation conditions on the CO_2 uptake of synthetic Ca-based CO_2 sorbents, ***Environ Sci Technol,*** 46:10849–10856 (2012).

[20] Li Y., Zhao CS., Qu C., CO_2 capture using CaO modified with ethanol/water solution during cyclic calcination/carbonation, ***Chem Eng Technol,*** 31:237–244 (2008).

[21] Pham TH., Lee BK., Kim J., Lee CH., Enhancement of CO_2 capture by using synthesized nano-zeolite, ***J Taiwan Inst Chem Eng,*** 64:220–226 (2016).

[22] Guo B., Chang L., Xie K., Adsorption of Carbon Dioxide on Activated Carbon, ***Journal of Natural Gas Chemistry,*** 15:223-229 (2006).

[23] Zhang C., Song W., Sun G., CO_2 capture with activated carbon grafted by nitrogenous functional groups, ***Energy and Fuels,*** 4818–4823 (2013).

[24] Vorokhta M., Morávková J., Dopita M., Effect of micropores on CO_2 capture in ordered mesoporous CMK-3 carbon at atmospheric pressure, ***Adsorption,*** 27:1221–1236 (2021).

[25] Cinke M., Li J., Bauschlicher CW., CO_2 adsorption in single-walled carbon nanotubes, ***Chem Phys Lett***, 376:761–766 (2003).

[26] Wang J., Mei X., Huang L., Synthesis of layered double hydroxides/graphene oxide nanocomposite as a novel high-temperature CO_2 adsorbent, ***Journal of Energy Chemistry,*** 24:127–137 (2015).

[27] De Marco M., Menzel R., Bawaked SM., Hybrid effects in graphene oxide/carbon nanotube-supported layered double hydroxides: enhancing the CO_2 sorption properties, ***Carbon N Y***, 123:616–627 (2017).

[28] Liu Y., Sajjadi B., Chen WY., Chatterjee R., Ultrasound-assisted amine functionalized graphene oxide for enhanced CO_2 adsorption, ***Fuel,*** 247:10–18 (2019).

[29] Cai J., Chen J., Zeng P., Molecular Mechanisms of CO_2 Adsorption in Diamine-Cross-Linked Graphene Oxide, ***Chemistry of Materials***, 31:3729-3735 (2019).

[30] Chen D., Feng H., Li J., Graphene oxide: Preparation, functionalization, and electrochemical applications, ***Chem Rev,*** 112:6027–6053 (2012).

[31] White RL., White CM., Turgut H., Comparative studies on copper adsorption by graphene oxide and functionalized graphene oxide nanoparticles, ***J Taiwan Inst Chem Eng,*** 85:18–28 (2018).

[32] Sari Yilmaz M., Graphene oxide/hollow mesoporous silica composite for selective adsorption of methylene blue, ***Microporous and Mesoporous Materials,*** 330 (2022).

[33] Bayer T., Bishop SR., Nishihara M., Characterization of a graphene oxide membrane fuel cell***, J Power Sources,*** 272:239–247 (2014).

[34] Liu S., Sun L., Xu F., Nanosized Cu-MOFs induced by graphene oxide and enhanced gas storage capacity, ***Energy Environ Sci,*** 6:818–823 (2013).

[35] Chen L., Tang Y., Wang K., Direct electrodeposition of reduced graphene oxide on glassy carbon electrode and its electrochemical application, ***Electrochem commun,*** 13:133–137 (2011).

[36] Johra FT., Jung WG., Hydrothermally reduced graphene oxide as a supercapacitor, ***Appl Surf Sci,*** 357:1911–1914 (2015).

[37] Sontakke AD., Purkait MK., A brief review on graphene oxide Nanoscrolls: Structure, Synthesis, characterization and scope of applications, ***Chemical Engineering Journal,*** 420 (2021).

[38] Zhao Y., Ding H., Zhong Q., Preparation, and characterization of aminated graphite oxide for CO_2 capture, ***Appl Surf Sci,*** 258:4301–4307 (2012).

[39] Oh J., Lee JH., Koo JC., Graphene oxide porous paper from amine-functionalized poly(glycidyl methacrylate)/graphene oxide core-shell microspheres, ***J Mater Chem***, 20:9200–9204 (2010).

[40] Song G., Zhu X., Chen R., An investigation of CO_2 adsorption kinetics on porous magnesium oxide, ***Chemical Engineering Journal,*** 283:175–183 (2016).

[41] Loganathan S., Tikmani M., Edubilli S., CO_2 adsorption kinetics on mesoporous silica under wide range of pressure and temperature, ***Chemical Engineering Journal,*** 256:1–8 (2014).

[42] Hsan, N., Dutta, P. K., Kumar, S., Bera, R., Das, N. Chitosan grafted graphene oxide aerogel: Synthesis, characterization and carbon dioxide capture study. ***International Journal Of Biological Macromolecules***, 125:300-306 (2019).

[43] Pokhrel, J., Bhoria, N., Anastasiou, S., Tsoufis, T., Gournis, D., Romanos, G., Karanikolos, G. N. CO_2 adsorption behavior of amine-functionalized ZIF-8, graphene oxide, and ZIF-8/graphene oxide composites under dry and wet conditions. ***Microporous and Mesoporous Materials***, 267:53-67 (2018).

[44] Serna-Guerrero R., Sayari A., Modeling adsorption of CO_2 on amine-functionalized mesoporous silica: Kinetics and breakthrough curves, ***Chemical Engineering Journal,*** 161:182–190 (2010).

[45] Songolzadeh M., Soleimani M., Takht Ravanchi M., Using modified Avrami kinetic and two component isotherm equation for modeling of CO2/N2 adsorption over a 13X zeolite bed, ***J Nat Gas Sci Eng,*** 27:831–841 (2015).