Transdigital®

journal

Volume 7, Issue 13: January-June 2026

ISSN: 2683-328X

Sociedad de Investigación sobre Estudios Digitales S. C.

Transdigital Scientific Journal is a biannual publication under a continuous publication model, edited by the Sociedad de Investigación sobre Estudios Digitales S.C. So far, the journal has been indexed in: *Latindex, Dialnet, ERIHPLUS, REDIB, EuroPub, LivRe, AURA, Academic Resource Index (ResearchBib), MIAR, OpenAire-Explore, Refseek, Sherpa Romeo, Elektronische Zeitschriftenbibliothek, ZDB Zeitschriften Datenbank, WorldCat, Dimensions, The University of Liverpool, Discovery, Erasmus University Rotterdam, Mir@bel, REBIUN, DARDO, UOCI, LatinRev, ROAD, Google Scholar, Crossref, Scite, Lens, Internet Archive, BASE, OpenAlex, Semantic Scholar, and ScienceOpen*. Official address: Circuito Altos Juriquilla 1132, C.P. 76230, Querétaro, Mexico. Tel. +52 (442) 301-3238. Official website: www.revista.transdigital.mx. Email: revista@transdigital.mx. Editor-in-Chief: Alexandro Escudero-Nahón (ORCID: 0000-0001-8245-0838). Exclusive Use Rights Registration No. 04-2022-020912091600-102. International Standard Serial Number (ISSN): 2683-328X — both granted by the Instituto Nacional del Derecho de Autor (Mexico). Responsible for the latest update: Editor-in-Chief Alexandro Escudero-Nahón.

Transdigital® journal

Evaluation of the process of neutralization and adsorption of pollutant gases from industrial process practices in the laboratory

Evaluación del proceso de neutralización y adsorción de gases contaminantes provenientes de prácticas de procesos industriales en el laboratorio

Juana María Nájera Ibarra
National Technological of Mexico
ORCID: 0009-0007-7777-3596

Karla Victoria Guevara Amatón*
National Technological of Mexico
ORCID: 0009-0000-2829-4861

Alejandro Romero Barrientos
National Technological of Mexico
ORCID: 0009-0002-5145-3520

Kimberlee Delgado Goytia
National Technological of Mexico

Section: Research article

Received: 20/10/2025

Corresponding author*

Accepted: 31/03/2026

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Evaluation of the process of neutralization and adsorption of pollutant gases from industrial process practices in the laboratory

Evaluación del proceso de neutralización y adsorción de gases contaminantes provenientes de prácticas de procesos industriales en el laboratorio

Abstract

This study evaluated the neutralization and adsorption process for mitigating pollutant gases generated during acid digestion with lime. A 2^3 factorial design was used for this purpose, in which the following factors were analyzed: the concentration of the neutralizing reagent, sodium hydroxide (NaOH), at levels of 0.5 and one mol (M), vacuum pressure (five and 10 cm Hg), and the type of adsorbent material (bentonite and silica gel) were analyzed as factors. The results showed that bentonite has a higher adsorption capacity for the generated acid gases compared to silica gel. Furthermore, higher neutralization percentages are achieved using a NaOH concentration of one M. Additionally, the pressure factor showed that reducing the vacuum pressure from 10 to five cm Hg yields better neutralization and adsorption results. Overall, the results indicate that the most favorable conditions for acid gas mitigation in the evaluated system correspond to the use of one M NaOH, a vacuum pressure of five cm Hg, and bentonite as the adsorbent material.

Keywords: adsorption, neutralization, pollution

Resumen

En el presente trabajo se evaluó el proceso de neutralización y adsorción para la mitigación de gases contaminantes generados durante digestiones ácidas con calcina. Para ello, se empleó un diseño factorial 23, en el cual se analizaron como factores la concentración del reactivo neutralizante de hidróxido de sodio (NaOH) con niveles de 0.5 y un mol (M), la presión de vacío (cinco y 10 cm Hg) y el tipo de material adsorbente (bentonita y sílica gel). Los resultados mostraron que la bentonita tiene mayor capacidad de adsorción de los gases ácidos generados en comparación con la sílica gel. Además, se logran mayores porcentajes de neutralización empleando una concentración de NaOH de un M. Asimismo, el factor presión mostró que al disminuir la presión de vacío de 10 a cinco cm Hg se obtienen mejores resultados de neutralización y de adsorción. En conjunto, los resultados indican que las condiciones más favorables para la mitigación de gases ácidos en el sistema evaluado corresponden al uso de NaOH a un M, una presión de vacío de cinco cm Hg y bentonita como material adsorbente.

Palabras clave: adsorción, neutralización, contaminación

Nájera-Ibarra, J. M., Guevara Amatón, K. V., Romero Barrientos, A., & Delgado-Goytia, K. (2026). Evaluation of the process of neutralization and adsorption of pollutant gases from industrial process practices in the laboratory. *Transdigital*, *7*(13), e604. https://doi.org/10.56162/transdigital604

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

1. Introduction

Environmental pollution is one of the world's major problems, making it necessary to seek alternatives that offer a prompt solution (Gálavis Román & Kabir, 2024; Palacios Anzules & Moreno Castro, 2022). The generation of pollutant gases in chemical and industrial processes represents a significant environmental problem, affecting air quality and human health (Jems, 2023). That is why the development of efficient technologies for their capture and treatment is a topic of growing interest in current research.

One of the most commonly used strategies for treating these gaseous effluents is chemical neutralization, which involves passing them through an alkaline solution. This neutralizes the H+ ions and, consequently, increases the pH (Flores-Armenta et al., 2009). The neutralization of acid gases in industrial processes, such as mineral roasting or the combustion of fossil fuels, is a key step in controlling pollutant emissions. This process is primarily based on the chemical absorption (neutralization) of gases such as sulfur dioxide (SO_2) and hydrochloric acid (HCl) using alkaline solutions, calcium hydroxide, or sodium hydroxide (Hang et al., 2024). Research has demonstrated that these methods can achieve efficiencies exceeding 90% in SO_2 removal, especially when variables such as pH (Krzyzynska & Hutson, 2012; Sajjad et al., 2021), temperature, and gas-liquid contact time (Sajjad et al., 2021) are optimized. Furthermore, the use of adsorbent materials that combine absorption and oxidation to improve efficiency and reduce secondary residues is highlighted (Park et al., 2021). The use of neutralization represents an effective and sustainable solution to mitigate the environmental impact of industrial emissions.

Among the various technologies available, adsorption has established itself as one of the most efficient methods for purifying gas streams due to its high efficiency, operational simplicity, and the ability to regenerate the adsorbent (Zhang, 2025). Gas adsorption in industrial processes is a widely used technique for removing pollutants such as SO_2, carbon dioxide (CO_2), nitrogen oxides (NOx), and volatile organic compounds (VOCs), based on the fixation of these species onto the surface of solid materials such as activated carbon, zeolites, or advanced adsorbents. This process depends on physical and chemical interactions, and its efficiency is strongly influenced by variables such as temperature, pressure, and the surface properties of the adsorbent (specific surface area, porosity, and functionalization). It has been reported that adsorption is particularly effective in low-concentration streams and can be integrated with regeneration processes to improve its economic viability using hybrid materials or modified activated carbon (Li et al., 2016, Bandosz, 2006).

It is important to optimize operating conditions and adsorbent properties to maximize the capacity and selectivity of the process in industrial applications. Various porous materials have been studied as adsorbents, including porous materials such as silica gel (Zheng et al., 2025). Silica gel has high porosity and abundant silanol groups on its surface, which promote the adsorption of various gaseous species (Jacobs et al., 2023). Silica gel is a highly versatile adsorbent and the most prevalent adsorbent due to its high surface area and stability (Hraiech et al., 2025), making it an excellent choice for adsorption. Meanwhile, recent studies have shown that bentonite—a clay material consisting mainly of montmorillonite and one of the most abundant clay minerals in the world—can

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

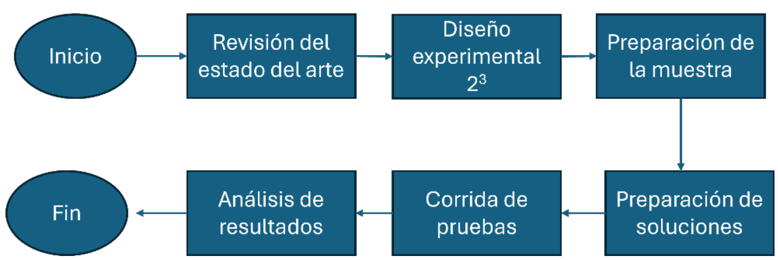
remove gases such as hydrogen sulfide, highlighting its potential for environmental applications (Jiang et al., 2023; Lasich, 2020). Furthermore, clays such as bentonite possess a layered structure and high ion exchange capacity, making them efficient adsorbents for the removal of contaminants (Mejri & Oueslati, 2024; Jemai et al.,2024).

Therefore, the objective of this study was to evaluate the performance of a neutralizing-adsorbent system for mitigating acid gases generated by acid digestion, analyzing the influence of operating conditions on the system's efficiency. The results obtained provided the basis for its subsequent installation in an extraction system in a school laboratory and, thereby, contributed to the care and preservation of the environment by reducing the environmental impact associated with the capture of gaseous pollutants from the simulation of industrial processes.

2. METHODO OF RESEARCH

This research was conducted using an applied experimental approach, with the aim of evaluating the efficiency of a gas neutralization and adsorption process by optimizing the concentration of sodium hydroxide (NaOH), the operating pressure, and the type of adsorbent. The study was carried out on a laboratory scale, employing quantitative analysis of the response variables to determine the optimal process conditions. The experimental system consisted of a gas treatment process comprising a chemical neutralization stage using aqueous NaOH solutions, followed by a solid adsorption stage, the objective of which was to remove acidic gaseous compounds present in the gas stream generated during the experimental process (Figure 1).

Figure 1
Methodological design



Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Initially, a literature review of the state of the art was conducted. The aim was to gather scientific and technical information related to gas generation during acid digestion processes, chemical neutralization methods, and gas adsorption processes. This enabled the definition of the study variables, the selection of appropriate reagents and materials, and the establishment of preliminary operating ranges. Subsequently, an experimental design was established to evaluate the efficiency of the neutralization and/or adsorption processes under different operating conditions (initial concentration of the neutralizing solution, vacuum pressure, and adsorbent material). Next, the samples were conditioned using a -200 mesh calcine, ensuring homogeneous characteristics in terms of particle size and composition. This step was essential to ensure the reproducibility of the tests and minimize variability in the results obtained during acid digestion.

In subsequent stages, the chemical solutions were prepared; their concentrations were determined based on the experimental design in order to evaluate their effect on the efficiency of the neutralization and adsorption process. For the acid solution, an acidity of 80 grams per liter (g/L) was used. To do this, 155 milliliters (mL) of concentrated sulfuric acid (98%, ρ = 1.84 g/mL) were slowly added to a container containing 60% of its volume of distilled water; once room temperature was reached, the solution was made up to a final volume of 3.5 liters (L). to verify the concentration of the acid solution, a 1 mL aliquot was taken, and the actual concentration of the sulfuric acid solution was verified by acid–base titration using 0.1 N NaOH as the titrant. Likewise, NaOH solutions were prepared at concentrations of 1 M and 0.5 M from solid NaOH; for this, 40 and 20 g of NaOH were weighed, respectively, and dissolved in distilled water. Once dissolved, the solution was made up to 1 L with distilled water and stored in an airtight bottle. and the molarity was immediately verified using potassium biphtalate and phenolphthalein.

Once the sample had been conditioned and the solutions prepared, the experiments were conducted in a randomized manner under the conditions specified in the experimental design. This involved performing acid digestions and passing the generated gases through the neutralization and adsorption system, while recording the variables necessary for evaluating the process. Finally, the results obtained were analyzed.

3. Results

During the experimental phase, the effect of the neutralizing solution concentration (0.5 M and 1 M NaOH) and vacuum pressure (5 and 10 cm Hg) on the neutralization efficiency and adsorption capacity of the materials used (bentonite and silica gel) was evaluated. All tests were conducted at a constant temperature and speed (80 °C and 400 revolutions per minute [rpm]), with a contact time of one hour (Table 1).

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Table 1
Results of the experimental tests

Material	Concentration (M)	Vacuum pressure (cm Hg)	Neutralisation (%)	Adsorption (gr)
Bentonita	0.5	5	2	5
Silica	0.5	5	5	5.45
Bentonita	1	5	34.5	19.1
Silica	1	5	25	19.9
Bentonita	0.5	10	3	6
Silica	0.5	10	3	5.2
Bentonita	1	10	25	27.7
Silica	1	10	22	2.3

To evaluate the effects of each of the factors influencing the neutralization/adsorption process, a main effects plot was created (Figure 2), as shown for the response variable Neutralization (%). The adsorbent material showed a moderate effect on the neutralization process, with slightly higher values observed when bentonite was used compared to silica gel, indicating a greater capacity for adsorbing acid gases. Meanwhile, the concentration of the neutralizing agent was the factor with the greatest influence on the process, with a considerable increase in neutralization efficiency observed when using a 1 M solution compared to a 0.5 M solution. Finally, the evaluated vacuum pressure did not show a significant effect on the neutralization process, so it can be concluded that it does not influence the neutralization process.

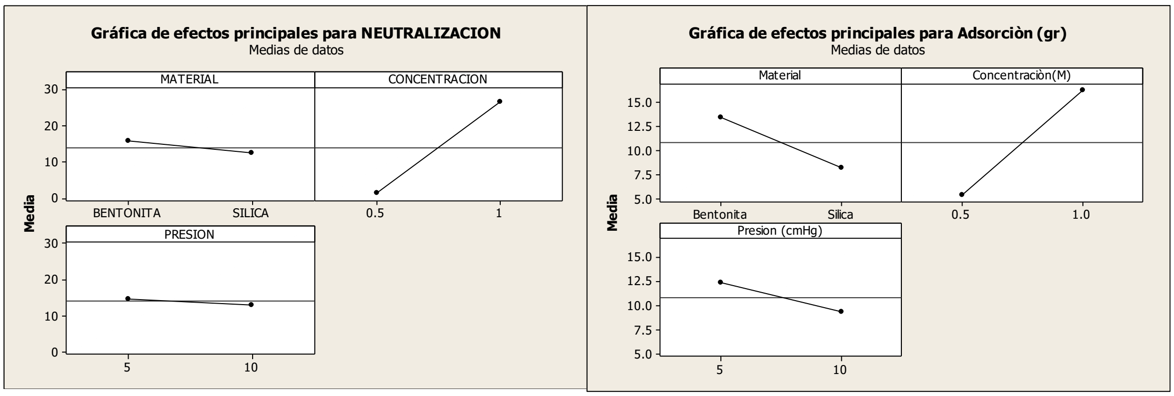
On the other hand, for the adsorption response variable, the downward slope in the material factor indicates that bentonite exhibits a higher adsorption capacity compared to silica gel under the evaluated conditions. Regarding concentration (M), the graph shows that an increase in NaOH concentration is associated with an increase in the amount adsorbed. With respect to pressure (cm Hg), a slight negative effect is observed; as pressure increases, adsorption decreases. The relatively gentle slope indicates that this factor has a moderate effect compared to concentration, although it does influence the system's response.

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Figure 2

Graph showing the main effects on the response variables: neutralization and adsorption



Overall, the results indicated that the material and concentration are the main determinants in the neutralization/adsorption process, with bentonite at a higher alkaline concentration being the combination that exhibits the best neutralizing and adsorbing capacity in the system. To analyze the individual behavior of each of the factors evaluated in the neutralization and adsorption system, a study was conducted on each of these variables (*material*, *concentration*, and *vacuum pressure*).

It was observed that the *material* factor had a moderate effect on the response variables of neutralization and adsorption across the evaluated levels. On the other hand, it was found that the use of bentonite yields higher neutralization and adsorption values compared to silica, suggesting that the surface characteristics and ion exchange capacity of bentonite promote greater interaction with the alkaline medium, improving the retention and neutralization of acidic compounds. When using bentonite as an adsorbent medium, a greater amount of adsorbed gases is obtained in grams. Therefore, bentonite is considered more effective for the process (Figure 3).

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

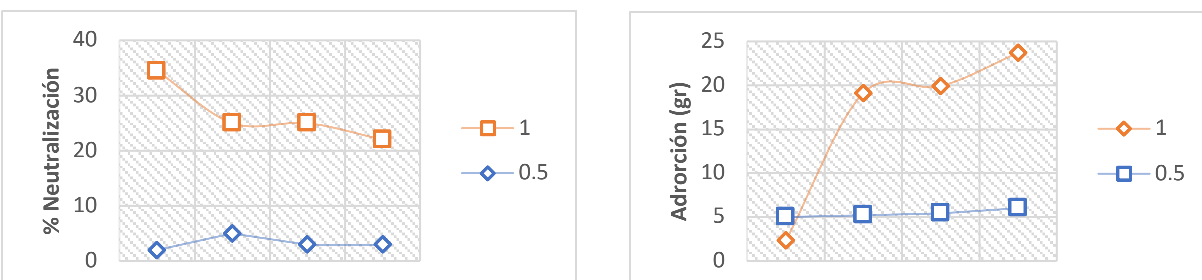
Figure 3

Effect of the material variable on the neutralization/adsorption system

The results showed a significant increase in the efficiency of the neutralization/adsorption system when the NaOH concentration was increased from 0.5 M to 1 M. Consequently, a 1 M concentration represents the most favorable condition for maximizing process efficiency; using a 1 M concentration of NaOH yielded higher neutralization percentages compared to when a 0.5 M concentration of NaOH was used (Figure 4).

Figure 4

Effect of varying NaOH concentrations on the neutralization/adsorption system



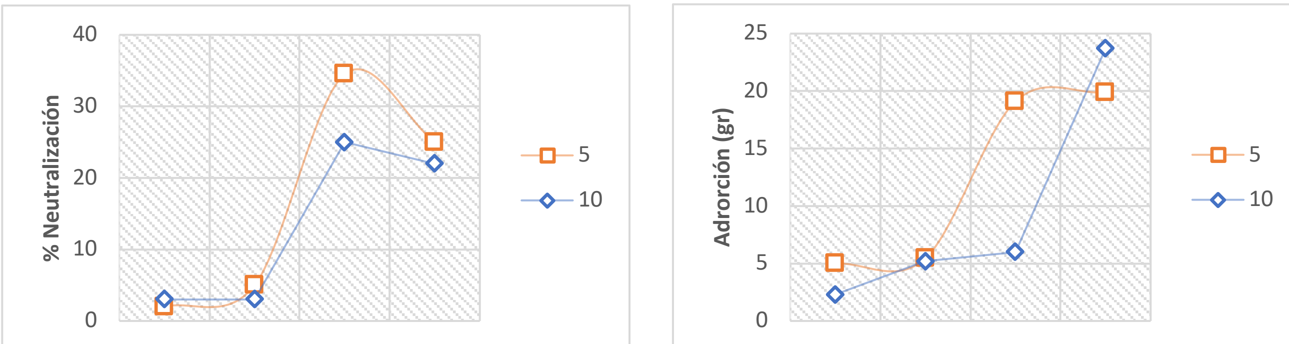
It was found that, when a vacuum pressure of 5 cm Hg was applied, there was a slight positive increase in both neutralization and adsorption (Figure 5), even though the pressure variable, according to the main effects plot, is a factor that has no influence on neutralization, as it showed a minimal or no effect (Figure 2). This indicates that within the studied vacuum pressure range (5 and 10 cm Hg), no significant changes in neutralization are observed.

Transdigital® journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Figure 5

Effect of varying vacuum pressure on the neutralization/adsorption system



4. Discussion and conclusions

An analysis of the main effects made it possible to evaluate the influence of the adsorbent material, neutralizing agent concentration, and vacuum pressure on the efficiency of the gas treatment system. The response variables analyzed were neutralization and acid gas adsorption capacity, which provided insight into the overall behavior of the neutralization/adsorption system.

According to the main effects plots, the NaOH concentration was the factor with the greatest influence on both response variables: neutralization efficiency and adsorption capacity. In both cases, a considerable increase was observed when the concentration was raised from 0.5 M to 1 M. This behavior can be explained by the principles of chemical adsorption and acid–base neutralization, where the availability of reactive species in solution controls the acid gas capture capacity (Sobrinho et al., 2025). In gas treatment systems using alkaline solutions, increasing the concentration of the reagent increases the reaction rate and improves mass transfer efficiency between the gas phase and the liquid phase, favoring the neutralization of the generated gases (Üresin 2025; Kurella et al., 2015). Consequently, the use of a more concentrated solution increases the system's neutralization capacity and reduces the presence of acidic species in the gas stream, creating more favorable conditions for the subsequent adsorption stage.

The results indicated that bentonite performed better than silica in both neutralization and the adsorption capacity of gaseous species. This behavior can be explained by the physicochemical properties of bentonite, which is composed mainly of montmorillonite, a clay mineral consisting of three layers (Jemai et al., 2024; Olegario & Gili, 2021). One of the main characteristics of this mineral is its high surface area, which provides a large number of active sites available for interaction with contaminants or chemical species; it has been reported that montmorillonite can have surface areas ranging from 600–800 m^2/g; This is due to its layered structure and the small size of its particles, which significantly enhances adsorption processes (Mejri & Oueslati, 2024; Jemai et al., 2024).

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

With regard to vacuum pressure, the results indicate that its effect was less significant compared to the other factors evaluated. Although the effect of vacuum pressure on the neutralization variable is not very significant, a slight improvement was observed when the system operated at 5 cm Hg compared to 10 cm Hg for both neutralization and adsorption. A moderate vacuum may promote a more stable gas flow, allowing for greater interaction between the generated gases and the materials present in the treatment train. As the vacuum increases, the gas flow may increase and reduce the contact time with the neutralizing agent and the adsorbent (González-Delgado et al., 2026), which could explain the slight decrease observed in process efficiency.

Therefore, for this system designed to neutralize and adsorb acid gases from acid digestions, the optimal conditions are: bentonite as the adsorbent material, a concentration of 1 M NaOH, and a vacuum pressure of 5 cm Hg. This study provides a basis for its subsequent implementation in a gas extraction system in a school laboratory. However, prior to implementation, it is recommended to analyze the saturation time of the adsorbent material and to modify the vacuum pressure levels to determine whether better results can be achieved, since in this system only neutralization percentages of up to 35% and an adsorption of approximately 30 g were attained.

References

Bandosz, T. J. (2006). Activated carbon surfaces in environmental remediation. *Journal of Hazardous Materials, 135*(1), 1–14.

Flores-Armenta, M., Ramírez-Montes, M., & García Cuevas, J. M. (2009) Propuesta para la neutralización de fluidos ácidos provenientes de pozos del campo geotérmico de Los Humeros, Pue. *Geotermia, 22*(2), 10-18.

Gálavis Román, Á. F., & Kabir, G. (2024). Assessing Carbon Dioxide Emissions in Manufacturing Industries: A Systematic Review. *Energies, 17*(20), 5119. https://doi.org/10.3390/en17205119

González-Delgado, Á., Villabona-Ortiz, Á., Ortega-Toro, R., Tejada-Tovar, C., & Bernal-Sanjuan, J. (2026). Technical Evaluation of the Influence of Inlet Flow Rate and Bed Height on a Packed Column Containing Residual Biomass During Computer-Aided Industrial Scale-Up. *Environments, 13*(1), 28.

Hang, Y., Chuanjia, S., Jinjin L., Xueyan, H. & Linjun, Y.(2024). Alkaline absorbents for SO2 and SO3 removal: A comprehensive review. *Journal of Environmental Management, 336*, 121531.

Hraiech, I., Zallama, B., Belkhiria, S., Zili-Ghedira, L., Maatki, C., Hassen, W., Hadrich, B., & Kolsi, L. (2025). Experimental characterization of silica gel adsorption and desorption isotherms under varying temperature and relative humidity in a fixed bed reactor. *Scientific Reports, 15*(1), 29041.

Jacobs, J. H., McKelvie, K. H., Nanji, S., & Marriott, R. A. (2023). Sour Gas Adsorption on Silica Gels. *ACS Omega, 8*(13), 12592-12602.

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Jemai, R., Chalghaf, R., Boubakri, S., Amine Djebbi, M., Naamen, S., Ben Rhaiem, H., & Ben Haj Amara, A. (2024). *Montmorillonite: Properties, Characteristics, and Its Harnessing in Environmental Applications*. IntechOpen. https://doi.org/10.5772/intechopen.1004763

Jems, D. (2023) Industrial Emissions: Unveiling the Environmental Impactsand the Pursuit of Sustainable Solutions. *Environ Pollut Climate Change 7*, 361.

Jiang, Q., Jiang, M., Han, T., He, Y., Li, T., Zhang, J., Su, Y., Wu, Y., Dian, B., & Zong, Y. (2023). Removal of hydrogen sulfide in the gas phase by carbide slag modified bentonite. *RSC Advances, 13*(30), 20844–20855.

Krzyzynska, R., & Hutson, N. D. (2012). Effect of solution pH on SO2, NOx, and Hg removal from simulated coal combustion flue gas in an oxidant-enhanced wet scrubber. *Journal of the Air & Waste Management Association, 62*(2), 212–220. https://doi.org/10.1080/10473289.2011.642951

Kurella, S., Balla, M., Bhukya P. K., & Meikap B. C. (2015). Scrubbing of HCl Gas from Synthesis Gas in a Multistage Dual-Flow Sieve Plate Wet Scrubber by Alkaline Solution. *Journal of Chemical Engineering & Process Technology, 6*(5). https://doi.org/10.4172/2157-7048.1000250

Lasich, M. (2020). Adsorption of H_2S from hydrocarbon gas using doped bentonite: A molecular simulation study. *ACS Omega, 5*(31), 19877-19883. https://doi.org/10.1021/acsomega.0c02934

Li, J., Wang, S., & Lu, G. Q. (2016). Adsorption of CO_2 on advanced porous materials: A review. *Chemical Engineering Journal, 281*, 1–15.

Mejri, C., & Oueslati, W. (2024). *A Critical Review of Clay Minerals for Groundwater Protection and Treatment*. IntechOpen. https://doi.org/10.5772/intechopen.1008385

Olegario, E. M., & Gili, M. B. Z. (2021). Characterization of Philippine natural bentonite. *Experimental Results, 2*, e25. https://doi.org/10.1017/exp.2021.16

Palacios Anzules, Í. del C., & Moreno Castro, D. W. (2022). Contaminación ambiental. *Recimundo, 6*(2), 93–103. https://doi.org/10.26820/recimundo/6.(2).abr.2022.93-103

Park, H. S., Kang, D., Kang, J. H., Kim, K., Kim, J., & Song, H. (2021). Selective Sulfur Dioxide Absorption from Simulated Flue Gas Using Various Aqueous Alkali Solutions in a Polypropylene Hollow Fiber Membrane Contactor: Removal Efficiency and Use of Sulfur Dioxide. *International Journal of Environmental Research and Public Health, 18*(2), 597. https://doi.org/10.3390/ijerph18020597

Sajjad, D., Ghorbani-Shahna, F., Babak, J., & Tapak, L. (2021). Development of scrubber with nano-TiO2 coated packing for H2S removal. *Journal Process Safety and Environmental Protection 149*, 158-168.

Sobrinho, R. A. L., De J Souza, W., De S. Souza, D. F., De O Júnior, A. M., & Marques, J. J. (2025). Mathematical Modeling of Acidity Removal from Natural Gas through Alkaline Scrubbing. *ACS Omega, 10*(35), 40625–40634.

Üresin, E. (2025). Experimental and Simulation-Based Study of Acid Gas Removal in Packed Columns with Different Packing Materials. *Sustainability, 17*(23), 10495.

Transdigital journal

Sociedad de Investigación sobre Estudios Digitales S.C. | ISSN: 2683-328X

Zhang, L. (2025). Global Insights into Adsorption Processes for Environmental and Industrial Applications. *Internacional Journal Waste Resour, 15*, 629.

Zheng, Y., Wang, Y., Lv, S., Chang, Y., Chen, P., & Ma, Z. (2025). Research progress of siloxanes adsorption from biogas based on porous materials. *Chemical Engineering Science, 319*, 122292.