Applications of aluminum oxide and nano aluminum oxide as adsorbents: review

Hawraa Kassem Hami, Ruba Fahmi Abbas*, Emad Mahmoud Eltayef, Neda Ibrahim Mahdi
Department of Chemistry, College of Science, Al-Mustansiriya University, Baghdad, Iraq (suha_rrr_1983@yahoo.com)

Article Information
Received: 24/01/2020
Accepted: 05/04/2020

Keywords:
Aluminum oxide, Nano Aluminum oxide, adsorbents, Dyes and Antibiotics

Abstract
Metal oxides are widely used in adsorption technology as adsorbent surfaces because of their efficiency, low cost and unique physical properties. The aim of this review to clarify the role of aluminium oxide and Nano aluminium oxide in removing some chemicals contain that influence on human health such as dyes, antibiotics, and heavy metals. This paper also includes the affective of some adsorption parameters like pH, contact time, removal percentageand temperature. The Adsorption nature, kinetic adsorption models and isotherm models are also reported here.

Introduction
Pollution is currently one of the most widespread environmental problems that began to emerge in the 20th century because of industrial growth associated with the industrial revolution, all this lead to the emergence of new categories of previously unknown chemicals[1]. Thus, it is necessary to find cheap and effective ways that contribute to decontamination and maintain a clean and healthy environment for future generations.

Over the past years, adsorption has emerged as an efficient technique widely used in removing pollutants from the environment. This technology is simple, cheap and environmentally friendly, one of the most important things for effective adsorption is chosen the right surface[2,3]. For all these reasons, there is an increasing trend of research papers published in adsorption removals in the aqueous phase[4].

Metal oxides are the most commonly used surfaces in the removal of contaminants; they are cheap and widely manufactured, In addition to their high mechanical properties and resistance to thermal decomposition compared to biological surfaces[5]. One of the renowned oxides is Aluminium oxide (Al₂O₃) which is an amphoteric oxide known as alumina and found in many crystalline structures like 'α-Al₂O₃, γ-Al₂O₃, θ-Al₂O₃, η-Al₂O₃' etc. "Fig. 1 and 2". different in physical and chemical properties as well as applications[6]. Aluminium oxide is characterized by its non-toxic, easy used, chemical stability and has many hydroxide groups all these property mad it efficient adsorbent. From 1923 Aluminium oxide had usage as adsorbed to remove Pigments, antibiotics, heavy metals, dissolved organics etc.[7,8].
In the light of the continuous development in the field of nanotechnology and its use in treatment pollution of the environment, interest increasing in the use of metal oxides as nanoparticles as absorbers to remove pollutants from the environment[9], especially Aluminium oxide nanoparticles inasmuch to it inexpensive, high surface area, surface reactivity, well adsorption ability, surface acidity and thermal stability[10,11]. There are many techniques to prepared aluminium oxide nanoparticles powder including ball milling, hydrothermal, sol-gel, co-precipitation, pyrolysis, laser ablation, vapour phase reaction and combustion methods[12].

![Figure 1: Structure of α-Al₂O₃](image)

![Figure 2: Characterization of alumina oxide (a)- Al₂O₃ powder (b)- SEM form at enlargement of 10.00 KX.14428 for Al₂O₃ nanoparticle[13].](image)

**Chemicals Pollution**

All living and non-living substances consist of chemicals and every manufactured product we use in our daily lives includes chemicals. These substances can contribute to improving our health and well-being when used duly. In contrast, hazardous chemicals can cause health and environmental damage when used improperly[14].

International organizations such as "WHO, USEPA, ATSDR and EU" analysis of the impact of toxic metal ions and pollutants on human health - the increase of concentration of these substances cause serious health damage. Table 1 summarizes some of the toxic elements and their admissible limits in water and their impact on human health according to these organizations.

**Table 1:** Toxic contaminants in drinking water and their influence on human health

---

**Table 1:**

| Toxic Contaminants | Concentration Limit (μg/L) | Impact |
|--------------------|---------------------------|--------|
| Lead (Pb)          | 10                        | Neurological disorders |
| Cadmium (Cd)       | 0.003                     | Renal failure |
| Mercury (Hg)       | 0.0005                    | Neurological disorders |
| Arsenic (As)       | 10                        | Skin and blood damage |
| Chromium (Cr)      | 5                         | Kidney damage |
| Barium (Ba)        | 2                         | Bone damage |
| Manganese (Mn)     | 2                         | Neurological disorders |
| Nickel (Ni)        | 5                         | Renal failure |
| Cobalt (Co)        | 5                         | Neurological disorders |
| Copper (Cu)        | 1                         | Liver damage |
| Zinc (Zn)          | 5                         | Neurological disorders |

---
| Contaminant       | Allowable Limits of concentration mg/l | Possible impact of toxic elements on human health                                                                 | Ref. |
|------------------|----------------------------------------|-------------------------------------------------------------------------------------------------------------------|------|
| Arsenic          | 0.01                                   | Skin harm or circulatory problems, may increase the risk of cancer, black foot disease                              | 15   |
| Azo dyes         |                                        | Causes chromosomal damage and cancer.                                                                               | 16   |
| Cadmium          | 0.05                                   | Kidney damage, lowering red blood cells, hypertension,                                                            | 17   |
| Chromium         | 0.1                                    | Loss Calcium from the bone, staining the yellow teeth (forming a cadmium ring) and damage to the bone marrow, renal failure, lung irritation | 18   |
| Copper           | 1.3                                    | Short-term exposure: digestive distress                                                                            | 18   |
|                  |                                        | Long-term exposure: damage in liver or kidney                                                                   | 18   |
| Fluoride         | 4                                      | Bone diseases and children may lose their teeth                                                                  | 18   |
| Eosin yellow     | -                                      | Skin irritation                                                                                                  | 5    |
| Lead             | 0.015                                  | Infants and children: delay in physical or mental development, high level cause coma and die Adults: kidney problems, Hypertension, Memory or focus problems | 17   |
| Iron             | 0.3                                    | Lung cancer                                                                                                     | 19   |
| Nickel           | 0.02                                   | Cancer of the lung, nose, laryngeal and nickel itch                                                              | 20   |
| Nitrate          | 11.3                                   | It poses a risk to infants younger than 6 months and pregnant women                                              | 18   |
| Malachite green dye | -                                    | Lung cancer                                                                                                     | 9    |
| Mercury          |                                        | Affects the digestive and immune systems, Cancer                                                                 | 18   |
| Molybdenum       | 10–15                                  | Joint pain, gout-like symptoms, and high uric acid in the blood                                                 | 18   |
| Phenol           | -                                      | Extremely Toxic, mutagenic and absorbed by skin                                                                  | 16   |
| Phosphate        | -                                      | Affect the calcium in the body and cause damage to the kidneys                                                   | 21   |
| Selenium         | 0.05                                   | Hair loss and nails circulatory problems, cancer                                                                  | 18   |
| Thallium         | 0.0005                                 | Hair loss; Blood changes, Problems with the kidney, intestine and liver.                                          | 16   |
| Zinc             | 5                                      | Short time: stomach cramps, nausea, vomiting may occur. Long time: anemia, pancreatic damage, and low-density lipoprotein cholesterol levels | 22   |

Continuing the production and use of chemicals worldwide requires a safety system to dispose of these chemicals. In this article, we will talk about some hazardous chemicals that removed by adsorption technology on the surface of Al₂O₃ and Nano Al₂O₃.
**Adsorption parameter**

Adsorption process happens either in one step or in a set of steps like Film or external diffusion, pore spreading, surface spreading and adsorption on the surface of the pores. Fig. 3 shows the pathways of adsorption process[23].

![Diagram of Adsorption Process](image)

**Fig. 3:** Pathways of adsorption process Knowing the optimum conditions will help increase the efficiency of the adsorption process and choose the right surface for best results.

There are several parameters that impact in the adsorption process which are studied to reach optimal conditions that give the highest removal percentage. In this review we take removal percentage, pH, temperature, time, and isotherm.

1. **Removal percentage:** It is known that the higher the percentage of removing pollutants from the environment, the more efficient the adsorption process. Therefore, knowing the percentage of removing pollutants contributes in choosing the appropriate conditions that give the highest efficiency [4].

2. **pH of solution** is vital factor that impact in the adsorption efficiency. It enhances adsorption removal of cationic or basic adsorbate but reduces that of anionic or acidic adsorbate[13].

3. **Temperature:** An increase in the adsorption capacity with an increase in temperature is recognized as an endothermic and a low absorption capacity with an increase in the temperature of the solution is called exothermic. So Temperature reinforces adsorption removal of water pollutant by increasing activity of the surface and kinetic energy of the adsorbate but may damage adsorbent physical structure[10].

4. **Contact time:** as shown in Fig. 4 the reinforces adsorption removal rate of adsorption pollutant by less its mass transfer resistance[10].

5. **Isotherm modelling:** It helps to know the adsorption mechanism, clarify surface properties and also helps in designing an effective adsorption system[16].
Fig. 4: Sample of adsorption parameter that effect of adsorption in Al₂O₃ and Nano Al₂O₃ surface[10, 13].

Applications
1-Dyes
Dyes are dangerous and carcinogenic organic pollutants that affect living organisms. Dyes are used in many industries like food colouring, cosmetics, paper and textile industries and they are characterized by being light-stable and non-biodegradable as well as causing water
discoloration. There were many techniques to depose dyes. Adsorption technology is most efficiency among them[24,25].

The dye adsorption process involves two mechanics (adsorption and ion exchange) and impacted by numerous parameters like dye/adsorbent reaction, Surface area of adsorbents, pH, contact time, particle size and temperature. The adsorption feature has become a cheap use of sorbents, which reduces the cost of the step[26].

Many Azo dyes like"Methylene Blue, Orange G, Acid Orange-7 and Eriochrom Black T" had removed by Al₂O₃ and Nano Al₂O₃ surface, Fig. 5. Table 2 listed the removal of some dyes in these two surfaces.

**Table 2: Adsorption of different dyes in Al₂O₃ and Nano Al₂O₃ surface**

| Dyes            | Adsorbed       | Removal % | Contact Time (min.) | Isotherm | Temp. | Adsorption nature | pH | Ref. |
|-----------------|----------------|-----------|---------------------|----------|-------|--------------------|----|------|
| Methylene Blue  | Nano Al₂O₃     | 81.2      | 25                  | Langmuir | Endothermic | Physical           | 10 | 13   |
| Orange G        | Nano Al₂O₃     | -         | 30                  | Langmuir | -       | Physical           | -  | 10   |
| Malachite green | Al₂O₃          | -         | 60                  | Langmuir | -       | Physical           | 7  | 3    |
| Eosin yellow    | Nano Al₂O₃     | 99.3      | 120                 | Langmuir | Endothermic | Chemical           | 4  | 27   |
| Acid Orange-7   | Nano Al₂O₃     | 100       | 60                  | -        | Endothermic | -                  | 2  | 28   |
| Eriochrom Black T | Al₂O₃        | 88        | 30                  | Langmuir | Endothermic | Chemical           | 7  | 29   |

**Fig.5: photographs of Eriochrom Black T before and after adsorption[29]**

**2-Antibiotics**

Antibiotics are deem as an environmental and health challenges due to their genotoxic and mutagenic influences and continuance in natural ecosystem[30].

The widespread use of antibiotics in the treatment of human and animal infections has led to the throw of these antibiotics in the form of wastes that cause soil and water contamination, So it is of vital to remove the antibiotic Waste from source like house, hospitals and pharmaceuticals factories before release them to ecological. One of these antibiotics is the tetracycline family which widely used in the treatment of many infections. The cheapness and availability of these antibiotics as well as their therapeutic effect has led to their widespread
use in developing countries. The majorities of these antibiotics are not absorbed by the body and released into the environment causing environmental pollution[31,32].

Previous studies have shown a strong relationship between tetracycline derivatives and the surface of aluminium oxide that made aluminium oxide surface is one of the best surfaces used in the removal of these antibiotics from the environment, as shown in table 3. The adsorption of tetracycline group on the surface of Al₂O₃ is chemical adsorption and ligand-promoted dissolution is obtained during the adsorption process[33]. The adsorption of tetracycline hydrochloride, chlortetracycline hydrochloride and oxytetracycline hydrochloride show that the deformation energy is much less than their non-bonding energy and the adsorption happen by non-bond reaction[34]. Other research reveals existence strong transformation reaction rate correlates by the formation of surface complex between tetracycline and Al₂O₃[35], also the nature of adsorption for this Antibiotics is physical.

**Table 3:** Adsorption of tetracycline derivatives in Al₂O₃ and Nano Al₂O₃ surface

| Antibiotics                  | Adsorbed | Removal % | Contact Time (min.) | Isotherm   | Temp.     | Adsorption nature | pH | Ref. |
|------------------------------|----------|-----------|---------------------|------------|-----------|-------------------|----|------|
| Chlorotetracycline           | Al₂O₃    | 22        | 180                 | -          | -         | -                 | 5  | 35   |
| Chlortetracycline hydrochloride | Al₂O₃    | 66.21     | 120                 | Freundlich | Endothermic| Physical           | 5  | 34   |
| Doxycycline                  | Al₂O₃    | 81.32     | 90                  | -          | -         | Physical           | 10 | 36   |
| Oxytetracycline              | Al₂O₃    | 15.8      | 180                 | -          | -         | Physical           | 5  | 35   |
| Oxytetracycline hydrochloride| Al₂O₃    | 69.48     | 120                 | Freundlich | Endothermic| Physical           | 5  | 34   |
| Tetracycline                 | Al₂O₃    | 18.8      | 180                 | -          | -         | -                 | 5  | 35   |
| Tetracycline hydrochloride   | Al₂O₃    | 95        | 1440                | -          | -         | Physical           | 5.3| 34   |
| Oetracycline hydrochloride   | Al₂O₃    | 72.62     | 120                 | Freundlich | Endothermic| Physical           | 7  | 34   |

**3-Heavy metals**

One of the serious environmental problems is the pollution of Heavy metal even when it is present in low concentrations significantly and non-degradability affects in the environment around us and accumulate in the food chain and causes many risks on human’s health, These metals discharged into water and soil in the form of liquid waste from various industrial processes causing water and soil pollution. Also it cannot biodegradable and tends to piling up in living organisms[37-38].

World Health Organization "WHO" had list arsenic, cadmium, mercury and lead in its list of ten chemicals of a major public health concern in 2018 [39]. Also cadmium, mercury, and arsenic are deem as the most toxic (Big Three) group of heavy metals with the utmost potential risk to humans and ecological [4]. Adsorption is one of the best methods used to remove heavy metals from waste water because of sorbent regeneration, chemical and biological sludge reduction, high efficiency, and possibility to recover metals. Also the adsorption process is appropriate even when metal ions are present low concentration up to 1 mg/L [23].
Metal oxide like Al$_2$O$_3$ and Nano Al$_2$O$_3$ is efficiency in separation of menace metal ion from aqueous solutions and that can see in table 2.

It is observed from 'Table 2' is that the contact time is reduced for same heavy metals when we used nano aluminum oxide surface instead of aluminum oxide, the contact time of adsorption Cd decrease by "25%, 16.6% for Pb, 33.3% for Ni and 55% for Zn" when we used nano Al$_2$O$_3$, also the % removal was found to be in order:

For Al$_2$O$_3$:
Ar (II)>Zn(II)>Ar(V)> Cd(II)>Pb(II)> Cu(II)> Ni(II)

For Nano Al$_2$O$_3$:
Cu(II)> Fe(III)> Cr (VI)>Pb(II)>Th(II) ~Se(VI)>Se (IV)>Cd(II)> Mo(II) ~ Zn(II)> Ni(II).

**Table 4:** Adsorption of different heavy metals in Al$_2$O$_3$ and Nano Al$_2$O$_3$ surface

| Heavy metals | Adsorbed | Removal % | Contact Time (min.) | Isotherm | Temp. | Adsorption nature | pH | Ref |
|--------------|----------|-----------|---------------------|----------|-------|------------------|----|-----|
| Arsenite     | Al$_2$O$_3$ | -         | 60                  | Langmuir | -     | -                | 6  | 40  |
| Arsenic(III) | Al$_2$O$_3$ | 99        | 60                  | Langmuir | -     | -                | 6  | 41  |
| Arsenate(V)  | Al$_2$O$_3$ | 95        | 60                  | Langmuir | -     | -                | 6  | 41  |
| Cadmium (II) | Al$_2$O$_3$ | 94.25     | 120                 | Langmuir Exothermic | Chemical | 5  | 2  |
| Cadmium (II) | Nano Al$_2$O$_3$ | 87        | 30                  | Freundlich | -    | -                | 5  | 42  |
| Cupper(II)   | Al$_2$O$_3$ | 85.42     | 60                  | Langmuir | -     | Physical         | 6  | 43  |
| Cupper(II)   | Nano Al$_2$O$_3$ | 100       | 360                 | -         | -     | -                | 7.5 | 44  |
| Chrome(VI)   | Nano Al$_2$O$_3$ | 99        | 60                  | Exothermic | Physical | 3  | 45  |
| Iron (III)   | Nano Al$_2$O$_3$ | 99.99     | 50                  | Langmuir Exothermic | Physical | 4  | 46  |
| Led (II)     | Al$_2$O$_3$ | 92.10     | 120                 | Langmuir Endothermic | Chemical | 5  | 2  |
| Led (II)     | Nano Al$_2$O$_3$ | 97        | 20                  | Freundlich | -    | -                | 5  | 42  |
| Nickel(II)   | Nano Al$_2$O$_3$ | 7.75      | 240                 | Langmuir | -     | -                | 5  | 45  |
| Nickel       | Al$_2$O$_3$ | 84.8      | 720                 | -         | -     | -                | 7.5 | 38  |
| Nickel-Zinc  | Al$_2$O$_3$ | 92.6      | 360                 | -         | -     | -                | 6  | 38  |
| Mercury (II) | Nano Al$_2$O$_3$ | -         | 1440                | Langmuir | -     | -                | 6  | 7   |
| Molybdenum   | Nano Al$_2$O$_3$ | 80        | 30                  | Langmuir | -     | -                | 5  | 47  |
| Selenite(VI) | Nano Al$_2$O$_3$ | 95        | 2160                | Langmuir | -     | -                | 6.5 | 5   |
| Selenate(IV) | Nano Al$_2$O$_3$ | 90        | 2160                | Langmuir | -     | -                | 6.4 | 5   |
| Thallium(IV) | Nano Al$_2$O$_3$ | 95        | 70                  | Langmuir Endothermic | -    | 4  | 48  |
| Zinc(II)     | Al$_2$O$_3$ | 98.9      | 180                 | -         | -     | -                | 7.5 | 38  |
| Zinc(II)     | Nano Al$_2$O$_3$ | 80        | 10                  | Freundlich | -    | -                | 6.5 | 49  |

3- Other compounds

There are many hazardous compounds that the surface of aluminium oxide used to remove them efficiently such as phenol, carboxylic acids in vegetable oils etc.[50-51]. Materials such as fluorine, phosphate and phosphorus are widely used in our daily life and the increasing of them poses a health hazard and causes environmental pollution[52-53], these materials can also remove by adsorption technique in Al$_2$O$_3$ and Nano Al$_2$O$_3$ surface, table 5.
Table 5: Adsorption of some other compounds in Al₂O₃ and nano Al₂O₃ surface

| Other            | Adsorbed | Removal % | Contact Time (min.) | Isotherm | Temp. | pH | Ref. |
|------------------|----------|-----------|---------------------|----------|-------|----|------|
| Andiroba oil     | Al₂O₃    | 40.29     | 30                  | Langmuir | -     | -  | 51   |
| Carbon dots      | Al₂O₃    | 21.7      | 30                  | Langmuir | -     | -  | 51   |
| Ferrocyanide     | Al₂O₃    | 100       | 1980                | -        | -     | -  | 55   |
| Fluoride         | Al₂O₃    | 99        | 180                 | -        | -     | -  | 56   |
| Fluoride         | Nano Al₂O₃ | 94      | 60                  | Freundlich | Endothermic | 4 | 52   |
| Nitrate          | Nano Al₂O₃ | 60      | 60                  | Freundlich | Endothermic | 4.4 | 57   |
| Palm oil         | Al₂O₃    | 21.7      | 30                  | Langmuir | -     | -  | 51   |
| Phenols          | Al₂O₃    | 14.7      | 1440                | Freundlich | Endothermic | 4.5 | 50   |
| Phosphorus       | Nano Al₂O₃ | 38      | 180                 | Langmuir | -     | -  | 53   |
| Phosphate        | Al₂O₃    | 86.3      | -                   | Langmuir | -     | -  | 58   |
| Sodium dodecyl   | Al₂O₃    | 90        | 180                 | -        | -     | -  | 59   |
| Sulfate          | Al₂O₃    | 80        | 180                 | -        | -     | -  | 59   |

Kinetic studies

Research in the adsorption kinetics helps clarify the mechanism that controls absorption Process. Adsorption kinetics is important as it provides value insight into the interaction paths and mechanism reactions[36].

In this review the studies of kinetic adsorption of dye, Antibiotics and heavy metals in Al₂O₃ and Nano Al₂O₃ surface show agreement with the pseudo second-order except the adsorption of Cd (II) in Nano Al₂O₃ surface was fit to pseudo first –order[45]. Adsorption mechanism of "Pd(II), Cd(II)[2], Cu(II)[43], Fe(III)"[46] were complex and involve two or more steps such as surface adsorption and intraparticle diffusion, Fig. 6. Nano Al₂O₃ surface had contact time less than Al₂O₃ surface.

Fig. 6: kinetic plots of "Ni" and "Zn" adsorption on γ-Al₂O₃; pseudo second-order[36].

Conclusions

There are many researchers studied the use of Al₂O₃ and nano Al₂O₃ surface for removal some chemical compounds such as dyes, antibiotics and heavy metals through the discussing of some adsorption factor such as time, isotherm, removal percentage, isotherm, temperature and pH.

The results showed:
1- That most of these compounds prefer the pH in the range 4-7.
2- Adsorption isotherms of Freundlich and Langmuir isotherms were used for studies and it was observed that most of them preferred Langmuir isotherms; also in general the result gave good agreement with endothermic and physical adsorption for most compounds.
3- Nano Al₂O₃ surface gave best removal percentage and less contact time in comparison with Al₂O₃ surface.
4- Adsorption kinetics for the adsorption processes follows the pseudo-second-order kinetic mode except "Cd (II)" in nano Al₂O₃ surface was fit to pseudo first–order.

Acknowledgements

We gratitude University of Mustansirriyah, College of Science, Department of Chemistry for helping to do this study.
Hawraa Kassem Hami, RubaFahmi Abbas*, Emad Mahmoud Eltayef and Neda Ibrahim Mahdi E-mail: rubaf1983@uomustansiriyah.edu.iq
Ruba Fahmi Abbas* (Department of Chemistry, College of Science, Al-Mustansirriyah University, Baghdad, Iraq)

References

1. Hassan, S. A., & Ali, F. J. (2014). Determination of kinetics, thermodynamics and equilibrium parameters of ciprofloxacin adsorption from aqueous solution onto wastes of spent black tea leaves and pomegranate peel. *Int. J. Adv. Sci. Tech. Res.*, 2, 237-253.
2. Naiya, T. K., Bhattacharya, A. K., & Das, S. K. (2009). Adsorption of Cd (II) and Pb (II) from aqueous solutions on activated alumina. *Journal of colloid and interface science*, 333(1), 14-26.
3. Aazza, M., Moussout, H., Marzouk, R., & Ahlafi, H. (2017). Kinetic and thermodynamic studies of malachite green adsorption on alumina. *Journal of Materials*, 8(8), 2694-2703.
4. Afroze, S., & Sen, T. K. (2018). A review on heavy metal ions and dye adsorption from water by agricultural solid waste adsorbents. *Water, Air, & Soil Pollution*, 229(7), 225.
5. Yamani, J. S., Lounsbury, A. W., & Zimmerman, J. B. (2014). Adsorption of selenite and selenate by nanocrystalline aluminum oxide, neat and impregnated in chitosan beads. *Water research*, 50, 373-381.
6. Yang, J., Hou, B., Wang, J., Tian, B., Bi, J., Wang, N., .. & Huang, X. (2019). Nanomaterials for the removal of heavy metals from wastewater. *Nanomaterials*, 9(3), 424.
7. Wang, X., Zhan, C., Kong, B., Zhu, X., Liu, J., Xu, W., .. & Wang, H. (2015). Self-curved coral-like γ-Al2O3 nanoplates for use as an adsorbent. *Journal of colloid and interface science*, 453, 244-251.
8. Hawksworth, D., K. (2013). Fluxless brazing of aluminium, Woodhead. *Canada*, 566-585.
9. Dhawale, V. P., Khobragade, V., & Kulkarni, S. D. (2018). Synthesis and Characterization of Aluminium Oxide (Al2O3) Nanoparticles and its Application in Azodye Decolourisation. *chemistry*, 27, 31.
10. Banerjee, S., Dubey, S., Gautam, R. K., Chattopadhyaya, M. C., & Sharma, Y. C. (2019). Adsorption characteristics of alumina nanoparticles for the removal of hazardous dye, Orange G from aqueous solutions. *Arabian Journal of Chemistry*, 12(8), 5339-5354.
11. Sharma, Y. C., Srivastava, V., & Mukherjee, A. K. (2010). Synthesis and application of nano-Al2O3 powder for the reclamation of hexavalent chromium from aqueous solutions. *Journal of Chemical & Engineering Data, 55*(7), 2390-2398.
12. Ismail, R. A., Zaidan, S. A., & Kadhim, R. M. (2017). Preparation and characterization of aluminum oxide nanoparticles by laser ablation in liquid as passivating and anti-reflection coating for silicon photodiodes. *Applied Nanoscience, 7*(7), 477-487.
13. Banerjee, S., Gautam, R. K., Jaiswal, A., Chattopadhyaya, M. C., & Sharma, Y. C. (2015). Rapid scavenging of methylene blue dye from a liquid phase by adsorption on alumina nanoparticles. *RSC Advances, 5*(19), 14425-14440.
14. Elliott, M., Day, J. W., Ramachandran, R., & Wolanski, E. (2019). A synthesis: what is the future for coasts, estuaries, deltas and other transitional habitats in 2050 and beyond?. In *Coasts and Estuaries* (pp. 1-28). Elsevier.
15. **Arsenic Free Water to pave way for a Healthy Life**. (2019). World Health Organization.
16. Singh, N. B., Nagpal, G., & Agrawal, S. (2018). Water purification by using adsorbents: a review. *Environmental technology & innovation, 11*, 187-240.
17. ATSDR Agency for Toxic Substances and Disease Registry. (2011). *U.S. Department of Health and Human Services*.
18. United States Environmental Protection Agency. (2009). *U.S. Department of Health and Human Services*.
19. United States Department of Health and Human Services. (2019). *U.S. Department of Health and Human Services*.
20. ATSDR Agency for Toxic Substances and Disease Registry. (2011). *U.S. Department of Health and Human Services*.
21. ATSDR Agency for Toxic Substances and Disease Registry. (2011). *U.S. Department of Health and Human Services*.
22. United States Department of Health and Human Services. (2019). *U.S. Department of Health and Human Services*.
23. Lata, S., & Samadder, S. R. (2016). Removal of arsenic from water using nano adsorbents and challenges: a review. *Journal of environmental management, 166*, 387-406.
24. AL-Abady, F. M. H. (2020). Prediction the effect of the most efficient factors on the adsorption process of some azo dyes compounds on carbon surface using quantum mechanical methods. *Samarra Journal of Pure and Applied Science, 2*(1), 35-45.
25. Mi, X., Shang, Z., Du, C., Li, G., Su, T., Chang, X. & Tie, J. (2019). Adsorption of an Anionic Azo Dye Using Moringa oleifera Seed Protein-Montmorillonite Composite. *Journal of Chemistry, 2019*.
26. Kyzas, G. Z., & Kostoglou, M. (2014). Green adsorbents for wastewaters: a critical review. *Materials, 7*(1), 333-364.
27. Thabet, M. S., & Ismaiel, A. M. (2016). Sol-Gel γ-Al 2 O 3 Nanoparticles Assessment of the Removal of Eosin Yellow Using: Adsorption, Kinetic and Thermodynamic Parameters. *Journal of Encapsulation and Adsorption Sciences, 6*(03), 70.
28. Khosla, E., Kaur, S., & Dave, P. N. (2013). Mechanistic study of adsorption of acid orange-7 over aluminum oxide nanoparticles. *Journal of Engineering, 2013*.
29. Khosla, E., Kaur, S., & Dave, P. N. (2013). Mechanistic study of adsorption of acid orange-7 over aluminum oxide nanoparticles. *Journal of Engineering, 2013.*
30. Naeimi, S., & Faghihian, H. (2018). Remediation of pharmaceutical contaminated water by use of magnetic functionalized metal organic framework. Physicochemical study of doxycycline adsorption. *Water and Environment Journal, 32*(3), 422-432.
31. Tian, X., Liu, J., Wang, Y., Shi, F., Shan, Z., Zhou, J., & Liu, J. (2019). Adsorption of antibiotics from aqueous solution by different aerogels. *Journal of Non-Crystalline Solids, 505, 72-78.*
32. Ghaemi, M., & Absalan, G. (2015). Fast removal and determination of doxycycline in water samples and honey by Fe 3 O 4 magnetic nanoparticles. *Journal of the Iranian Chemical Society, 12*(1), 1-7.
33. Gu, C., & Karthikeyan, K. G. (2005). Interaction of tetracycline with aluminum and iron hydrous oxides. *Environmental Science & Technology, 39*(8), 2660-2667.
34. Chen, Y., Duan, L., Wang, F., Yang, H., Mao, C., & Gao, J. (2018). Tetracyclines adsorption onto alumina: A comparative experimental and molecular dynamics simulation study. *Journal of Dispersion Science and Technology, 39*(9), 1376-1384.
35. Chen, W. R., & Huang, C. H. (2010). Adsorption and transformation of tetracycline antibiotics with aluminum oxide. *Chemosphere, 79*(8), 779-785.
36. Abbas, R. F., Hami, H. K., & Mahdi, N. I. (2019). Removal of doxycycline hyclate by adsorption onto cobalt oxide at three different temperatures: isotherm, thermodynamic and error analysis. *International Journal of Environmental Science and Technology, 16*(10), 5439-5446.
37. Bedemo, A., Chandravanshi, B. S., & Zewge, F. (2016). Removal of trivalent chromium from aqueous solution using aluminum oxide hydroxide. *SpringerPlus, 5*(1), 1288.
38. Gou, W., Siebecker, M. G., Wang, Z., & Li, W. (2018). Competitive sorption of Ni and Zn at the aluminum oxide/water interface: an XAFS study. *Geochemical transactions, 19*(1), 9.
39. Ten chemicals of major public health concern. (2019). World Health Organization
40. Weidner, E., & Ciesielczyk, F. (2019). Removal of Hazardous Oxyanions from the Environment Using Metal-Oxide-Based Materials. *Materials, 12*(6), 927.
41. Iervolino, G., Vaiano, V., Rizzo, L., Sarno, G., Farina, A., & Sannino, D. (2016). Removal of arsenic from drinking water by photo-catalytic oxidation on MoOx/TiO2 and adsorption on γ-Al2O3. *Journal of Chemical Technology & Biotechnology, 91*(1), 88-95.
42. Tabesh, S., Davar, F., & Loghman-Estarki, M. R. (2018). Preparation of γ-Al2O3 nanoparticles using modified sol-gel method and its use for the adsorption of lead and cadmium ions. *Journal of Alloys and Compounds, 730, 441-449.*
43. Naeema, H. Y. (2014). Removal of toxic copper ions using alumina. *Int. J. Curr. Microbiol. App. Sci, 3, 415-431.*
44. Li, X., Zhou, S., & Fan, W. (2016). Effect of nano-Al2O3 on the toxicity and oxidative stress of copper towards Scenedesmus obliquus. *International journal of environmental research and public health, 13*(6), 575.
45. Poursani, A. S., Nilchi, A., Hassani, A. H., Shariat, M., & Nouri, J. (2015). A novel method for synthesis of nano-γ-Al 2 O 3: study of adsorption behavior of chromium, nickel, cadmium and lead ions. *International Journal of Environmental Science and Technology, 12*(6), 2003-2014.
46. Mahmoud, M. A. (2015). Kinetics and thermodynamics of aluminum oxide nanopowder as adsorbent for Fe (III) from aqueous solution. *Beni-Suef University Journal of Basic and Applied Sciences, 4*(2), 142-149.

47. Denkova, A. G., Terpstra, B. E., Steinbach, O. M., Dam, J. T. & Wolterbeek, H. T. (2013). Adsorption of Molybdenum on Mesoporous Aluminum Oxides for Potential Application in Nuclear Medicine. *Separation Science and Technology, 48*(9), 1331-1338.

48. Broujeni, B. R., Nilchi, A., Hassani, A. H., & Saberi, R. (2019). Comparative adsorption study of Th 4+ from aqueous solution by hydrothermally synthesized iron and aluminum oxide nanoparticles. *International Journal of Environmental Science and Technology, 16*(8), 4069-4082.

49. Stietiya, M. H., & Wang, J. J. (2014). Zinc and cadmium adsorption to aluminum oxide nanoparticles affected by naturally occurring ligands. *Journal of environmental quality, 43*(2), 498-506.

50. Safwat, S. M., Medhat, M., & Abdel-Halim, H. (2019). Adsorption of phenol onto aluminium oxide and zinc oxide: A comparative study with titanium dioxide. *Separation Science and Technology, 54*(17), 2840-2852.

51. Amaral, A. R., & Machado, N. T. (2015). Kinetic and Isotherms Adsorption of the Palm and Andiroba Vegetable Oils on γ-Alumina. *Technology, 10*(6), 241-253.

52. Chinnakoti, P., Chunduri, A. L., Vankayala, R. K., Patnaik, S., & Kamisetti, V. (2017). Enhanced fluoride adsorption by nano crystalline γ-alumina: adsorption kinetics, isotherm modeling and thermodynamic studies. *Applied Water Science, 7*(5), 2413-2423.

53. Moharami, S., & Jalali, M. (2014). Effect of TiO2, Al2O3, and Fe3O4 nanoparticles on phosphorus removal from aqueous solution. *Environmental Progress & Sustainable Energy, 33*(4), 1209-1219.

54. Liu, X., Li, J., Wu, X., Zeng, Z., Wang, X., Hayat, T., & Zhang, X. (2017). Adsorption of carbon dots onto Al2O3 in aqueous: Experimental and theoretical studies. *Environmental Pollution, 227*, 31-38.

55. Bushey, J. T., & Dzombak, D. A. (2004). Ferrocyanide adsorption on aluminum oxides. *Journal of colloid and interface science, 272*(1), 46-51.

56. Tripathy, S. S., Bersillon, J. L., & Gopal, K. (2006). Removal of fluoride from drinking water by adsorption onto alum-impregnated activated alumina. *Separation and purification technology, 50*(3), 310-317.

57. Bhatnagar, A., Kumar, E., & Sillanpää, M. (2010). Nitrate removal from water by nano-alumina: Characterization and sorption studies. *Chemical Engineering Journal, 163*(3), 317-323.

58. Xie, J., Lin, Y., Li, C., Wu, D., & Kong, H. (2015). Removal and recovery of phosphate from water by activated aluminum oxide and lanthanum oxide. *Powder Technology, 269*, 351-357.

59. Nguyen, T. M. T., Do, T. P. T., Hoang, T. S., Nguyen, N. V., Pham, H. D., Nguyen, T. D. & Pham, T. D. (2018). Adsorption of anionic surfactants onto alumina: Characteristics, mechanisms, and application for heavy metal removal. *International Journal of Polymer Science, 2018*. 


تطبيقات أوكسيد الألومنيوم وأوكسيد الألومنيوم النانوي كمميز مراجعة

حورية قاسم حامي، ريا فهمي عباس*، عماد محمود الطيف، نداء إبراهيم مهدي
قسم الكيمياء، كلية العلوم، الجامعة المستنصرية، بغداد، العراق
(suha_rrr_1983@yahoo.com)

الخلاصة:
تستخدم أكسيد المعادن على نطاق واسع في تكنولوجيا الامتصاز كونها سطح مازة بسبب كفاءتها، وانخفاض كلفتها وخصائصها الفيزيائية الفريدة. تهدف هذه المقالة إلى توضيح دور أوكسيد الألومنيوم وأوكسيد الألومنيوم النانوي في إزالة بعض المواد الكيميائية التي تؤثر على صحة الإنسان مثل الأصباغ، والمضادات الحيوية والمعادن الثقيلة. وشملت أيضاً تأثير بعض معاملات الامتصاز مثل درجة الحموضة ووقت الانصال ونسبة الإزالة ودرجة الحرارة، وطبيعة الامتصاز، ونماذج الامتصاز الحركية ونماذج الأيزوثيرم.

معلومات البحث:
تاريخ الاستلام: 24/01/2020
تاريخ القبول: 05/04/2020

الكلمات المفتاحية:
أوكسيد الألومنيوم، نانو أوكسيد الألومنيوم، الامتصاز، أصباغ، مضادات حيوية