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Effect of aluminum oxide nanoparticles on biotic factors of the environment - A Review

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Abstract

Aluminum oxide (Al_2O_3) nanoparticles are among the most widely used nano sized materials in various industries, increasing the chances of dispersal around the environment. Hence, this paper reviews the toxicity of Al_2O_3 nanoparticles on various organisms but with particular interest in a sensitive aquatic organism and a tobacco plant species, Artemia Salina Larvae and Nicotiana Tabacum respectively. It is reported that Artemia Larvae excretes accumulated Al_2O_3 nanoparticles at a slower rate than the rate of accumulation and that γ-Al_2O_3 nanoparticles is more toxic to the organism than α-Al_2O_3 nanoparticles. For the tobacco plant seedlings, it is observed that its exposure to Al_2O_3 nanoparticles does not significantly affect germination but significantly affects growth. Bioaccumulation of the nanoparticles in rats has been reported to induce different kinds of toxicity. Al_2O_3 nanoparticle has anti-microbial effect, retards growth in plants, increases the mortality rate of some organisms and has other adverse effects on living things which are duration, dosage and organ dependent. Bioaccumulation and toxicity of the nanoparticles increases with decreasing particle size, though the toxicity level is not alarming. It is concluded that unprotected exposure to Al_2O_3 nanoparticles be avoided and measures to minimize their dispersal into the environment be pursued.

Keywords: Artemia Larvae, tobacco plant, mortality, growth, organism.

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1. Introduction

The effect of nanoparticles on the ecosystem has become a cause for concern, necessitating studies on the toxicity of different kinds of nanoparticles in the environment. There is a considerable risk of nanoparticle dust explosion due to its proliferation in manufactured products and industrial activities. Inhaled nanoparticles may present a potential source of health hazards. Studies have shown that nanoparticles can be deposited along the respiratory tract by diffusion and this deposition increases with decreasing particle size. A study conducted with human volunteers showed high depositions in the nasal airways than theoretical predictions [1]. New technological applications of engineered nanoparticles are explored at an increasing rate and present information on their toxicology is also growing, emphasizing the need to be alert on their potential impact on health and environment.

The environmental effect of Aluminum oxide (Al_2O_3) nanoparticle has been selected for review in this paper because of its various industrial applications especially in the oil and gas industry. Al_2O_3 nanoparticles have been recommended for use in control of fines migration in hydrocarbon reservoirs [2, 3, 4, 5]. Studies have shown that Al_2O_3 nanoparticles supported on metal catalysts can reduce oil viscosity, especially the viscosity of heavy crude. In one study of heavy crude derived from the Gulf of Mexico, the API gravity of the crude was increased from 12.5 to values between 21 – 26^o API. The kinematic viscosity was reduced and the distillable oil fraction was increased [6]. Al_2O_3 nanoparticle has also been reported to improve rheological properties of drilling fluids [7-8].

Al_2O_3 nanoparticle has been reported as a good agent for asphaltene removal from crude oil [9] and heavy crude oil. The experiment involved applying Al_2O_3 nanoparticles to different asphaltene concentrations and the effect of variables such as contact time, temperature, heptanes and toluene ratio, coexisting molecules and water content were studied. The thermodynamics of asphaltene adsorption on the Al_2O_3 nanoparticles indicated that the adsorption was fast, spontaneous and exothermic in nature [10-11]. Nares (2007) also made a similar report of asphaltene removal from heavy crude using Al_2O_3 nanoparticles. There are several other applications of Al_2O_3 nanoparticles in various industries such as in biomedical science, material science, ceramic, construction, pharmaceutical, glass and automotive industries. The various uses of this nanoparticle have invariably increased its chances of dispersal around the environment which has prompted studies on its environmental effects and toxicity.

Every environment is made up of biotic and abiotic factors; living and non-living things respectively. The biotic components of an environment consist of all the living organisms in that ecosystem such as humans, plants, animals, fungi and bacteria. The natural abiotic composition of an environment includes wind, light, soil, water, atmosphere, temperature, air, snow, ocean current and salinity. External abiotic factors that can be introduced into an environment and that can affect living organisms consist of chemicals, structures, noise and pollutants. In this review, the focus is on the biotic environment and the effect of an external abiotic factor, Al_2O_3 nanoparticles on selected organisms. Since the use of Al_2O_3 nanoparticles in various industries is proliferating, it is necessary to review its effect on the biotic components of an environment. Every living organism needs sustenance which is often dependent on other organisms and the abiotic factors of the environment. Any disruption created in the environment invariably alters normalcy and balance in the system, creating a chain reaction. This is important because biotic and abiotic factors play a role in the food chain and in the sustenance of other organisms in the ecosystem.

2. Toxicity Studies of Al_2O_3 Nanoparticles

Several studies on the toxicity of Al_2O_3 nanoparticle on plants have been conducted and generally its effect has been detrimental to the growth of plants. The ability of plants to accumulate Al_2O_3 nanoparticles from water and soil has been investigated [12] and its eco toxicity has also been reported [13]. Findings have shown that Al_2O_3 nanoparticles can inhibit growth in aquatic microalgae [14], induce programmed cell death in plant cells [15] and can adversely affect the growth of several plants [16].

The antibacterial effect of Al_2O_3 nanoparticles has also been reported. The anti-microbial and anti-growth effects of Al_2O_3 nanoparticle on bacterium E. coli, Bacillus Subtilis and Pseudomonas Fluorescens have been observed [17]. In one study, the antibacterial activity of Al_2O_3 nanoparticles of less than 50nm in size against P. putida bacteria was investigated by Doskocz (2017) and its effect was compared with the effect of macro Al_2O_3 on the bacteria. Growth inhibition test of the bacteria was also conducted in the presence of the two forms of Al_2O_3. It was reported from the results that Al_2O_3 nanoparticles inhibited the growth process of P. putida and it was concluded that the macro form of Al_2O_3 has less impact on bacteria than the nano form of Al_2O_3. In accordance with the EU and US EPA criteria, the toxicity of Al_2O_3 nanoparticle was rated high [18].

Al_2O_3 nanoparticles can also adversely affect other organisms and animals on excessive exposure. In one study, it was found to be among the nanoparticles present in the guts of daphnias kept in suspension of different nanoparticles for 48hours [19]. It has also been observed that chronic exposure of flies to Al_2O_3 nanoparticles can result in health problems and deformities [20]. The nanoparticles can accumulate in the organs of albino rats and has the ability to induce genotoxicity, though bioaccumulation is time, dose and organ dependent [21]. Al_2O_3 nanoparticles have also been reported to be detrimental to human cell lines, though it has several biomedical applications but it has also demonstrated environmental bio toxicity [22, 13]. Another report shows that Al_2O_3 nanoparticles can induce physiological stress response in rats, change their behavior pattern and metabolic activities, but no mortality was recorded. The nano material can induce cognitive deficits and oxidative stress in frontal cortex and cerebellum of Wistar male rat brain. [23]. Exposing rats to Al_2O_3 nanoparticles can influence cellular signal pathways of kidney and cerebrum while exposing female pregnant mice to it induces neurodevelopmental toxicity in their offspring [24, 25].

3. Effect of Al_2O_3 Nanoparticles on Two Selected Species of Living Things

In this review, special attention is given to the work of Ates (2013) and Bucklew (2012) [26, 27] following their published experimental work. The focus is on two living things; an aquatic organism called Artemia Salina Larvae and a tobacco plant species botanically called Nicotiana Tabacum. The mortality rate of Artemia Salina Larvae and the germination and growth of tobacco plants on exposure to Al_2O_3 nanoparticles were examined.

3.1 Effect of Al_2O_3 Nanoparticles on Artemia Salina Larvae

The toxicity of Al_2O_3 nanoparticles on marine organisms has been experimentally investigated using Artemia Salina larvae, a marine species of crustacean filter feeder in the absence of food. Artemia Larvae is commonly used for such analysis because of their sensitivity to toxic substances. The toxic response of this marine organism under exposure to two kinds of Al_2O_3 nanoparticles for 24hours and 96hours and the elimination rate of the ingested Al_2O_3 nanoparticles were studied and reported [26]. The p values of the results were used to determine if the mortality rate of the organism in the presence of Al_2O_3 nanoparticles is statistically significant or not. When $P > 0.05$, it is statistically insignificant but when $P < 0.05$, it is statistically significant. The two kinds of Al_2O_3 nanoparticles used to conduct this study were alpha (α) and gamma (γ) nanoparticles. Two different sizes of Al_2O_3 were used for each (50nm and 3.5µm for α-Al_2O_3 and 5nm and 0.4µm for γ-Al_2O_3). Interestingly, the α-Al_2O_3 (50nm) nanoparticles used by Ates is similar to the α-Al_2O_3 nanoparticles (40nm) used by Ogolo who worked on the use of Al_2O_3 nanoparticles in control of fines migration in hydrocarbon sands [2, 3, 4, 5]. Both researchers acquired their Al_2O_3 nanoparticles from the same source, Skyspring Nanomaterials in Houston, Texas.

The reported mortality rate in percentage range from the experimental results of the work conducted by Ates (2013) [26] are plotted in Figures 1 and 2 for 24 and 96hours exposure respectively. Figure 1 shows that the results of the control case and α-Al_2O_3 micrometer are similar while the nanoparticles mortality rate of Artemia Larvae is higher by more than 100%. For γ-Al_2O_3, the mortality rate of the organism on exposure to the nanoparticle sizes of Al_2O_3 is higher than for the micro-sized particles. The results also show that the micro size γ-Al_2O_3 is more toxic than the micro-size α-Al_2O_3 compound. The results in Figure 2 are similar to the results in Figure 1, and it is clear that the lethal effect of Al_2O_3 nanoparticles is higher at 96hours than at 24hours. This confirms the general observation that the mortality rate of the organism is higher at longer durations of exposure.

Figure 1: Mortality Rate of Artemia Larvae at 24hours [26].

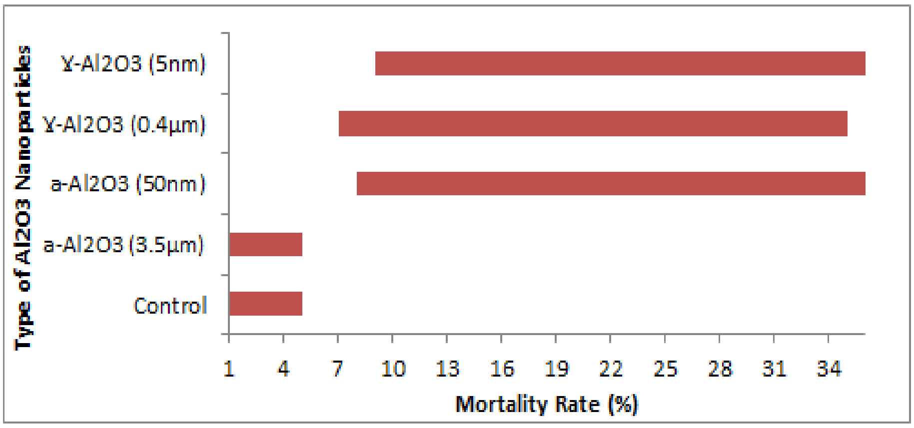

Figure 2: Mortality Rate of Artemia Larvae at 96hours [26].

It was reported that Artemia Larvae substantially accumulated α-Al_2O_3 and Ɣ-Al_2O_3 nanoparticles in their guts and slowly eliminated the ingested nanoparticles. However, the larger particles of α-Al_2O_3 (3.5µm) nanoparticles were not taken up by Artemia in either exposure periods. It was observed that the total Al_2O_3 nanoparticles taken by Artemia Larvae increased with increasing concentration in the medium and with increased exposure time. The excretion of the ingested nanoparticles was observed to be slow compared to the rapid rate of accumulation probably due to the formation of large aggregates of the nanoparticles inside the guts. Results also indicate that smaller sizes of Al_2O_3 nanoparticles are more toxic than larger particle sizes [26].

There are environmental concerns about Al_2O_3 nanoparticles especially to living organisms as observed from the results of the work by Ates [26]. Although these organisms were exposed to large dosages of Al_2O_3 nanoparticles without food but it simply indicates that introducing too much of these very small sizes of nanoparticles in the environment can be detrimental to living organisms which invariably will affect the ecosystem. There is therefore need to consider the toxicity of Al_2O_3 nanoparticles to living organisms, though the level of toxicity is not acute. Findings on these various toxic effects of Al_2O_3

nanoparticles though mild, emphasize the need to prevent their spread, inhalation and consumption by living organisms.

It is also speculated that a large quantity of silver nanoparticles in the environment can disturb the ecosystem. Silver nanoparticle has been known to have both anti-bacterial and anti-fungal properties; it kills bacteria and fungi and prevents their growth. Hence, silver nanoparticle is used in medicine and in environmental science to destroy unwanted bacteria and other micro-organisms and for the breakdown of organic matter in water treatment plants. This implies that disposing a large quantity of silver nanoparticles in the environment can destroy useful micro-organisms in the ecosystem which is not environmentally acceptable [28]. Just like silver nanoparticles, large doses of Al_2O_3 nanoparticles in the environment could have the same but less severe effects, destroying important organisms in the ecosystem or inhibiting their growth [17].

3.2 Effect of Al_2O_3 Nanoparticles on a Tobacco Plant, Nicotiana Tabacum

The effect of Al_2O_3 nanoparticles on the germination and growth of a tobacco species, Nicotiana Tabacum has been studied. Tobacco seedlings were grown in different concentrations of Al_2O_3 nanoparticles and after ten days, the germination rates were calculated. After three weeks of culture, the root lengths, leave counts and biomass of the seedlings were also determined by Burklew [27]. The results of the study of Al_2O_3 nanoparticles on the tobacco plants as reported are plotted and presented in Figures 3 to 6. Figure 3 shows that the average germination rate of the tobacco plant in all the cases of exposure to different concentrations of Al_2O_3 nanoparticles are lower than the control case but not statistically significant. This agrees with a previous study conducted by Lin [16] and the reason for this was attributed to the coating on tobacco seeds which most likely are not permeable to Al_2O_3 nanoparticles. It is therefore after the plants have germinated from the protective seed coatings that they were exposed and seriously affected by the presence of Al_2O_3 nanoparticles.

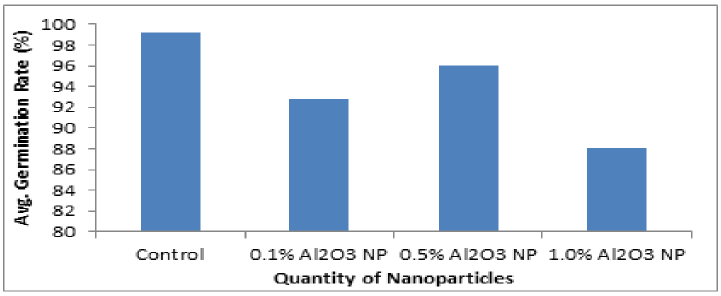

Figure 3: Average Germination Rate of Nicotiana Tabacum on Exposure to Al_2O_3 Nanoparticles

In Figures 4, 5 and 6, there is a steady decrease in the average root length, leave count and biomass per seedling of the plant respectively as the concentration of Al_2O_3 nanoparticles increased. Similar results have been reported for the germination and growth rates of other agricultural crops such as radish, rape, ryegrass, lettuce, corn and cucumber [16]. The experimental results generally indicate that exposure of tobacco seedlings to Al_2O_3 in different concentrations does not significantly affect the germination rates of the seeds but significantly affect the growth of the seedlings.

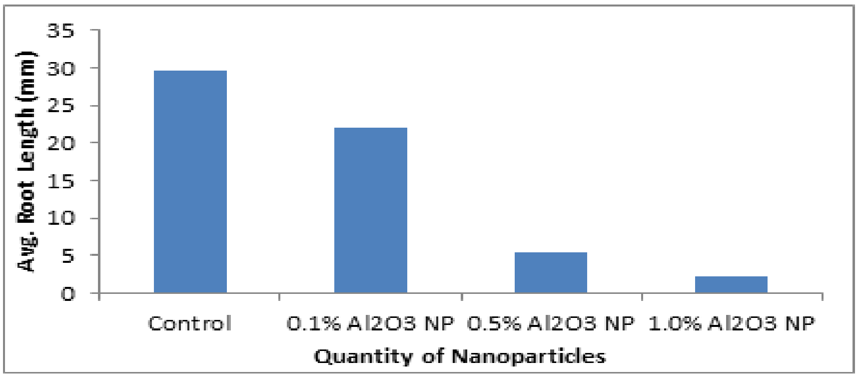

Figure 4: Average Root Length of Nicotiana Tabacum on Exposure to Al_2O_3 Nanoparticles

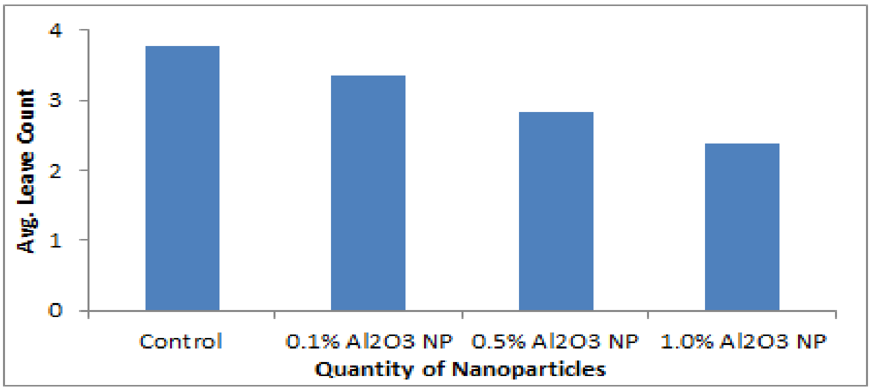

Figure 5: Average Leave Count of Nicotiana Tabacum on Exposure to Al_2O_3 Nanoparticles

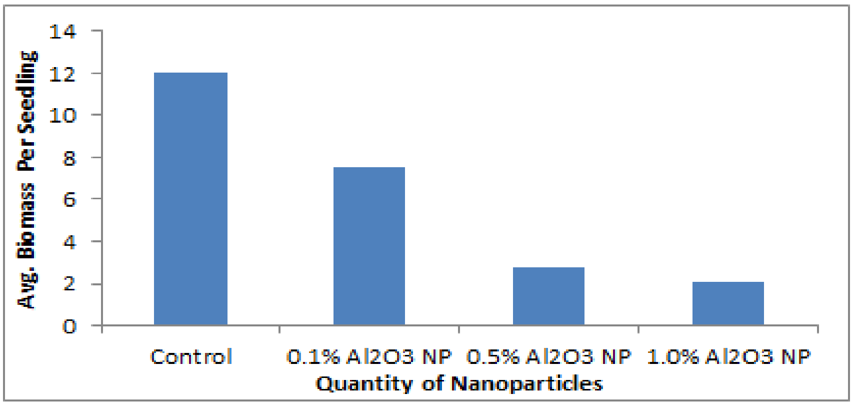

Figure 6: Average Biomass per Seedling of Nicotiana Tabacum on Exposure to Al_2O_3 Nanoparticles

All the studies that have been reviewed indicate that Al_2O_3 nanoparticles could have adverse effects on plants, animals, microbes and invariably on the ecosystem. It is presently uncertain how disposed nanoparticles will affect health and environment in future, necessitating strategic steps to minimize negative impacts. Therefore, unnecessary and unprotected human exposure to it should be avoided. Adequate measures should be taken to minimize the dispersal of Al_2O_3 nanoparticles into the environment since its lethal effect is dependent on large dosages and duration of exposure. Even if a type of nanoparticles does not appear toxic, its interaction with other compounds in biological systems may cause cell malfunctions. With adequate caution, nanotechnology can be explored, exploited and enjoyed with negligible damage to health and environment.

4.0 **Other Effects of Al_2O_3 nanoparticles on Living Things**

It has been reported that Al_2O_3 nanoparticles also adversely affect mammals in other ways. Studies have shown that the central nervous system in mammals can be a potential target to aluminum oxide nanoparticles [29] and this nano material can also disrupt activities in the brain [30]. Another potential toxicity of Al_2O_3 nanoparticles on mammals was demonstrated by exposing Swiss albino mice to repeated low doses of aluminum oxide nanoparticles. The male albino mice were orally administered with Al_2O_3 nanoparticles in 15, 30 and 60mg/kg body weight for five days. Results showed that the brain, liver, spleen, kidney and testes had high retention levels of the nanoparticles. Histopathological lesion in the brain and liver were observed. Other effects include alteration of enzyme activities, DNA damage, abnormalities and adverse health consequences [31].

Al_2O_3 nanoparticles has been listed as one of the metal oxide nanoparticles that is harmful to organisms [32]. Some of these harmful effects include decrease in reproduction and behavior of Eisenia Fetida, a terrestrial earthworm [33], negative effects on aquatic organisms [34], toxic effects on bacteria [35] and plant roots [36] and disruption in enzymatic activities. In a certain investigation where the enzymatic activity of a sequencing batch reactor was studied, it was reported that the existence of Al_2O_3 nanoparticles stress led to variation of microbial richness and diversity in sequencing batch reactor due to their bio-toxicity [37]. In another work, zinc, silica and Al_2O_3 nanoparticles were recommended for use in pest control programs of Earias Insulana because these nanoparticles have toxic effects on the growth, development, malformation and chitin formation parameters of Earias Insulana [38].

Conclusions

The conclusions drawn from this review are as follows:

1. Excessive exposure of living organisms and plants to high concentrations of Al_2O_3 nanoparticles in the environment can be toxic, leading to mortality in some organisms and retarded growth in plants.
2. Decreasing sizes of Al_2O_3 nanoparticles increases the rate of bioaccumulation in living organisms and plants, and the level of toxicity is dose, organ and duration dependent.
3. The anti-bacterial effect of Al_2O_3 nanoparticles can adversely affect the ecosystem.

Recommendation

It is recommended from this review that unnecessary and unprotected human exposure to Al_2O_3 nanoparticles be avoided while safety measures to control dispersion of Al_2O_3 nanoparticles into the environment should be pursued.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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