Synthesis of Zinc Oxide Nanoparticles for Wastewater Treatment to Recovery of Heavy Metal

Induja P[1,*], Sivaraman S [2], Narendhiran M [3], Prasanth K [4]

Department of Chemical Engineering, Hindusthan College of Engineering & Technology, Coimbatore.

ABSTRACT

The fabrication of zinc oxide nanoparticles is a concept since zinc oxide nanoparticles can effectively cling onto things that it reacts to light and zinc oxide nanoparticles do not pose any threat to the environment. This paper prepared zinc oxide nanoparticles through a technique known as controlled precipitation and ultimately we monitored the appearance of zinc oxide nanoparticles as well as the process through which zinc oxide nanoparticles were prepared. We then cleaned the water with the use of these zinc oxide nanoparticles with a particular aim of eliminating metals, such as lead, cadmium and chromium. ZnO is very reactive and it has a surface area. This implies that ZnO is able to capture the metals and degrade them thereby decreasing the metal ions in the water. This informs us that ZnO nanoparticles may be a viable approach towards cleaning heavy metals in factory wastewater. This will ensure that it is safer to the environment. Some of the resources can be recovered. ZnO nanoparticles are a water cleaning material and heavy metal recovery material. ZnO nanoparticles are able to clean the water and render it safer. At this, ZnO nanoparticles are truly good. In this paper, the researcher examines how Zinc Oxide Nanoparticles can be prepared e.g. through chemical precipitation, sol-gel and green synthesis. It identifies the good and bad things regarding each of these approaches to the production of Zinc Oxide Nanoparticles. Another aspect that the paper discusses is the application of Zinc Oxide Nanoparticles in water treatment. As an example, Zinc Oxide Nanoparticles have the ability to pick pollutants. It is possible to disperse them with light and filter them. We also talk of getting metals back using Zinc Oxide Nanoparticles. Some techniques such as adsorption-desorption and electrochemical recovery can be applied to the Zinc Oxide Nanoparticles to retrieve the metals back. ZnO NPs are a good method of treating water and recovering heavy metals. ZnO NPs are quite effective in the treatment of water. Removing the heavy metals since they possess some good qualities. The paper discusses the latest development of ZnO NPs such as how to make them easily, eco-friendly, and how ZnO NPs are used to trap harmful compounds in the water using sunshine to dissipate them and using ZnO NPs to filter the water by using ZnO NPs. ZnO NPs prove to be great in the elimination of metals. We can also apply such techniques as adsorption-desorption or electrochemical recovery to recover metals using ZnO NPs. ZnO NPs is a cheap method of purifying water and recover heavy metals. The most pleasant thing is the fact that the ZnO NPs can be utilized on a scale without damaging the environment. ZnO NPs are a cleaning and retrieving heavy metals back solution to water using ZnO NPs.

KEY WORDS: *Cardamom, Aloe vera, Zinc nitrate hexahydrate*, *wastewater treatment, lead, UV visible spectroscopy, FTIR, XRD, SEM / TEM.*

1 INTRODUCTION

Zinc nitrate water solutions, obtained as a result of treated wastewater, can be used to make zinc oxide nanoparticles. It is accomplished with the aid of Aloe vera and Black Cardamom extracts to regulate zinc Rasli, N.I *et al.*(2020)[1] oxide nanoparticles formation. The zinc oxide nanoparticles in such a manner is informed by the goodness of Aloe vera and Black Cardamom extracts Agarwal, H. *et al.*(2017)[4]. Such a method is good, to the earth, since it is based on the components of the Aloe vera and the Black Cardamom plants Ansar, N.*et al.*(2024)[2]. It uses zinc oxide nanoparticles at the moment to collect and eliminate bad stuffs such as lead, cadmium and arsenic in non-clean water. The fact that heavy metals in water are harmful is because they damage the environment. They are poisonous. The heavy metals are persistent and do not disperse. The common methods of water are costly. Such strategies are ineffective and even may result in new pollution. Cleaning of wastewater is a good application of nanotechnology. The advantage of nanotechnology is that it is not only good but also very active since the surface area is high. Nanotechnology is effective in terms of absorbing impurities such as metals in water Sundrarajan, M., & Gowri, S. (2011)[5]. The plant extracts come in handy. They offer things that are agents. These mild agents assist in the production of small ZnO. We are able to prepare these ZnO particles without bad chemicals. At temperatures we may also make them. This is one, to purify water of heavy metals. XRD, FTIR, SEM /TEM, UV - Vis and BET surface area analysis were used to study the ZnO nanoparticles. This was to ensure that the ZnO nanoparticles are whom, the correct groups, the correct shape and the correct surface area. The ZnO nano-particles were employed to determine their efficiency in removing Pb(II) Cd(II) and Cr(VI) in the solution. We were interested in testing the performance of the ZnO nanoparticles in varying the pH, time, concentration and amount of the ZnO nanoparticles (Kaur, H. et al)[3]. Nanoparticles of ZnO were experimented with solutions to determine the way they absorb. The findings indicate that Zinc oxide has the size of between 20 and 60 nanometers structure referred to as wurtzite. Biomolecule groups also constitute Zinc Oxide. Zinc Oxide is quite efficient in elimination of lead and cadmium in water it is able to eliminate over 80 percent of these metals. It succeeds when the water is a little acidic with a pH of 5 to 6 and in the cases where we have a low amount of Zinc Oxideof about 0.5 grams per liter of the water. The absorption of these metals by Zinc Oxide is as an order reaction.

Such models as Freundlich and Langmuir can be used to understand the way Zinc Oxide takes on various metals in various environments. Zinc Oxide is able to absorb high quantities of metal the limit is tens of milligrams per gram of Zinc Oxide. This informs us on how to synthesize Zinc Oxide absorbers in plants to eliminate the toxic metals such as lead and cadmium in wastewater. Zinc Oxide absorbers may come in handy, in cleaning up the wastewater which contains metals. Chemicals that aid in making ZnO nanoparticles at low temperatures are found in plants. These chemicals are mild. Not requiring hazardous materials. The groups in these plants contribute to the retention of the ZnO nanoparticles small. In this manner we are not left with waste or products left over. The ZnO nanoparticles which were prepared were now evaluated. To check them we used XRD, FTIR, SEM, TEM UV-Vis and Bet Surface Area Analysis. We were interested in knowing the appearance of the ZnO nanoparticles and their surface area. We also desired the groups and structure of the ZnO nanoparticles. We ran some tests to establish the ability of Zinc Oxide to eliminate lead, cadmium and chromium in waste. The solutions of Pb(II) Cd(II) and Cr(VI were used in these tests to determine the way in which Zinc Oxide eliminates them Khan, I., Saeed, K., & Khan, I. (2019)[16]. We were interested in knowing the extent to which Zinc Oxide absorbs these metals under varying conditions of the acidity of the solution, time and volume of the solutions used. The reaction of Zinc Oxide was experimented to find its behaviour in the presence of Pb(II) Cd(II) and Cr(VI) at the levels of acidity and time and under varying contents of the solutions. Tests indicate that the ZnO when mixed with plant things has a structure referred to as wurtzite. In most cases it removes the Pb(II) and Cd(II) ions when the water is slightly acidic, such as at pH levels of 5 or 6 and when a very small amount of it is used such as 0.5 grams per liter. The manner in which the ZnO absorbs such things takes a pattern and can be explained by two models the Freundlich and the Langmuir models which are subject to a type of metal we are attempting to remove and which are described by these models. The quantity of material that can be absorbed by the ZnO is quite large approximately tens of milligrams per gram. The significance of the work is that it demonstrates us how to prepare a good ZnO adsorbent using plants to remove heavy metals in wastewater. ZnO adsorbent is an instrument that is used to eliminate heavy metals such as Pb (ii) and Cd (ii) ions in wastewater and is manufactured using plants which are readily available.

2 EXPERIMENTAL

2.1 Aloe vera extract (aqueous):

You will also need to wash twenty grams of aloe vera leaves thoroughly in order to remove all the dirt. Then you have to peel the aloe leaves. Take, ten or so grams of aloe vera gel of them. To begin with you should cut the gel into pieces after which you should place these pieces in a beaker containing 100 mL of distilled water. This mixture should then be heated at a temperature of 60 to 70 degrees Celsius between 15 to 20 minutes long. This is done by ensuring that the mixture of gel and water is stirred dry as it heats up and to avoid boiling it. Strain and cool using Whatman/filter paper to attain extract. Keep at 4°C if not using soon. Ramesh, M., Anbuvannan, M., & Viruthagiri, G. (2015)[6].

2.2 Cardamom extract (aqueous):

Green cardamom seeds crush 5g (mortar and pestle). In order to prepare this drink, it is necessary to boil the seeds in 50ml of water within 10-15 minutes. Then you are to allow it to cool and strain it. You may also place the seeds in water at room temperature, then leave that hour, and strain them. Both methods work fine. The thing, with cardamom, is that it brings you good. Kaur, H. et al.(2025)[3].

2.3 Combined extract:

In order to prepare the mixture you will be required to mix aloe vera extract and cardamom extract. Use 100 millilitres of the aloe vera extract. To this add 25-50 millilitres of cardamom extract. The proportion of aloe vera extract to cardamom extract may be 2: 1 or 4 which implies that there is aloe vera extract followed by cardamom extract. The reason is that aloe vera extract is readily available and it prevents the mixture to be unstable. Depending on the quantity of the zinc solution you have you can dilute the extract mixture to about 125-150 millilitres.) Azizi, S., Ahmad, M. B., Namvar, F., & Mohamad, R. (2014)[13]

2.4 (0.1 M Solution) preparation:

To prepare a solution that you should combine 2.98 grams of Zinc Nitrate that is $Zn(NO_3)_2$ H_2O in 100 millilitres of water. This water is supposed to be distilled. This is aimed at achieving a solution of 0.1 M. You may vary the quantities, You can make changes in the proportions. You must warm this mixture a little to, say 30 to 40 degrees Celsius, to dissolve the Zinc Nitrate in the water.

3 PREPARATION OF ZINC OXIDE

Add the mixture of about 125 mL of the plant extract in a 250 mL beaker placed on a magnetic stirrer. Warm to 6080^0C and stir (gently, say 400-600 rpm). Keep this temperature.

3.1 You need to combine the extract and heat them together:

Add the mixture of about 125 mL of the plant extract in a 250 mL beaker placed on a magnetic stirrer. Warm to 6080^0C and stir (gently, say 400-600 rpm). Keep this temperature.

3.2 Add zinc solution slowly:

Gradually, one drop at a time, add the $Zn(NO_3)_2$ solution to the heated plant extract. Do this for 15 to 30 minutes. How many seconds it takes to stir mixture. In the process of doing this you will observe that the color of the mixture begins to change. The mixture may also appear slightly milky when $Zn(NO_3)_2$ solution is added. The reason is that $Zn(NO_3)_2$ solution is complexing with the plant extract. Having added the volume of the $Zn(NO_3)_2$ solution, which is necessary, you should continue to stir the mixture and it will require 15 to 20 minutes to finish.

3.3 pH adjustment to precipitate:

As you are working with your reaction mixture, you must pour NaOH into the reaction. When doing this, monitor the level and continue adding NaOH until the pH level reaches an approximate of pH 10 of about 9 to 11. You will have a white substance emerge every time you add some NaOH. This is attributed to the fact that the Zn (OH)2 is becoming ZnO nuclei. NaOH should be added gradually in order not to alter the level of pH significantly. The optimal pH regime to utilize in the formation of ZnO is, 9 to11.

3.4 Stir & age:

In case of the pH that it should be. At 60-80 degrees Celsius it must be. Do so 30-60 minutes. Following this allow the mixture to rest 6-12 hours. You may even leave it overnight at room temperature. This will allow the mix to put on age.

3.5 Isolation (centrifuge/filtration):

Spin the suspension at 600010 rpm within 815 min (where the vacuum strain is possible) or vacuum strain. Get rid of liquid. Keep the white stuff.

3.6 Washing:

To extract the nitrate, you have to wash the stuff three times using deionized water. Whenever you wash the stuff, you will have to centrifuge it after resuspending it. When you wash the stuff, you use ethanol instead of deionized water to allow it to dry up.

Fig 3.2.3 Preparation of ZnO Nanoparticles

3.7 Drying:

You need to dry up the stuff in the oven to obtain a powder. The temperature of the oven ought to be 60-80 C. You should do it 8 to 12 hours or, that is, overnight. This will produce low-crystalline Zinc Oxide or ZnO in short but I shall refer to it as Zinc Oxide. On completion, the Zinc Oxide will have been reduced in form of a powder.

3.8 Calcination (to make crystalline ZnO):

To prepare Zinc Oxide nanoparticles, you have to take some powder and place it in a ceramic and then you place it in a special furnace. It is supposed to be in the range of 350 to 500 degrees Celsius. One to three hours should be heated to it. The most popular method to accomplish this is by heating it at 400 degrees Celsius during two hours and raising the temperature at a rate of five degrees Celsius per minute. This is referred to as calcination. It assists in the elimination of organic substances and forms Zinc Oxide nanoparticles. Getting smaller crystals with the temperature is possible, though they will not be, as crystalline. Conversely with increased temperature you will have bigger crystals, and that is the desire with Zincoxide nanoparticles. Allow to cool to room temperature in a desiccator and keep ZnO NPs in a sealed vial, in the absence of moisture and direct light.

3.9 Store:

Cool to room temperature and keep ZnO NPs in a sealed container, away from moisture and light**.**

4 SEPARATION OF LEAD HEAVY METALS FROM WASTEWATER TREATMENT:

4.1 Quantity Requirements

Lead concentration: Measured in mg/L or pp. The amount of waste water flowing through the system is the basis to determine the treatment capacity. This is normally quantified by the number of litters of wastewater flowing per minute or the number of gallons of waste water flowing per day. Treatment capacity is variable with respect to flow rate of the wastewater.

4.2 Step-by-Step Procedure:

Step 1: Coagulation/Precipitation

Chemical addition: Add chemicals to get lead ions out of the water. pH adjustment: Adjust pH to 6-8.

Step 2: Flocculation and Sedimentation

Flocculation refers to the act of putting stuff in water to allow the dirt and the other small particles to be at the bottom. It is in this manner the water is made clearer. The dirt is not suspended in the water. You do this by putting sorts of stuff into the water to make the little particles stick together so they become heavy, and they then go down to the bottom, and this is what Flocculation is all, to help the things get down. The act of letting the lead settle down to the bottom is called sedimentation. This is to wait till the lead settles. You just let the lead settle.

Step 3: Filtration

Filter media: Use activated carbon, sand, or membrane filters.

Step 4: Additional Treatment (Optional)

Ion exchange: Leftover lead can be removed with the help of materials. The ion exchange process is also quite effective in the removal of lead and hence will be used to extract any leftover lead, in the item we are cleaning. Our adsorption is when we take carbon to pick up anything that remains in the water or air. We are referring to adsorption, and it involves carbon to dispose of the stuff. Therefore, a form of cleaning up is adsorption to carbon.

Fig 3.2.5 Separation of Lead Heavy metal

4.3 Reagent Quantities

The volumes of the chemicals to be used may not be the same. Approximately, it is between 10 and 500mg per litre. This actually is determined by the extent of lead in the water. Depending on the concentration, more or lesser amounts of chemicals will be used. The quantities of settlement substance may vary. It is approximately between 1 -10 milligrams per litre. This is actually dependant on the wastewater. The quantity of the settlement matter in the wastewater is subject to change. The average amount of the settlement material is usually, between 1 and 10mg/L.

4.4 Monitoring

Lead concentration: Check lead levels before and after.PH and turbidity: We must monitor the

turbidity and the pH of the water. This translates into ensuring that we check the pH and turbidity to ensure that they are, at safe levels. The things to be observed are the PH and the turbidity since they have the capacity to influence the water quality. We will therefore monitor the pH and turbidity to maintain clean and safe water

4.5 Regulatory Compliance

When it comes to laws, the treatment must be as far as the established standards allow. We have to ensure that we meet the standards that are in place on the treatment. Local regulations are quite significant. The therapy should be able to address these standards.

5 CHARACTERIZATION:

5.1 UV VISIBLE SPECTROSCOPY

UV-Visible spectroscopy is a method of observation of the extent of light that materials absorb in the UV region and

Volume: 10 Issue: 03 | March - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

the visible region. The UV is 190 to 400 nanometres and the visible is 400 to 800 nanometres.

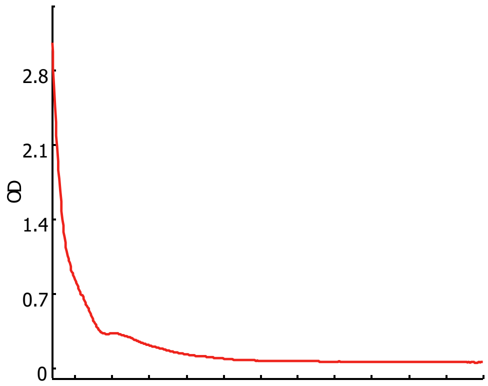

Fig 4.1 This UV–Vis curve shows strong UV absorption with an absorption edge (excitonic band) at ~370 nm — characteristic of ZnO nanoparticles (implied band-gap ≈ 3.35 eV).

The important wavelength in this graph is the absorption wavelength and this is denoted as lambda A max. This λA max will serve as a fingerprint to every UV. Substance. The Beer- Lambert Law is that the quantity of light that a substance on the UV- Visible absorbs is proportional to the quantity of the UV. Substance that is present. UV -Visible spectroscopy is of assistance. It is fast and convenient to calculate about UV. Observable materials, in most diverse disciplines. Electrons become excited to a state when absorption occurs. The process of electrons leaping up to such energy levels is essentially what absorption is all. It is actually these electrons and their movement, to energy states, in the process of absorption.

5.2 FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is a method which is applied in the analysis of chemical composition and molecular structure of materials. It determines how infrared radiation is taken up by the molecules giving data on functional groups, bonding and chemical composition. The atoms are interconnected with the assistance of light. With this light the atoms are pushed to and fro like the springs in a toy. The lowest points are significant when we consider a graph. They demonstrate to us the points where the light is the most consumed. It is these low points that inform us on the actual part of the molecule that is absorbing the light. All these indicate to us what is in the chemical and what is composed of atoms like what type of atoms make up, the chemical. Horizontal Line: The vitality of the light engulfed.

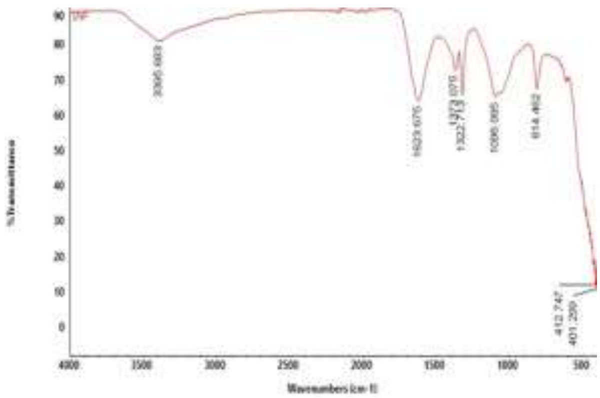

Fig 4.2 The FTIR spectrum shows a strong absorption band around 401–616 cm⁻¹ corresponding to Zn–O stretching vibrations, confirming the presence of ZnO nanoparticles in the synthesized sample

The Vertical Line is really significant due to the fact that it demonstrates the extent to which light was able to penetrate. The Vertical Line, is as a measure of this. The amount of light that passed through is seen on the Vertical Line. The large dip at 3366cm -1 belongs to O- bonds such as the ones present in water and alcohols. The range and round structure are attributed to the O-H bonds due to the manner through which molecules of water attach to one another through hydrogen bonding.

The implication of this is that the stuff has taken in some moisture in the air and that is why you observe the O-H bonds, in the reading. In examining the results we find a peak at 1623 cm -1. This is associated with water molecule which consists of H-O -H. The tiny peak of which we are conscious, tells us that the water molecule is wet. This implies that the sample upon which we are observing presence of moisture in or it is close to water and this is the reason why we observe this peak, in the water molecule. Peaks with values less than 800 cm -1 such as that of 412 cm -1 are actually significant in the study of minerals or metal oxides. These peaks demonstrate to us the vibrations of the atoms in metals or metal oxides. Minerals or metal oxides contain atoms and these peaks assist us in learning more about the vibrations of these heavy atoms, in minerals or metal oxides. The FTIR chart informs us of a thing. On the FTIR chart we first observe moisture. In FTIR chart, one can also identify that it has a backbone.

This composite backbone consists of Metal-Oxide bonding or M-O bonding in short. On the FTIR chart, the composite backbone includes the M-O bonding.

5.3 FESEM

Field Emission Scanning Electron Microscopy (FESEM) is a method of investigating the surface morphology, composition and structure of materials in the nanoscale. It also gives high-resolution images (down to 1 nm) and is typical in the characterization of nanoparticles, such as zinc oxide nanoparticles (ZnO NPs). The FESEM is better since it allows us to examine the surface of the materials at amounts. We may observe the appearance of the minute particles. They exist in size and have some sort of a texture. The shape of the small particles can also be observed. The surface as depicted in the images is entirely clumpy. You are able to observe the particles that are stuck together. This sample consists of powder. With the help of the images, we will be able to examine the nanostructure of your sample. They, for instance, verify the shape it has and its size. The images help us to visualize the shape and size of the nanostructure of your sample.

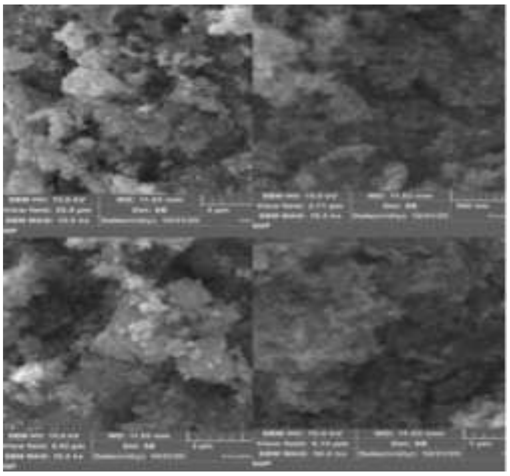

Fig 5.3 FE-SEM shows porous, highly agglomerated ZnO nanoparticle clusters — primary grains ~20–80 nm packed into micron-scale (≈1–5 µm) aggregates.

6. CONCLUSION

Fabrication of Zinc Oxide nanoparticles using ingredients such as cardamom and aloe vera is a cheap method of producing it. This is due to the fact that the Zinc Oxide nanoparticles prepared using cardamom and aloe vera are superior since bad chemicals are utilized during the making of the products and they are also safer. Such Zinc Oxide nanoparticles are very good pickers and can aid in the breakdown.

They are effective because the surface of the Zinc Oxide nanoparticles is actually very large and possesses numerous active sites that are capableof capturing the bad stuff and eliminate it within a short period of time. This can be used to assist in cleaning up the heavy metal remediation and create safety enhancements to handle the wastewater. When we make nanoparticles, the impact will be mitigated by the use of plant extracts such as Cardamom and Aloe Vera which will decrease the level of impact on the environment. This application of plant extracts will actually assist in treating wastewater and establishing metals. Both the plant extracts of Cardamom and Aloe Vera were employed as agents to achieve the homogeneous distribution of the Zinc Oxide Nanoparticles and its high degree of interactivity which is excellent in terms of metal remediation and wastewater management. The application of Cardamom and Aloe Vera extracts to create Zinc Oxide Nanoparticles is one of the directions to create nanomaterials that can assist in the removal of heavy metal in wastewater. The ZnO nanoparticles are quite excellent in absorbing and breaking down. They are able to remove such metals as Pb, Cr and Ni in wastewaters. The surface area of the ZnO nanoparticles facilitates their attachment to other objects this is better than other means. The benefit of the ZnO nanoparticles in the environment is that they minimize pollution. The work containing the ZnO nanoparticles indicates that they are capable of purifying water and this is one means of ensuring our planet is clean as well as making a green pollution strategy through the use of the ZnO nanoparticles.

7. REFERENCES:

1) Rasli, N.I.et al.(2020). green synthesis of ZnO using aloe vera — protocol & characterization (open access). PMC

2) Ansar, N.et al.(2024). Aloe-inspired synthesis using $Zn(NO_3)_2 \cdot 6H_2O$ (procedure with NaOH addition and sonication). Nature

3) Kaur, H. et al.(2025). ZnO synthesis using Elettaria (cardamom) pods — dual functional material for water purification. PMC

4) Agarwal, H. et al.(2017). review on green synthesis of ZnO nanoparticles (overview of parameters). ScienceDirect.

5) Sundrarajan, M., & Gowri, S. (2011). Green synthesis of titanium dioxide nanoparticles using Aloe vera extract. International Journal of Nanotechnology and Applications, 5(3), 41–50.

6) Ramesh, M., Anbuvannan, M., & Viruthagiri, G. (2015). Green synthesis of ZnO nanoparticles using Aloe vera plant extract and their antimicrobial activities. Materials Science in Semiconductor Processing, 39, 594–599.

7) Krishnamoorthy, K., Moon, J. Y., Hyun, H. B., Kim, S. J., & Kim, S. H. (2012). Mechanistic investigation of photocatalytic activity of ZnO nanoparticles. Materials Chemistry and Physics, 133, 291–297.

8) Elumalai, K., & Velmurugan, S. (2015). Green synthesis, characterization, and antimicrobial activities of zinc oxide nanoparticles from *Plectranthus amboinicus* leaf extract. Materials Letters, 142, 152–154.

9) Sangeetha, G., Rajeshwari, S., & Venckatesh, R. (2011). Green synthesis of zinc oxide nanoparticles by Aloe barbadensis miller leaf extract: Structure and optical properties. Materials Research Bulletin, 46(12), 2560–2566.

10) Gautam, R. K., Sharma, S. K., & Mahiya, S. (2015). Heavy metals removal and wastewater treatment using nanomaterials. In Nano-Materials as Photocatalysts for Degradation of Environmental Pollutants (pp. 1–24). Springer.

11) Aloulou, F., & El Feki, A. (2018). Adsorption and removal of heavy metals using green-synthesized nanoparticles: A review Journal of Environmental Chemical Engineering, 6(4), 5931–5945.

12) Ibrahim, H. M. M. (2015). Green synthesis and characterization of silver and zinc oxide nanoparticles using Azadirachta indica leaf extract. Journal of Radiation Research and Applied Sciences, 8(3), 265–275.

13) Azizi, S., Ahmad, M. B., Namvar, F., & Mohamad, R. (2014). Green biosynthesis and characterization of zinc oxide nanoparticles using brown marine macroalga Sargassum muticum aqueous extract. Materials Letters, 116, 275–277.

14) Vijayakumar, S., Vaseeharan, B., Malaikozhundan, B., & Gobi, N. (2015). Synthesis and characterization of ZnO nanoparticles using Cissus quadrangularis plant extract and its antibacterial activity. Microbial Pathogenesis, 87, 7–15.

15) Kolekar, N., Yadav, H. M., & Bandgar, D. (2020). Plant-mediated synthesis of ZnO nanoparticles and their application in wastewater treatment. Journal of Environmental Management, 260, 110061.

16) Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles for heavy metal detection and removal: Green synthesis and environmental applications. Environmental Chemistry Letters, 17, 1495–1521.