ORIGINAL ARTICLE

# Cadmium Oxide Nanoparticles Synthesis Using Pulsed Laser Ablation in a Liquid Medium and Investigation of Their Antibacterial Activity

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## Abstract

**Purpose:** Recent years have witnessed a significant amount of research into laser ablation in liquids due to the many potential applications of laser microprocessing of materials, including the synthesis of nanomaterials and nanostructures. This study aims to explore the antibacterial effects of cadmium oxide on both positive and negative bacteria.

**Materials and Methods:** Pulsed Laser Ablation (PLA) in liquid is a straightforward and environmentally friendly technical technique that works in water or other organic liquids under ambient conditions, in contrast to other, usually chemical methods. Here, 30 milliliters of deionized water were used to create Cadmium Oxide (CdO) nanoparticles using the PLA method. UV-vis spectrometry, FT-IR, X-ray spectroscopy, and FESEM were utilized to analyze the products' morphology, spectral content, and particle size.

**Results:** The produced nanocomposites were tested as antibacterial agents against gram-negative bacteria (Proteus mirabilis and Escherichia coli) as well as gram-positive bacteria (Staphylococcus aureus and Enterococcus faecalis). The MIC results on the MTP plate with the synthesized Cd NPS compound were as follows: Proteus mirabilis (6.25%), Escherichia coli (12.5%), Enterococcus faecalis (12.5%), and Staphylococcus aureus (12.5%). These findings indicate that the synthesized nanoparticles exhibit comparable antibacterial activity against both Gram-positive and Gram-negative bacteria.

**Conclusion:** The synthesized nanoparticles made of CdO demonstrated notable antibacterial activity that was effective against all of the bacteria that were tested in the experiments. This indicates that the CdO nanocomposite has the potential to inhibit the growth of a wide variety of bacterial strains.

**Keywords:** Pulsed Laser Ablation; Cadmium Oxide Nanoparticles; Antibacterial Activity; Liquid Medium.

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## 1. Introduction

Current scientific efforts focus on nanotechnology, enabling new applications in agriculture, food processing, and medicine [1]. Nanoparticles are widely used in physics, biology, and chemistry, with their size and shape playing crucial roles in applications such as magnetic materials, electronic devices, wound healing, antimicrobial agents, and biocomposites [2].

For instance, in the realm of physics, nanoparticles are employed to create advanced magnetic materials that can enhance data storage and processing capabilities. In biology, they play a vital role in wound healing by promoting tissue regeneration and providing targeted drug delivery. Furthermore, in the field of chemistry, nanoparticles are utilized as antimicrobial agents that can effectively combat infections and improve the safety of food products. Additionally, they are integral to developing biocomposites, which combine biological materials with synthetic substances to create sustainable and high-performance materials [3, 4].

CdO, a polycrystalline material with excellent optical properties, is a popular nanomaterial for photodiodes, phototransistors, photovoltaic cells, infrared detectors, and supercapacitors. Its nanostructures, along with other semiconducting materials, show promise for biological applications [5-7]. The n-type semiconductor cadmium oxide (CdO) has an indirect optical bandgap of 1.36 eV and a direct bandgap of 2.3 eV. CdO is an oxide that falls into the II-VI group. It has a high exciton binding energy of 75 mV and unique optical, electronic, and structural properties that make it useful for a wide range of technological applications.

Bacteria are generally classified into two groups: Gram-positive and Gram-negative. Gram-negative bacteria possess a thin peptidoglycan layer with saccharides on the outer side, and aminoglycoside drugs enhance their activity. In contrast, Gram-positive bacteria have a thicker peptidoglycan layer and lack an outer membrane, making them more resistant to antibiotics. Both types of bacteria feature nanometer-sized pores, so nanoparticles can inhibit bacterial growth by penetrating these structures and reducing their activities [8].

Drug development and medicine face significant challenges from emerging diseases brought on by drug resistance. Patients with these infections have high rates of morbidity and mortality [9-11]. Research has been concentrated on developing novel chemically altering agents as an advanced solution to this issue. The pace, at which drug resistance is evolving, however, far outpaces efforts made to stop this phenomenon in the lab [12, 13]. 16 percent of hospital-acquired infections are caused by strains of Staphylococcus aureus, Pseudomonas aeruginosa, and Klebsiella pneumoniae, which are critically resistant to many of the approved antibiotic drugs [14, 15]. Antibiotic therapy and cancer treatment have advanced significantly as a result of the use of nanoparticles in a variety of medical applications [16]. The development of nanotechnology has revolutionized this field of study, and there is a growing demand for products derived from it. Antimicrobial resistance can be prevented in a number of ways, such as by avoiding the overuse and abuse of antimicrobial agents in farm animals, developing new medications, reducing the general use of antimicrobials, and, more recently using nanotechnology [17-20].

The physical characteristics of nanoparticles are obviously affected by their small size, which sets them apart from their comparable parent materials in a big way. As a result, the close correlation between the characteristics of nanoparticles has created a wealth of chances for numerous scientific discoveries [21, 22]. Applications for cadmium nanoparticles in biology and medicine are widespread. Some treatments for urinary tract infections have focused on using cadmium to kill bacteria [23-26]. According to the mentioned above, the current investigation was carried out to demonstrate the physical characteristics and assess the antimicrobial efficaciousness of cadmium nanoparticles against bacteria that are resistant to multiple drugs.

## 2. Materials and Methods

A sheet of Cadmium (Cd) metal (≥99.9%) was acquired from the pool of BDH Chemical Ltd. in England.

Materials and tools that were used in bacterial growth are Mueller-Hinton broth, nutrient medium, Microtiter Plate (MTP), McFarland standard solution 0.5, and resazurin dye. The control was a blank liquid culture medium free of bacteria.

A mode-locked amplified Nd:YAG laser (Leopard, Continuum) was employed for the pulsed laser ablation test in liquid, using a 1064 nm wavelength at a 10 Hz repetition rate.

### 2.1. Preparation of Colloids by PLA

Figure 1 A 100 mL beaker is taken and a cadmium plate is placed in it, after which deionized water is added. After this step, the target was irradiated with the third harmonic (1064 nm) of an Nd:YAG laser operating at a frequency of 10 Hz, and the target surface was the focus of the laser beam. After 30 minutes, the color of the solution changed to light yellow, and this change indicated the formation of cadmium oxide. After that, the colloidal solution of cadmium oxide nanoparticles was obtained and the nanoparticles were separated from the water using a centrifuge [27].

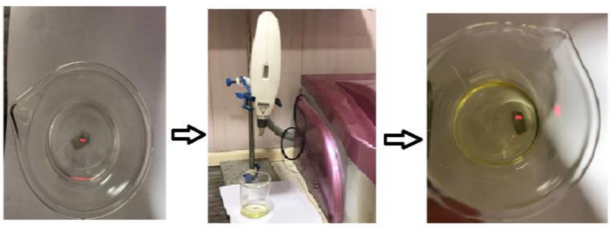

**Figure 1.** Steps of preparation of cadmium oxide nanoparticle colloids by PLA

### 2.2. Nanoparticles Characterization

The synthesis of cadmium oxide nanoparticles prepared by pulsed laser ablation was characterized by UV–vis spectra, FT-IR spectra, and XRD spectra. The morphology of the NPs was examined using FESEM.

### 2.3. Method of Bacterial Growth Inhibition

The Minimum Inhibitory Concentration (MIC) test was conducted to determine the lowest inhibitory concentration. We followed the procedures outlined by Elshikh *et al.* (2016), Barnes *et al.* (2023), Rodríguez-Tudela *et al.* (2003), Balouiri *et al.* (2016), and Gonelimali *et al.* (2018). The procedures are as follows:

This was a pre-activated bacterial inoculum prepared on MHA medium and diluted to 0.5 McFarland's standard (1.5 x $10^8$ bacterial cells/ml). 100 µL of Mueller Hinton broth was added to each MTP well. The absolute concentration of the chemical compound was loaded in the first well, and then a series of dilutions (11 dilutions) was performed for each solution. After this, 10 microliters of bacterial inoculum were added and the path of each bacterium was marked with a short letter to distinguish it from the others. The models were incubated at 37-35 degrees Celsius for 24 hours, then we observed the results.

## 3. Results & Discussion

### 3.1. UV-Visible Spectra

The produced CdO solution's UV-visible spectra are displayed in Figure 2. A new absorption peak at 283 nm is visible in the inclusion spectra of cadmium metal produced by the pulsed laser ablation method. Consequently, the absorption that took place in this area demonstrated that the CdO nanocluster was absorbed. This aligns with research findings from a few investigators [28].

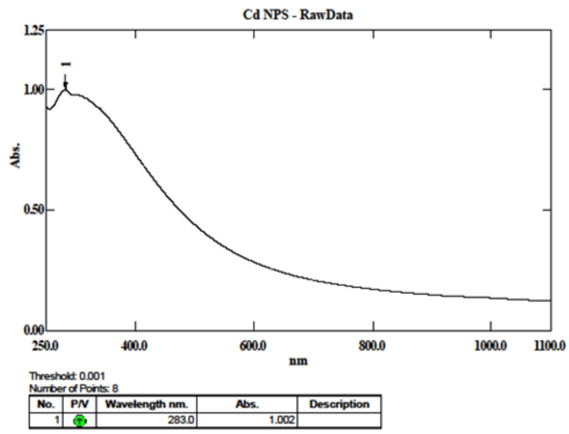


**Figure 2.** UV-Vis spectroscopy absorbance; a significant absorption peak at 283 nm has been identified in the integration spectrum of cadmium metal produced by the pulsed laser method

### 3.2. FTIR Spectrum

The Fourier Transform Infrared (FTIR) spectrum, as shown in Figure 3, has a broad band at 3388.93 $cm^{-1}$ that corresponds to the OH group's vibration mode

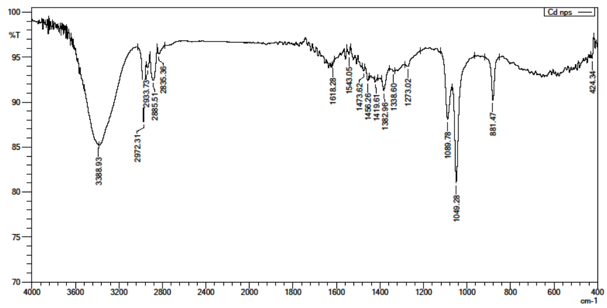


**Figure 3**. F-TIR spectroscopy; the broad spectrum and vibrational modes linked to OH suggest a small amount of water adsorbed on the surface

and denotes the presence of a small amount of surface-adsorbed water. The C-H group's stretching mode is represented by the bands at 1049.28, 1089.78, 2885.51 $cm^{-1}$, 2933.73 $cm^{-1}$, and 2972.31 $cm^{-1}$. The Cd-O is represented by the peak at 1618.28 and 881.47 $cm^{-1}$. This aligns with research studies carried out by certain investigators [29].

### 3.3. XRD Spectrum

Figure 4 displays the nano-sized CdO's XRD pattern. The production of CdO is responsible for the diffraction peaks at 2θ values of 32.0º, 37.3º, 55.3º, 65.8º, and 65.7º, respectively. These values correspond to the (100), (111), (200), and (220) planes. This is consistent with investigations conducted by certain researchers [30].

### 3.4. FESEM Analysis

The morphology of green synthesized Cd NPs was viewed by FESEM. Figure 5 shows a well-dispersed Cd NPs identified in the size 25.95 nm (Figure 5B). The particles are clearly identified by their spherical shapes [31].

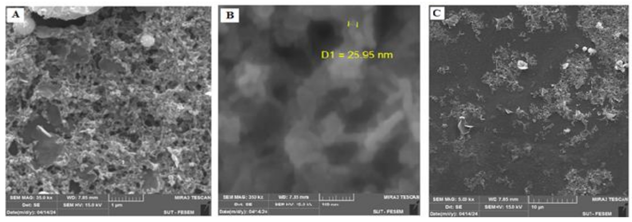


**Figure 5.** FESEM images of CdO NPs at different magnifications; synthesized NPs have a size of approximately 29 nm

### 3.5. Activity Bacterial Assay

Table 1 Shows the minimum effective concentrations in percentage (descending from 100% to 0.75%) of the Cd/NPs compound using the MTP method.

Figure 6 shows the result of measuring the MIC on the MTP plate for the Cd NPS compound against both Gram-positive and Gram-negative bacteria. The resazurin reagent was used to detect the presence or absence of growth in the MTP test dishes. The blue color indicates the absence of growth (occurrence), and the pink color indicates the presence of growth (no

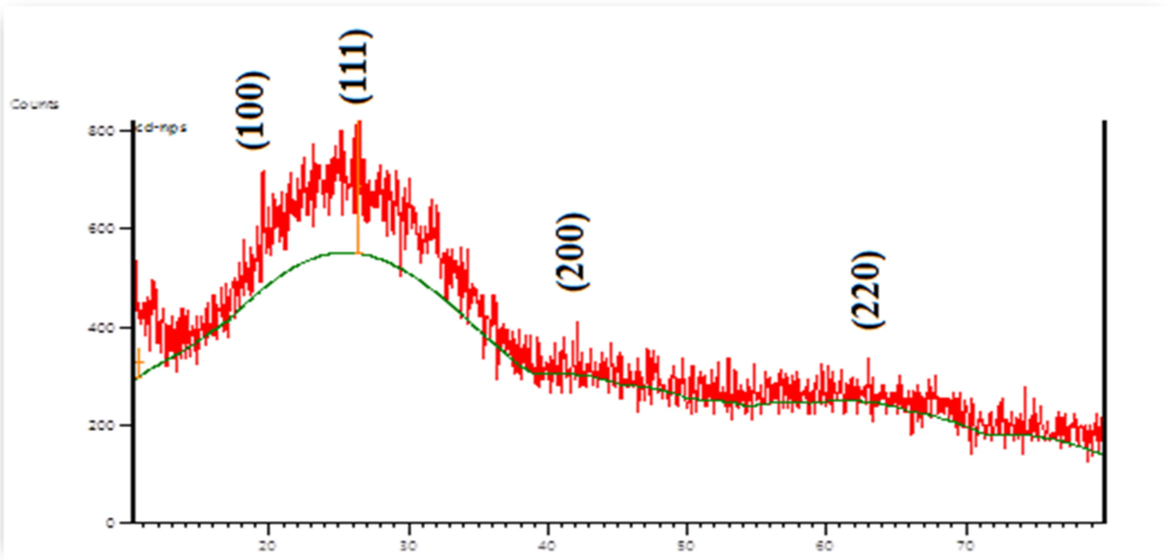


**Figure 4.** XRD spectrum image; the XRD spectrum displays several peaks that indicate the material types at four distinct locations

**Table 1.** The MIC result is expressed as a percentage of bacterial presence when exposed to Cd NPs on various plates

| Staphylococcus aureus (SA) | Enterococcus faecalis (E.f) | Escherichia coli (E.C) | Proteus mirabilis (Pr) |
|---|---|---|---|
| 12.5 % | 12.5 % | 12.5 % | 6.25 % |

Note: A lower percentage indicates a more effective solution.

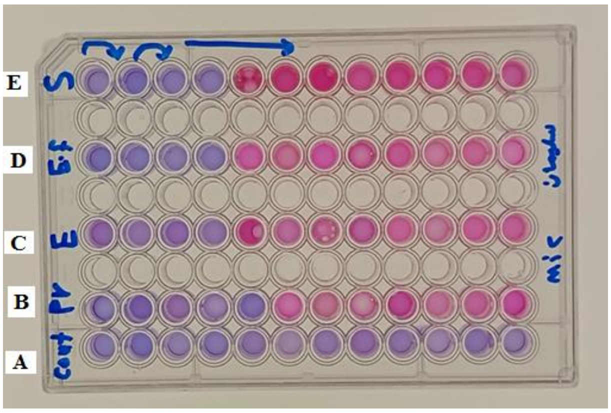


**Figure 6.** MIC on the MTP plate; the antibacterial activity of CdO NPs. (**A**) *control,* (**B**) *Proteus mirabilis (PM)*, (**C**) *Escherichia coli* (EC),(**D**) *Enterococcus faecalis(EF)*, (**E**) *Staphylococcus aureus(SA)*

inhibition occurs), as the blue color remains in inhibitory concentrations and turns to pink when there is growth. Descending dilution was performed from pit No. 1 to pit No. 12 in the direction of the arrow indicator on the upper side of the plate. The bottom line is left for positive control [32-34].

The article's novelty lies in our hypothesis that altering the synthesis method would yield similar antibacterial properties across different Gram-positive and Gram-negative groups. While most studies indicate a stronger effect on Gram-positive bacteria, our findings show comparable results for both groups. Recent research conducted by Agammy *et al.* involved the exposure of two distinct cadmium oxide compounds to Nd-YAG lasers, utilizing wavelengths of 532 nm and 1064 nm. The antibacterial tests indicated that the incorporation of silver into cadmium oxide significantly enhances its efficacy in eliminating harmful germs and microbes. Additionally, the findings revealed that the 1064 nm wavelength outperforms the 532 nm wavelength when tested in pure water [35].

In summary, CdO nanoparticles were successfully synthesized via laser ablation in a liquid medium, achieving an average particle size of 25.95 nm. The shape, size, and characteristics of the products were evaluated using FT-IR, UV-vis spectroscopy, FESEM, and Energy-Dispersive X-ray spectroscopy (EDX). The resulting NPs were tested as antibacterial agents against both Gram-negative bacteria (Proteus mirabilis and Escherichia coli) and Gram-positive bacteria (Staphylococcus aureus and Enterococcus faecalis). The synthesized CdO NPs demonstrated antibacterial activity against all bacterial strains tested.

## 4. Conclusion

The synthesized nanoparticles made of CdO demonstrated notable antibacterial activity that was effective against all of the bacteria that were tested in the experiments. This indicates that the CdO nanocomposite has the potential to inhibit the growth of a wide variety of bacterial strains.

## References

1- Sahar Naji Rashid, Kadhim A Aadim, Awatif Sabir Jasim, and Arshad Mahdi Hamad, "Synthesized zinc nanoparticles via pulsed laser ablation: characterization and antibacterial activity." *Karbala International Journal of Modern Science,* Vol. 8 (No. 3), pp. 462-76, (2022).

2- Vaishali N Sonkusare, Ratiram Gomaji Chaudhary, Ganesh S Bhusari, Alok R Rai, and Harjeet D Juneja, "Microwave-mediated synthesis, photocatalytic degradation and antibacterial activity of α-Bi2O3 microflowers/novel γ-Bi2O3 microspindles." *Nano-Structures & Nano-Objects,* Vol. 13, pp. 121-31, (2018).

3- Seraj Mohaghegh, Ali Tarighatnia, Yadollah Omidi, Jaleh Barar, Ayuob Aghanejad, and Khosro Adibkia, "Multifunctional magnetic nanoparticles for MRI-guided co-delivery of erlotinib and L-asparaginase to ovarian cancer." *Journal of Microencapsulation,* Vol. 39 (No. 4), pp. 394-408, (2022).

4- Shiza Malik, Khalid Muhammad, and Yasir Waheed, "Emerging applications of nanotechnology in healthcare and medicine." *Molecules,* Vol. 28 (No. 18), p. 6624, (2023).

5- Peyman Ghoranneviss, Davoud Dorranian, and Amir Hossein Sari, "Effects of laser fluence on the Cd (OH) 2/CdO nanostructures produced by pulsed laser ablation method." *Optical and Quantum Electronics,* Vol. 51 (No. 3), p. 88, (2019).

6- NB Sonawane, PK Baviskar, RR Ahire, and BR Sankapal, "CdO necklace like nanobeads decorated with PbS nanoparticles: room temperature LPG sensor." *Materials Chemistry and Physics,* Vol. 191, pp. 168-72, (2017).

7- Savita Patil, Shrikant Raut, Ratnakar Gore, and Babasaheb Sankapal, "One-dimensional cadmium hydroxide nanowires towards electrochemical supercapacitor." *New Journal of Chemistry,* Vol. 39 (No. 12), pp. 9124-31, (2015).

8- Ameer Azam, Arham S Ahmed, Mohammad Oves, Mohammad S Khan, Sami S Habib, and Adnan Memic, "Antimicrobial activity of metal oxide nanoparticles against Gram-positive and Gram-negative bacteria: a comparative study." *International Journal of Nanomedicine,* pp. 6003-09, (2012).

9- ABEER A Abass, MA Wasna'a, and ZUHAIR S Alsehlawi, "Characterization Of Antimicrobial Activity Of Gold Nanoparticlesprepared By Pulse Laser Ablation In Liquid." *Asian Jr of Microbiol Biotech Env Sc,* Vol. 21 (No. 1), p. 2, (2019).

10- Alessia Catalano *et al.*, "Multidrug resistance (MDR): A widespread phenomenon in pharmacological therapies." *Molecules,* Vol. 27 (No. 3), p. 616, (2022).

11- Megan Bergkessel, Barbara Forte, and Ian H Gilbert, "Small-molecule antibiotic drug development: need and challenges." *ACS Infectious Diseases,* Vol. 9 (No. 11), pp. 2062-71, (2023).

12- Ali H Attallah, Farah Shamil Abdulwahid, Yasir A Ali, and Adawiya J Haider, "Effect of liquid and laser parameters on fabrication of nanoparticles via pulsed laser ablation in liquid with their applications: a review." *Plasmonics,* Vol. 18 (No. 4), pp. 1307-23, (2023).

13- Regina Huang *et al.*, "Nano-based theranostic approaches for the infection control: current states and perspectives." *Materials Chemistry Frontiers,* (2024).

14- Ashley N Brown, Kathryn Smith, Tova A Samuels, Jiangrui Lu, Sherine O Obare, and Maria E Scott, "Nanoparticles functionalized with ampicillin destroy multiple-antibiotic-resistant isolates of Pseudomonas aeruginosa and Enterobacter aerogenes and methicillin-resistant Staphylococcus aureus." *Applied and Environmental Microbiology,* Vol. 78 (No. 8), pp. 2768-74, (2012).

15- Molly Kukua Abban, Eunice Ampadubea Ayerakwa, Lydia Mosi, and Abiola Isawumi, "The burden of hospital acquired infections and antimicrobial resistance." *Heliyon,* (2023).

16- Shreelaxmi Gavas, Sameer Quazi, and Tomasz M Karpiński, "Nanoparticles for cancer therapy: current progress and challenges." *Nanoscale Research Letters,* Vol. 16 (No. 1), p. 173, (2021).

17- Rabiya Tabbassum Khan and Shafaq Rasool, "Nanotechnology: A new strategy to combat bacterial infections and antibiotic resistant bacteria." in *Nanotechnology and Human Health*: *Elsevier*, (2023), pp. 167-90.

18- Hans Ram Meena and Vikash Kumar, "Antimicrobial resistance and rational use of antimicrobials in livestock: developing countries' perspective." *Livestock Health and Farming,* p. 11, (2019).

19- Helal F Hetta *et al.*, "Nanotechnology as a promising approach to combat multidrug resistant bacteria: a comprehensive review and future perspectives." *Biomedicines,* Vol. 11 (No. 2), p. 413, (2023).

20- Wei Zou, Alyssa McAdorey, Hongbin Yan, and Wangxue Chen, "Nanomedicine to overcome antimicrobial resistance: Challenges and prospects." *Nanomedicine,* Vol. 18 (No. 5), pp. 471-84, (2023).

21- AM Ismail, Rania Ramadan, and Mai M El-Masry, "The role of nanoparticles inclusion in monitoring the physical properties of PVDF." *Journal of the Australian Ceramic Society,* Vol. 59 (No. 2), pp. 333-41, (2023).

22- Mohammad Tabish, Mohd Moonis Zaheer, and Abdul Baqi, "Effect of nano-silica on mechanical, microstructural and durability properties of cement-based materials: A review." *Journal of Building Engineering,* Vol. 65, p. 105676, (2023).

23- Alireza Ghasempour *et al.*, "Cadmium sulfide nanoparticles: preparation, characterization, and biomedical applications." *Molecules,* Vol. 28 (No. 9), p. 3857, (2023).

24- J Christina Rhoda, S Chellammal, Helen Merina Albert, K Ravichandran, and C Alosious Gonsago, "Synthesis, Spectroscopic, and antibacterial characterizations of cadmium–based nanoparticles." *Journal of Fluorescence,* Vol. 34 (No. 2), pp. 587-98, (2024).

25- Ikechukwu P Ejidike *et al.*, "Cadmium oxide nanoparticles from new organometallic Cd (II)-Schiff base complex and in vitro biological potentials: dual S. aureus and E. coli DNA gyrase inhibition by the precursors via in silico binding modes' study." *Research on Chemical Intermediates,* Vol. 50 (No. 6), pp. 2763-91, (2024).

26- Khanderao Pagar *et al.*, "Bio-inspired synthesis of CdO nanoparticles using Citrus limetta peel extract and their diverse biomedical applications." *Journal of Drug Delivery Science and Technology,* Vol. 82, p. 104373, (2023).

27- MA Gondal, Tawfik A Saleh, and QA Drmosh, "Synthesis of nickel oxide nanoparticles using pulsed laser ablation in liquids and their optical characterization." *Applied Surface Science,* Vol. 258 (No. 18), pp. 6982-86, (2012).

28- Eman A Mwafy, Mohamed S Hasanin, and Ayman M Mostafa, "Cadmium oxide/TEMPO-oxidized cellulose nanocomposites produced by pulsed laser ablation in liquid environment: synthesis, characterization, and antimicrobial activity." *Optics & Laser Technology,* Vol. 120, p. 105744, (2019).

29- D DurgaVijaykarthik, M Kirithika, N Prithivikumaran, and N Jeyakumaran, "Synthesis and characterization of Cadmium Oxide nanoparticles for antimicrobial activity." (2014).

30- M Tabatabaee, AA Mozafari, M Ghassemzadeh, M Reza Nateghi, and I Abedini, "A simple method for synthesis of cadmium oxide nanoparticles using polyethylene glycol." *Bulg. Chem. Comm,* Vol. 45, pp. 90-92, (2013).

31- Ahmed N Abd, Mohammed F Al-Marjani, and Zahraa A Kadham, "Antibacterial activity of cadmium oxide nanoparticles synthesized by chemical method." *Journal of Multidisciplinary Engineering Science and Technology,* Vol. 3 (No. 6), pp. 5007-11, (2016).

32- Lucien Barnes, Douglas M Heithoff, Scott P Mahan, John K House, and Michael J Mahan, "Antimicrobial susceptibility testing to evaluate minimum inhibitory concentration values of clinically relevant antibiotics." *STAR Protocols,* Vol. 4 (No. 3), p. 102512, (2023).

33- Faraja D Gonelimali *et al.*, "Antimicrobial properties and mechanism of action of some plant extracts against food pathogens and spoilage microorganisms." *Frontiers in Microbiology,* Vol. 9p. 1639, (2018).

34- Mohamed Elshikh *et al.*, "Resazurin-based 96-well plate microdilution method for the determination of minimum inhibitory concentration of biosurfactants." *Biotechnology Letters,* Vol. 38, pp. 1015-19, (2016).

35- EF El Agammy, MF Hasaneen, Amr A Essawy, Shaima MN Moustafa, GE Khalil, and AM Nassar, "Effect of Nd: YAG pulsed laser on the antibacterial activity and physical properties of newly synthesized composites, CdO/Co3O4 and Ag/CdO/Co3O4." *Physica Scripta,* Vol. 99 (No. 1), p. 015903, (2023).