

RESEARCH PAPER

Efficient Synthesis of CeVO₄ Nanoparticles Using Combustion Route and Their Antibacterial Activity

Damayanti Ramchandra Kamble¹, Sachin Vasant Bangale^{2*}, Suresh Kushinath Ghotekar³, Sambhaji Rau Bamane⁴

¹ Department of Chemistry, Shankarrao Mohite Mahavidyala, Akulj 416 101, University of Solapur, Maharashtra, India.

² Department of Chemistry, G. M. Vedak College of Science, Tala 402 111, University of Mumbai, Maharashtra, India

³ Department of Applied Science & Humanities, G. M. Vedak Institute of Technology, Tala 402 111, University of Mumbai, Maharashtra, India.

⁴ Department of Chemistry, Raja Shripatrao Bhagwantrao College, Aundh 415 510, Shivaji University, Maharashtra, India.

ARTICLE INFO

Article History:

Received 29 February 2018

Accepted 18 March 2018

Published 01 April 2018

Keywords:

Antibacterial activity

CeVO₄

Nanotechnology

ABSTRACT

CeVO₄ (Cerium orthovanadate) nanoparticles were synthesized by urea-assisted simple and efficient combustion method. Phase formations of synthesized nanoparticles were characterized by thermogravimetric-differential thermal analyzer (TG-DTA). X-ray diffraction (XRD) pattern revealed the crystal planes and size of synthesized CeVO₄ nanoparticles. The average size, morphological shape and the crystalline nature of the nanoparticles were determined by scanning electron microscopy (SEM), transmission electron microscopic with selected area electron diffraction (TEM-SAED). Energy-dispersive X-ray spectroscopy (EDX) confirmed the presence of elemental composition and purity of the synthesized nanoparticles. Fourier transform Infrared spectroscopy (FT-IR) confirmed the possible stretching frequency on the surface of CeVO₄ nanoparticles. Surface area and porosity studies of synthesized nanoparticles were analyzed by Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) curve. Moreover, CeVO₄ nanoparticles evinced excellent antibacterial activity against Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Proteus vulgaris, Salmonella typhi, Staphylococcus aureus, Streptococcus pyogenus, Bacillus subtilis, Streptococcus pneumoniae and Staphylococcus epidermidis. The studies describing the synthesis of CeVO₄ nanoparticles by efficient combustion method followed by the investigation of antibacterial activities may be useful for research opening a new arena in the field of nanobiotechnology.

How to cite this article

Kamble D. R, Bangale S. V, Ghotekar S. K, Bamane S. R. Efficient Synthesis of CeVO₄ Nanoparticles Using Combustion Route and Their Antibacterial Activity. J Nanostruct, 2018; 8(2):144-151. DOI: 10.22052/JNS.2018.02.004

INTRODUCTION

Nowadays, the synthesis of nanosized rare earth orthovanadates (RVO₄)/metal oxides has attracted much curiosity due to their miraculous and extensive applications in the field of catalysis,

* Corresponding Author Email: bangale_sv@rediffmail.com

bioengineering and material science [1-5]. Amongst them, CeVO₄ nanoparticles has wide potential applications in various fields such as gas sensor [6-8], electrochromic material [9], photocatalyst [1,10], lubricating additives [11], luminescence

[12] and batteries fields [13]. Considering CeVO₄ nanoparticles have excellent physical and chemical properties, it was particularly important to seek a facile, efficient and energy saving preparation method. The scrutiny of the literature revealed some notable methods were used for synthesis of CeVO₄. For example, sol-gel method [14], microwave assisted synthesis [8], ultrasound method [15], hydrothermal method [16], solid-state reaction method [17] and sonochemical method [18] have been reported. Therewith, metal oxide nanoparticles can be used as an anti-biotic, antioxidant, pesticide formulation, antimicrobial and antifungal agent when incorporated in textiles, coatings and plastics [19-22].

In this work, we rapidly synthesized CeVO₄ nanoparticles by simple and efficient combustion method using urea as a fuel. These synthesized nanoparticles were evaluated for antimicrobial activities by employing against some selected human pathogens. It was found that efficiently synthesized CeVO₄ nanoparticles evinced good biomedical application in nanobiotechnology.

MATERIALS AND METHODS

Synthesis of CeVO₄ nanoparticles

In this study, CeVO₄ powder was successfully synthesized by solution combustion route using the starting reagents as Ce(NO₃)₃.6H₂O, V(NO₃)₃.6H₂O and Urea as a fuel. Urea possesses a high heat of combustion. It is an organic fuel providing a platform for redox reactions during the course of combustion. Initially cerium nitrate, vanadium nitrate and urea are taken in the 1:1:4 stoichiometric amount and homogenous paste was made. The paste formed was evaporated on hot plate at about 70 to 80 °C to get thick gel. This kept on a hot plate for auto combustion and heated at 170 to 180 °C. To obtain nanocrystalline CeVO₄ powder, this was sintered at 800 °C for 4 hrs. A fine dark brown colored material was obtained and this was carefully collected and packed for further characterization purposes.

Characterization techniques

The synthesized CeVO₄ nanoparticles were characterized using thermogravimetric-Differential thermal analyzer (TG-DTA, PERKIN ELMER, USA, Diamond TG/DTA). The crystallinity and crystal phases were characterized by X-ray diffraction (XRD, Bruker, D8-Advanced Diffractometer) pattern measured with Cu-Kα

Radiation ($\lambda = 1.5406 \text{ \AA}$) in the range of 20–90°. The morphology and composition of the synthesized CeVO₄ nanoparticles were examined by scanning electron microscopy (SEM, JEOL, JSM-6360), SEM coupled energy-dispersive X-rays spectroscopy (EDX, Bruker, XFlash 6130). Find the exact morphological structures and size of the CeVO₄ nanoparticles using transmission electron microscopic (TEM) with selected area electron diffraction (SAED) analysis is done by using a PHILIPS, CM200 with an accelerating voltage of 200 kV. The Fourier transform Infrared (FTIR) spectrum was recorded by JASCO 4100 in the range of 4000–400 cm⁻¹. The specific surface area, pore size and volume were characterized by Brunauer-Emmett-Teller (BET) and Barrett-Joyner-Halenda (BJH) analysis method at 77.40 deg. K (NOVA-100 Ver. 3.70).

Antibacterial activity of synthesized CeVO₄ nanoparticles

The Minimum inhibition concentrations (MIC) of synthesized CeVO₄ nanoparticles were carried out by broth micro dilution protocol as described by Rattan [23]. DMSO (Dimethyl sulphoxide) was used as diluents to get desired concentration of drugs to test upon standard bacterial strains. Serial dilutions were prepared in primary and secondary screening. The control tube containing no antibiotic was immediately subculture by spreading evenly over a plate of medium suitable for the growth of the test bacterial pathogens and incubated overnight at 37 °C. The MIC of the control bacterial strain was measured to check the accuracy of the drug concentrations. The lowest concentration inhibiting growth of the bacterial pathogen was recorded as the MIC. The amount of growth from the control tube before incubation was compared. Subcultures might evince similar number of colonies indicating bacteriostatic, a reduced number of colonies indicating a partial or slow bactericidal activity and no growth if the whole inoculum has been killed. The test must include a second set of the same dilutions inoculated with a bacterial pathogen. A synthesized CeVO₄ nanoparticle was diluted obtaining 2000 µg/ml concentration, as a stock solution. In primary screening, 500, 250 and 125 µg/ml concentrations of the synthesized CeVO₄ nanoparticles were taken. The synthesized CeVO₄ nanoparticles found in this primary screening was further tested in a second set of dilution against all microorganisms. The CeVO₄ nanoparticles found

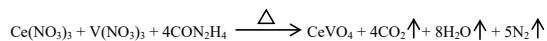
active in primary screening was similarly diluted to obtain 100, 50, 25, 12.5, 6.250, 3.125 and 1.5625 µg/ml concentrations. The highest dilution showing at least 99 % inhibition is taken as MIC.

RESULTS AND DISCUSSION

TG-DTA

TG-DTA curve recorded for thermal decomposition of CeVO₄ is shown in Fig. 1. The curve indicates that the slight weight loss in CeVO₄ powder due to little loss of moisture, nitrogen and carbon dioxide gas. The DTA curve of CeVO₄ recorded in static air and is shown in Fig. 1. The curve exhibited that CeVO₄ did not decompose,

but weight loss was due to dehydrogenation, decarboxylation and denitration and yield final product at 800°C. This weight change was in the synthesized powder was almost remain stable from the beginning as shown in reaction.



Structural & crystallographic analysis

The synthesized CeVO₄ formation was confirmed by the characteristic peaks observed in the XRD patterns, as shown in Fig. 2. Such a powder XRD was carried out using monochromatic CuKα1 radiation (wavelength 1.5406Å), operating at a voltage of 40 KV and a current of 40 mA, in

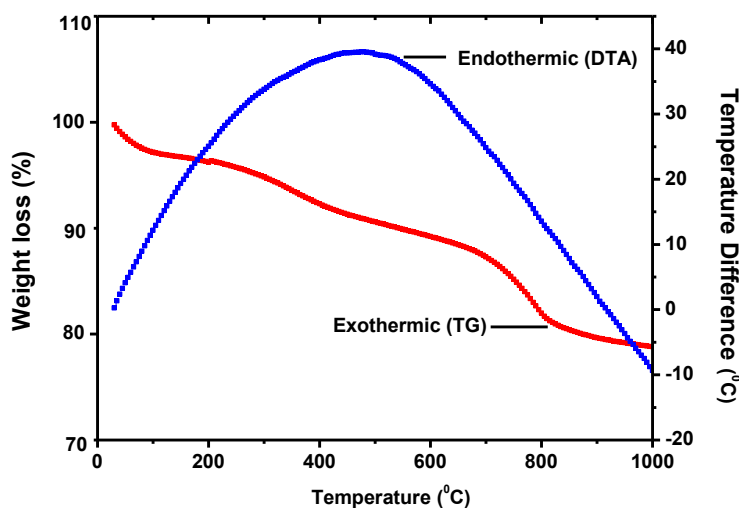


Fig. 1. TG-DTA curve of synthesized CeVO₄ nanoparticles.

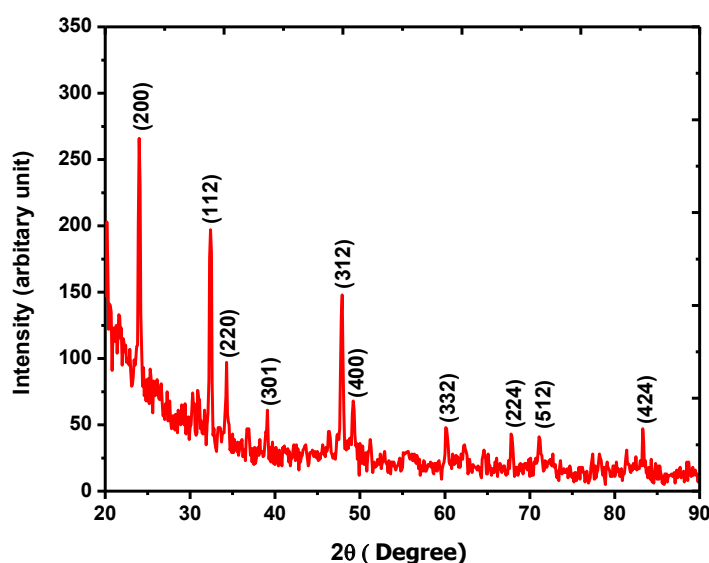


Fig. 2. XRD pattern of synthesized CeVO₄ nanoparticles sintered at 800 °C for 4 hrs.

the angular range 2θ of 20-90 deg. XRD analysis showed a series of diffraction peaks at 24.0°, 32.40°, 34.30°, 39.10°, 47.90°, 49.20°, 60.10°, 67.80°, 71.10° and 83.30°, corresponding to (200), (112), (220), (301), (312), (400), (332), (224), (512) and (424) crystal planes of tetragonal CeVO₄ nanostructures (JCPDS No. 12-0757). The sharp XRD peaks exposed that synthesized CeVO₄ nanoparticles are good crystalline in nature.

SEM microphotographs

Morphologies and sizes of synthesized CeVO₄ nanoparticles were examined by SEM techniques. It can be seen that the average crystal grain size of the CeVO₄ nanoparticles was mainly 51-93 nm except slightly agglomeration (Fig. 3). This result exceed to the literature result which tetragonal

structure of CeVO₄ nanoparticles was prepared by ultrasound method [13].

TEM images

TEM images and SAED pattern of the synthesized CeVO₄ nanoparticles were characterized. Fig. 4 indicates the hexagonal shape of CeVO₄ nanoparticles with size 45-95 nm. The SAED pattern shows a number of bright spots, which confirmed that, the as-synthesized CeVO₄ nanoparticles are single phase nature of the material.

EDX studies

The composition of synthesized CeVO₄ nanoparticles has been analyzed by investigating the energy-dispersive X-ray spectroscopy (EDX), as shown in Fig.5. This was carried out to understand the composition of the cerium,

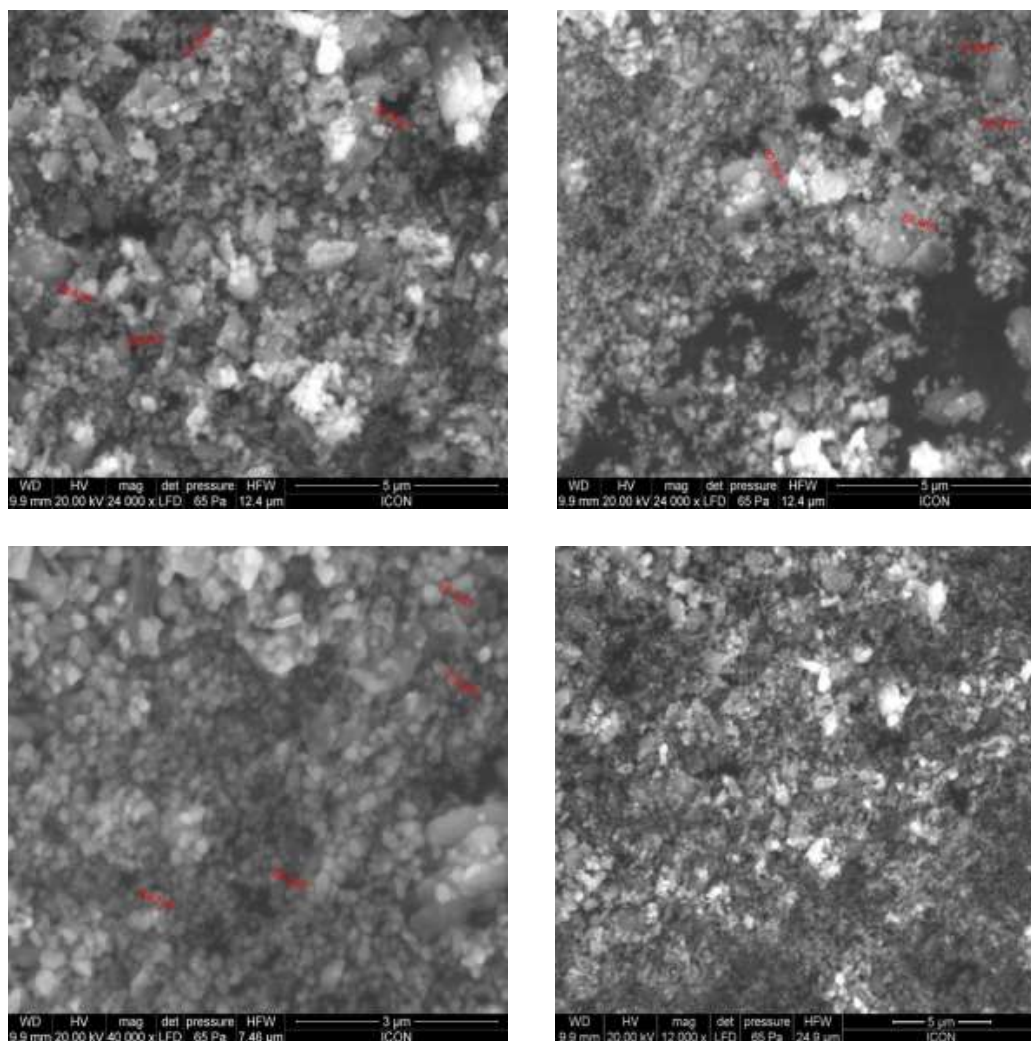


Fig. 3. SEM images of synthesized CeVO₄ nanoparticles sintered at 800 °C for 4 hrs.

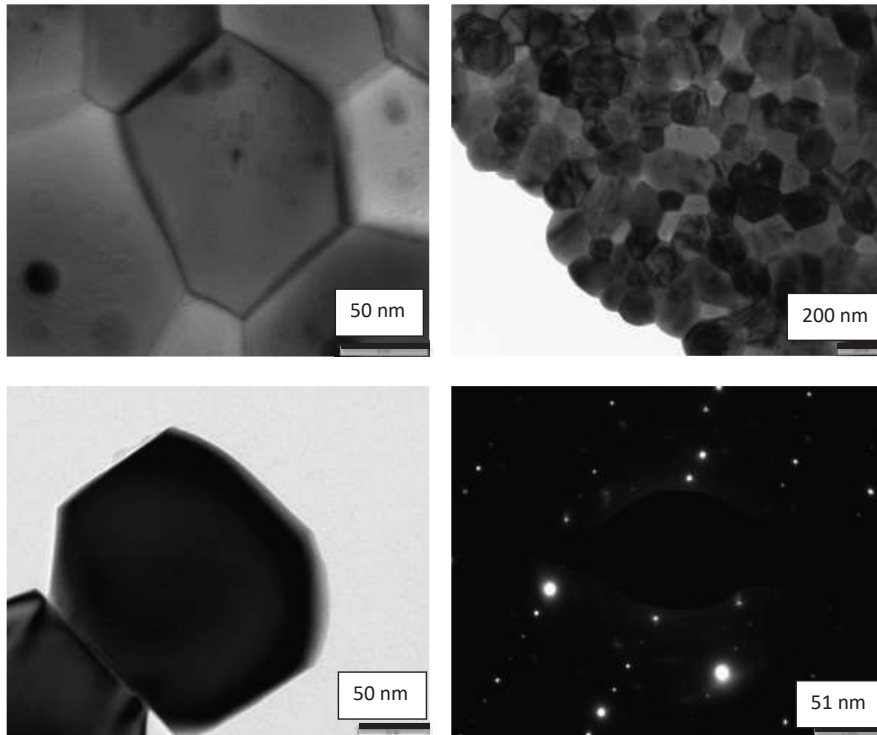


Fig. 4. TEM images with SAED pattern of synthesized CeVO₄ nanoparticles.

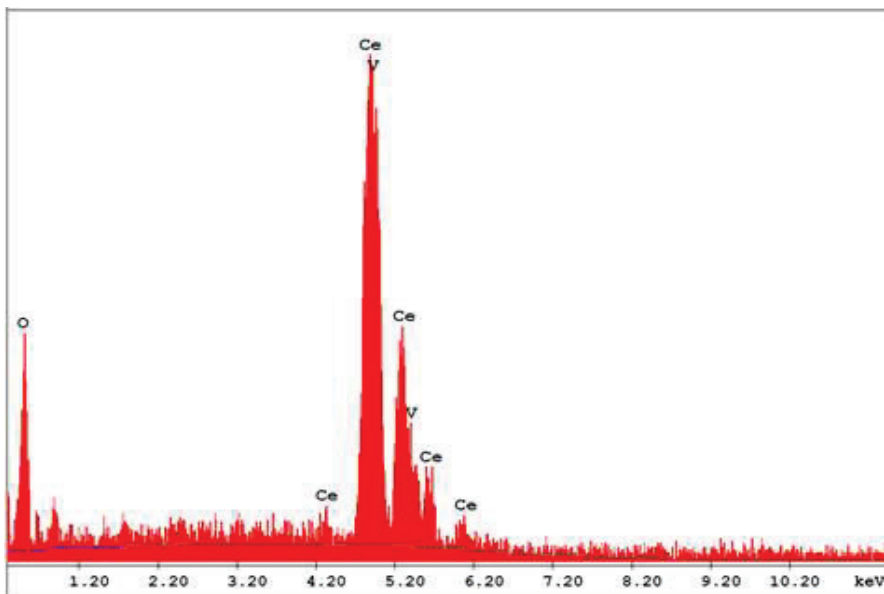


Fig. 5. EDX pattern of synthesized CeVO₄ nanoparticles sintered at 800 °C for 4 hrs.

vanadium and oxygen in the synthesized material. There was no unidentified observed in EDX. This quantitative data confirms the purity, composition and formation of CeVO₄ nanoparticles.

Vibrational properties

Fig. 6 represents the FTIR spectrum of CeVO₄ nanoparticles synthesized from combustion method. The IR band at 810 cm⁻¹ is attributed to the Re-O-V vibrations of ReVO₄. Residual water

and -OH group are detected around 3449 cm⁻¹, corresponding to the O-H stretching frequency due to the bending vibration of associated water. It suggested that the CeVO₄ nanoparticle was successfully fabricated by facile and efficient combustion method.

Surface area and porosity studies

The specific surface area of the CeVO₄ nanoparticles calculated using multipoint BET

equation is 16.52 m²/g and according that the CeVO₄ nanoparticles have solid and smooth surface. Furthermore, the corresponding BJH analyses indicate that the cumulative pore volume was 0.005 cm³/g and the pore size of which estimated from the peak position was 3.32 nm possesses a relatively narrow pore size distribution. Most of the pores ranged from 1.36 nm to 34.79 nm, as shown in the inset of Fig. 7. Therefore, these particles are polycrystalline in

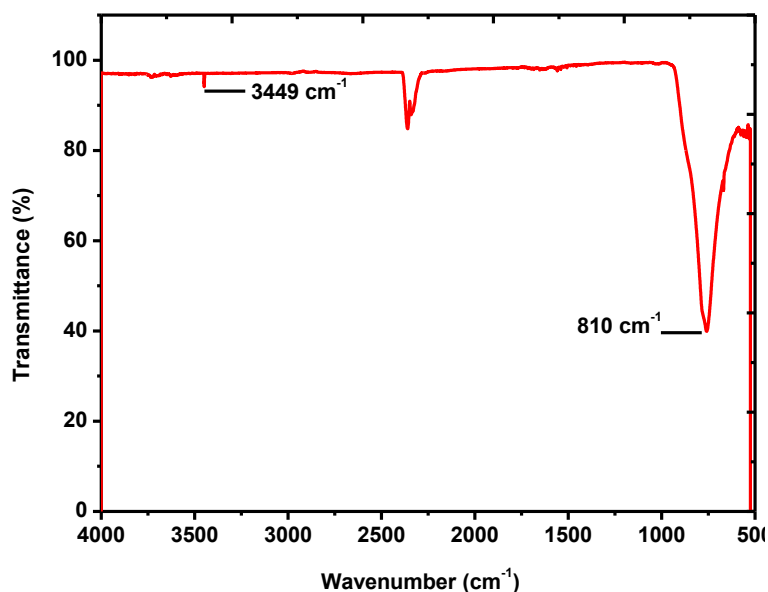


Fig. 6. FTIR spectra of synthesized CeVO₄ nanoparticles.

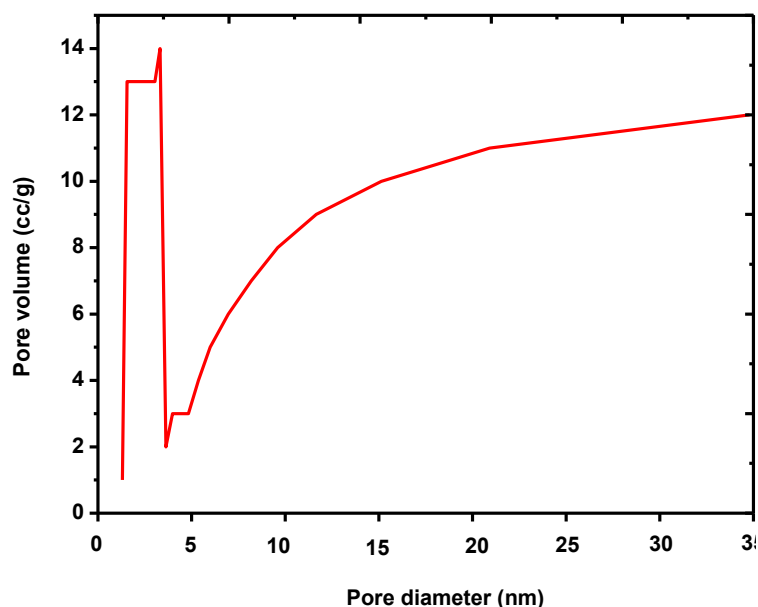


Fig. 7. BJH pore size distribution curves of synthesized CeVO₄ nanoparticles.

Table 1. Minimum inhibition concentration of CeVO₄ against selected bacterial pathogens.

Test pathogens	MIC (µg/ ml) of CeVO ₄	MIC (µg/ ml) of Reference drug
<i>E. coli</i> (MTCC-443)	50	100
<i>K. pneumoniae</i> (MTCC-109)	125	100
<i>P. aeruginosa</i> (MTCC-1688)	62.5	100
<i>P. vulgaris</i> (MTCC-8427)	100	100
<i>S. typhi</i> (MTCC-98)	100	100
<i>S. aureus</i> (MTCC-96)	125	250
<i>S. pyogenes</i> (MTCC-442)	200	100
<i>B. subtilis</i> (MTCC-441)	62.5	250
<i>S. pneumoniae</i> (MTCC-6305)	100	250
<i>S. epidermidis</i> (MTCC-12228)	100	100

nature.

Antimicrobial activity of CeVO₄ nanoparticles

The results of antibacterial activity of the synthesized CeVO₄ nanoparticles are presented in Table 1. Moderate to good antibacterial activity is observed against some bacteria. Synthesized CeVO₄ nanoparticles exhibited potent and good antibacterial activity against *E. coli*, *P. aeruginosa*, *S. aureus*, *B. subtilis*, *S. pneumoniae* and moderate activity against other bacteria with ampicillin was used as the reference drug.

CONCLUSION

The convenient utilization of urea as a fuel for the efficient synthesis CeVO₄ nanoparticles through a combustion method to obtain significantly biologically active material. The synthesized CeVO₄ nanoparticles were hexagonal in shape as observed in TEM analysis. The synthesized CeVO₄ nanoparticles have shown potential upshot against selected pathogenic bacteria. This encouraging result provides useful information for designing a much better medicinal compound using a synthesis of CeVO₄ nanoparticles with minimal side effects and play significant role in biomedicine.

ACKNOWLEDGEMENT

Authors are thankful to SAIF IIT Powai, Shivaji University Kolhapur and Microcare Laboratory Gujrat for providing the technical, instrumental and biological activities supports.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

REFERENCES

- Phuruangrat A, Kuntalue B, Thongtem S, Thongtem T. Effect of PEG on phase, morphology and photocatalytic activity of CeVO₄ nanostructures. *Mate. Lett.* 2016; 174: 138–141.
- Aher YB, Jain GH, Patil GE, Savale AR, Ghotekar SK, Pore DM, Pansambal SS, Deshmukh KK. Biosynthesis of copper oxide nanoparticles using leaves extract of *Leucaena leucocephala* L. and their promising upshot against the selected human pathogen. *Int. Jou. Mol. Clin. Micro.* 2017; 7: 776-786.
- Pande SN, Bharati KT, Wakchure SK, Ghotekar SK, Gujrathi DB, Phatangare ND. Green synthesis of silver nanoparticles by *Caralluma fimbriata* L. and its characterization. *Ind. Jou. App. Res.* 2015; 5: 749-750.
- Nguyen T, Dinh C, Do T. Monodisperse samarium and cerium orthovanadate nanocrystals and metal oxidation states on the nanocrystal surface. *Langmuir.* 2009; 25: 11142–11148.
- Bangale SV, Bamane SR. Preparation and electrical properties of nanostructured spinel ZnCr₂O₄ by combustion route. *J Mater. Sci: Mater. Elect.* 2013; 24: 277-281.
- Wang H, Meng Y, Yan H. Rapid synthesis of nanocrystalline CeVO₄ by microwave irradiation. *Inorg. Chem. Comm.* 2004; 7: 553–555.
- Bangale SV, Patil DR, Bamane SR. Nanostructured spinel ZnFe₂O₄ for the detection of chlorine gas. *Sensors & Transducers.* 2011; 134: 107-119.
- Bangale SV, Dhapte VV, Patil DR, Bamane SR. A novel combustion route for the preparation of nanocrystalline LaAlO₃ oxide based electronic nose sensitive to NH₃ at room temperature. *Sensors & Transducers.* 2015; 146: 145-155.
- Chen L. Hydrothermal synthesis and ethanol sensing properties of CeVO₄ and CeVO₄-CeO₂ powders. *Mater. Lett.* 2006; 60: 1859–1862.
- Fan C, Liu Q, Ma T, Shen J, Yang Y, Tang H, Wang Y, Yang J. Fabrication of 3D CeVO₄/graphene aerogels with efficient visible-light photocatalytic activity. *Ceram. Inter.* 2016; 42:

- 10487-10492.
- Fengzhen L, Xin S, Yibin Y, Limin Z, Zhuwei S, Xuehua L, Xianhua M. Shape controlled synthesis and tribological properties of CeVO₄ nanoparticles as lubricating additive. *J Rare Ear*. 2011; 29: 688-691.
 - Zhu L, Li Q, Li J, Liu X, Meng J, Cao X. Selective synthesis of mesoporous and nanorod CeVO₄ without template. *J Nano. Res*. 2007; 9: 261–268.
 - Picardia G, Varsanoa F, Deckera F, Opara-Krasovecb U, Surcab A, Orel B. Electrochemical characterization of optically passive CeVO₄ counter electrodes. *Elect. Acta*. 1999; 44: 3157–3164.
 - Opara-Krasovecb U, Orel B, Surca A, Bukovec N, Reisfeld R. Structural and spectro electrochemical investigations of tetragonal CeVO₄ and Ce/V-oxide sol-gel derived ion-storage films. *Solid State Ionics*. 1999; 118: 195–214.
 - Zheng Y, Qian Y, Jiqi J, Piesong T. Synthesis and characterization of nanoparticulate CeVO₄ by ultrasound method and its photocatalytic activity. *Asia-Paci. Ene. Equip. Eng. Res. Conf*. 2015: 229-232.
 - Guang L, Xuejun Z, Fei W, Hui W, Wei L. Facile fabrication of CeVO₄ microspheres with efficient visible-light photocatalytic activity. *Mater. Lett*. 2017; 195: 168–171.
 - Akiteru W. Highly conductive oxides, CeVO₄, Ce_{1-x}M_xVO_{4-0.5x} (M=Ca, Sr, Pb) and Ce_{1-y}Bi_yVO₄, with zircon- type structure prepared by solid-state seaction in air. *J Sol. Sta. Chem*. 2000; 153: 174-179.
 - Mosleh M, Mahinpour A. Sonochemical synthesis and characterization of cerium vanadate nanoparticles and investigation of its photocatalyst activity. *J Mate Sci: Mater in Elec*. 2016; 27: 8930-8934.
 - Borkow G, Zatzoff RC, Gabbay J. Reducing the risk of skin pathologies in diabetics by using copper impregnated socks. *Med. Hypotheses*. 2009: 1–4.
 - Savale A, Ghotekar S, Pansambal S, Pardeshi O. Green synthesis of fluorescent CdO nanoparticles using *Leucaena leucocephala* L. extract and their biological activities. *J Bacteriol Mycol open access*. 2017; 5: 00148.
 - Ghotekar SK, Vaidya PS, Pande SN, Pawar SP. Synthesis of silver nanoparticles by using 3-methyl pyrazol 5-one (chemical reduction method) and its characterizations. *Int. J. Multidis. Res and Deve*. 2015; 2(5): 419-422.
 - Pansambal S, Deshmukh K, Savale A, Ghotekar S, Pardeshi O, Jain G, Aher Y, Pore D. Phytosynthesis and biological activities of fluorescent CuO nanoparticles using *Acanthospermum hispidum* L. extract. *J Nanostruct*. 2017; 7: 165-174.
 - Rattan A. *Antimicrobials in laboratory medicine*. Churchill B I, Livingstone, New Delhi. 2000: 85–108.