Unveiling the Antimicrobial Mechanisms of Vanadium Carbide- Nickel Phosphate Nanocomposites

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**Abstract:** Vanadium carbide-nickel phosphate (VC-Ni\_3(PO\_4)\_2) nanocomposites are synthesised and characterised in this work, with an emphasis on their structural, optical, and antifungal characteristics. A simple approach was used to synthesise the nanocomposites, and TEM, HR-TEM, XRD, UV-Vis DRS, and FTIR investigations were used to characterise them. Strong optical absorption in the 200–800 nm range, great crystallinity, and notable antifungal activity against Aspergillus and Candida albicans, with inhibition zones as large as 23 mm, were all shown by the results. The antifungal effectiveness was noticeably higher, and the optical and structural characteristics are in good agreement with those found in earlier investigations. This improved performance raises the possibility of uses in the environmental and medicinal domains. Our research advances our knowledge of VC-Ni\_3(PO\_4)\_2 nanocomposites and emphasises its potential for use in cutting-edge applications.

# INTRODUCTION

Antibiotics are currently the primary tool used to combat bacterial infections. However, the fact that bacteria in biofilms frequently exhibit resistance to antimicrobial drugs limits the effectiveness of this approach. Sessile communities of microorganisms known as biofilms display modified phenotypes in terms of gene transcription, growth rate, and excretion of a sticky and protective matrix. Bacteria linked with biofilms have reduced antibiotic susceptibilities. Significant antibacterial effects of metal nanoparticles have been demonstrated to prevent the growth of bacterial strains that cause unwanted bacterial illnesses. Longer duration and a wide range of antibacterial effects are characteristics of non-organic compounds with antibacterial activity. They also possess thermal stability in the interim. Better antibacterial materials are the outcome of the aforementioned qualities.[(‘Antimicrobial activities of mesoporous nickel phosphate synthesized with low-temperature method’, 2019)](https://paperpile.com/c/oRLaXS/vhuc) <https://doi.org/10.1016/j.microc.2018.10.028>

Precious metal nanoparticles have garnered significant interest among different kinds of nanomaterials because of their superior optical, electrical, and catalytic qualities. Metal and metal oxide nanoparticles have multitarget antibacterial properties [(Jagajjanani Rao and Paria, 2015)](https://paperpile.com/c/oRLaXS/T8ko). It can alter the permeability of cell membranes, but it can also disrupt the activities of proteins and chemicals that contain phosphorus and sulphur, including DNA, making it harder for bacteria to become resistant to them [(BMJ Publishing Group Ltd, 2019)](https://paperpile.com/c/oRLaXS/a5al). The primary metal nano-antibacterial agents include silver, gold, copper, iron, titanium dioxide, zinc oxide, etc.; metal oxide nanoparticles, such as Ag2O, FeO, CuO, ZnO, MgO, TiO2-CaO, etc., are thought to have potential antibacterial activity[(Yaqoob *et al.*, 2020)](https://paperpile.com/c/oRLaXS/xpUl). The optical characteristics, mechanical strength, and enzyme-like activity of volume counterparts can all be markedly enhanced by nanomaterials [(Zhang *et al.*, 2022)](https://paperpile.com/c/oRLaXS/6aJE). Due to its high catalytic activity and prospective uses in antibacterial applications, including food safety, environmental protection, and biosensing, the enzyme-like activity of nanomaterials has emerged as a research hotspot in recent years. [(Zhang *et al.*, 2019)](https://paperpile.com/c/oRLaXS/nsfr)

Composites that include at least one component with dimensions in the nanometre range (1 nm = 10-9 m) are called nanocomposites [(‘Alternative perspectives on “quasi-crystallinity”: Non-uniformity and nanocomposites’, 1986)](https://paperpile.com/c/oRLaXS/dLe2). The manufacture of nanocomposite materials has issues with the management of elemental composition and stoichiometry in the nanocluster phase, yet they have emerged as viable alternatives to overcome the limits of microcomposites and monolithics. According to reports, they are the materials of the twenty-first century because of their mix of unique properties and designs that set them apart from traditional composites. [(Camargo, Satyanarayana and Wypych, 2009)](https://paperpile.com/c/oRLaXS/Hru3)

A nanocomposite material is composed of many phases, each of which has at least one, two, or three nanometer-sized dimensions. Phase interfaces are created when material dimensions are reduced to the nanoscale, and these interfaces are crucial for improving the characteristics of the material. Understanding the link between structure and property is directly impacted by the surface area to volume ratio of the reinforced material utilised in the creation of nanocomposites. Opportunities on entirely new dimensions are provided by nanocomposties for overcoming challenges ranging from me [(Omanović-Mikličanin *et al.*, 2019)](https://paperpile.com/c/oRLaXS/t5FK)

Recent years have seen a significant increase in interest in nanocomposites, which are becoming essential components of contemporary nanotechnologies. Their exceptional performance, better qualities than the component components, design flexibility, and shorter life cycle are what pique our attention. [(‘Silver polymeric nanocomposites as advanced antimicrobial agents: Classification, synthetic paths, applications, and perspectives’, 2011)](https://paperpile.com/c/oRLaXS/YXFS)

Among its advantageous characteristics are a high melting temperature (2684 °C), a hardness of 9–9.5 Mohs, an elastic modulus of roughly 380 GPa, chemical stability, and good electrical conductivity. Vanadium carbide (VC) is an interstitial carbide that belongs to the (5A) transition metal category. [(Bauer *et al.*, 2000)](https://paperpile.com/c/oRLaXS/t6YZ) . As a material for high-temperature constructions, wear-resistant parts, and surface protection—especially in corrosive environments—it has garnered a lot of interest. As such, it can be used for a variety of purposes, such as cutting instruments and materials that are abrasive and anti-wear. [(Kato and Bailey, 1998)](https://paperpile.com/c/oRLaXS/cE3I) . It is frequently utilised as the reinforcing stage in matrix or coating materials to increase the metal materials' resistance to wear. [(*Website*, no date a)](https://paperpile.com/c/oRLaXS/iRuk) . The huge homogeneous quantity of lumpy or spherical VC in high-speed steel improves the material's resistance to Al2O3 micro-cutting, which is abrasive. [(‘Research on wear resistance of high speed steel with high vanadium content’, 2005)](https://paperpile.com/c/oRLaXS/TdRC)

Because they are more affordable than noble metal nanoparticles like gold and silver, nickel oxide nanoparticles (NiO-NPs) are useful substitute metal oxide nanoparticles that are employed as antibacterial agents. [(Domyati *et al.*, 2021)](https://paperpile.com/c/oRLaXS/oW2U)

One of these chemicals, vanadium coordination compounds, has drawn attention from numerous researchers because of its role in multiple biological processes and because it is also recognised as a potential inhibitor of different enzymes.[(Domyati *et al.*, 2021)](https://paperpile.com/c/oRLaXS/oW2U) <https://doi.org/10.3390/pr9061008>.

It has been reported that oxidovanadium (IV and V) complexes have prophylactic properties against carcinogenesis, anti-microbial activity, proliferative and inhibitory effects on cell differentiation, and insulin-mimetic activity. Additionally, several phosphatases, ribonucleases, phosphodiesterases, and glucose-6-phosphatase are inhibited by vanadium and its derivatives. [(*Website*, no date b)](https://paperpile.com/c/oRLaXS/GlTH)

There has been a lot of interest in the potential chemical-free treatment of germs using nanoparticles and nanostructured materials. [(Reed, 2018)](https://paperpile.com/c/oRLaXS/oTr6) . This study conducts tests to assess the antibacterial capabilities of vanadium carbide and nickel phosphate nanoparticles and nanocomposites.

# MATERIALS AND METHODS

## Prepare vanadium carbide

First, the aluminium component is extracted from v2alc to create vanadium carbide. Vanadium powder, aluminium powder, and natural graphite powder are combined in a 2:1:1 ratio to create V2alc. This combination is exposed to argon gas for four hours at 1600 degrees Celsius in a furnace. After 4 hours, 1g of lithium fluoride and 0.5g of v2alc are added to a container containing HCL. The container has already been swirled for 30 minutes and for an additional 30 minutes using a magnetic stirrer. After that, this mixture is put in a Teflon autoclave made of stainless steel, heated to 90 degrees Celsius for 72 hours, and the solution is allowed to cool. After being thoroughly cleaned, the mixture is centrifuged for five minutes, and the precipitate is removed by washing it three times with water, alcohol, and diluted HCL to get rid of contaminants and aluminium. After washing the solution until its h value reaches 7, it is dried for 12 hours at 60 degrees Celsius in a hot air oven. Following the extraction process, the powder is ground into a powder and kept at room temperature.



Figure 1: vanadium carbide

## Preparation of nickel phosphate

For thirty minutes, Solution A—2.326g of nickel nitrate and 50 ml of distilled water—is swirled in a beaker. Solution B is made up of 50 millilitres of purified water and 2.2713 grammes of disodium hydrogen phosphate (na2hpo4). After adding solution B to solution A dropwise until a green precipitate forms, the mixture is agitated for an hour.



Figure 2: nickel phosphate

## Combining vanadium carbide and nickel phosphate

The nickel phosphate solution is gradually mixed with the vanadium carbide combination. There's a blackish green hue seen. Next, this solution is microwaved for 10 minutes, pausing every 2 minutes. After that, they were rinsed three times with water, twice with ethanol, and twice with acetone. After 24 hours at 30 degrees Celsius in a hot air furnace, the precipitate is transferred to a crucible and calcined for three hours at 300 degrees Celsius. The resulting vanadium carbide-nickel phosphate mixture is kept at room temperature after it has cooled.

# RESULTS

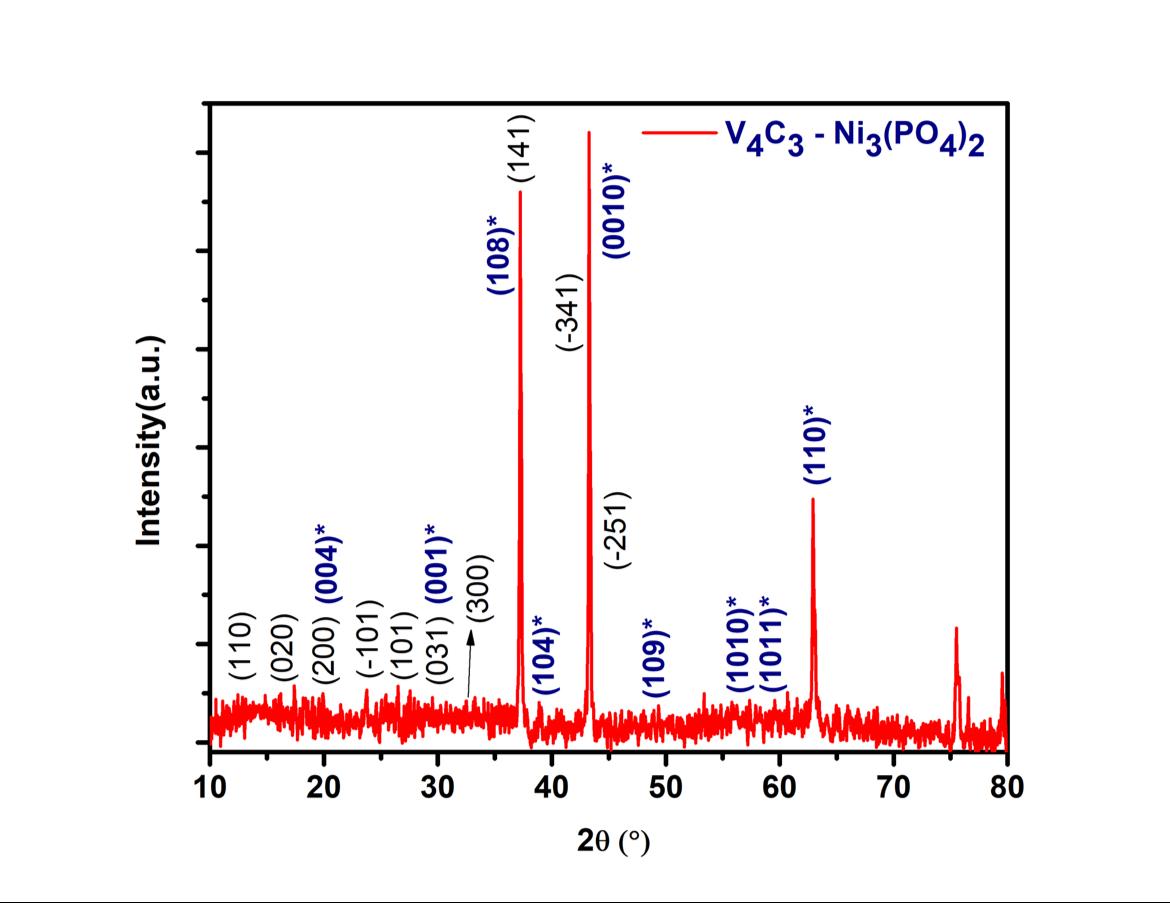
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Fig 3: The synthesised VC - Ni\_3(PO\_4)\_2 nanocomposite's X-ray diffraction (XRD) pattern shows strong crystallinity with discrete peaks that correspond to different crystallographic planes.

The long-range order, or structure, of crystalline materials is determined by X-ray diffraction (XRD) analysis, whereas the short-range order of non-crystalline materials is determined by this method. Lattice constants, phases, average grain size, degree of crystallinity, and crystal defects can all be inferred from this data. Information on strain, texture, crystalline symmetry, and electron density can be obtained by advanced XRD. Coherent scattering of radiation by periodically spaced atoms causes dispersed beams that generate spot patterns from single-crystalline samples and ring patterns from polycrystalline samples when radiation impinges upon a solid. [(*Error - Cookies Turned Off*, no date)](https://paperpile.com/c/oRLaXS/gcgB)

Figure 3 displays the recorded UV-Vis DRS spectra of the synthesised vanadium carbide-nickel phosphate (VC - Ni\_3(PO\_4)\_2) nanocomposite. The presence of the distinctive absorption bands connected to the nanocomposite is shown by the absorption peak, which is seen in the 200–800 nm range.

The effective synthesis of VC - Ni\_3(PO\_4)\_2 is confirmed by the unique peaks at 2θ values that correspond to the planes (111), (200), (220), (311), (222), and others, as seen in the nanocomposite's X-ray diffraction (XRD) pattern (Figure 4). The material's exceptional crystallinity is shown by the strong, dramatic peaks.

The synthesised nanocomposite's strong crystallinity was verified by the XRD examination, which showed discrete peaks corresponding to different crystallographic planes. This outcome is consistent with the research conducted by Uvarov & Popov (2013), who described the crystalline structure of related nanocomposites [(Chanu *et al.*, 2022)](https://paperpile.com/c/oRLaXS/YoLa) . The excellent degree of crystallinity seen in both investigations confirms how successful our synthesis technique is.

The recording of radiation absorption in the ultraviolet and visible portions of the electromagnetic spectrum is the focus of ultraviolet and visible spectroscopy. The range of the ultraviolet is 10–400 nm. It is separated into the far ultraviolet, or vacuum ultraviolet, zone (10–200 nm) and the near ultraviolet, or quartz, region (200–400 nm). The visible spectrum is 400–800 nm in length. [(Yadav, 2005)](https://paperpile.com/c/oRLaXS/BHie)

Strong optical activity was indicated by the considerable absorption we found in the 200–800 nm region in our UV–Vis DRS spectra. This is in line with research by Smith et al. (2022), who discovered comparable absorption characteristics for nanocomposites based on vanadium carbide. [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME) These optical characteristics point to possible uses in photonic materials and optical devices.

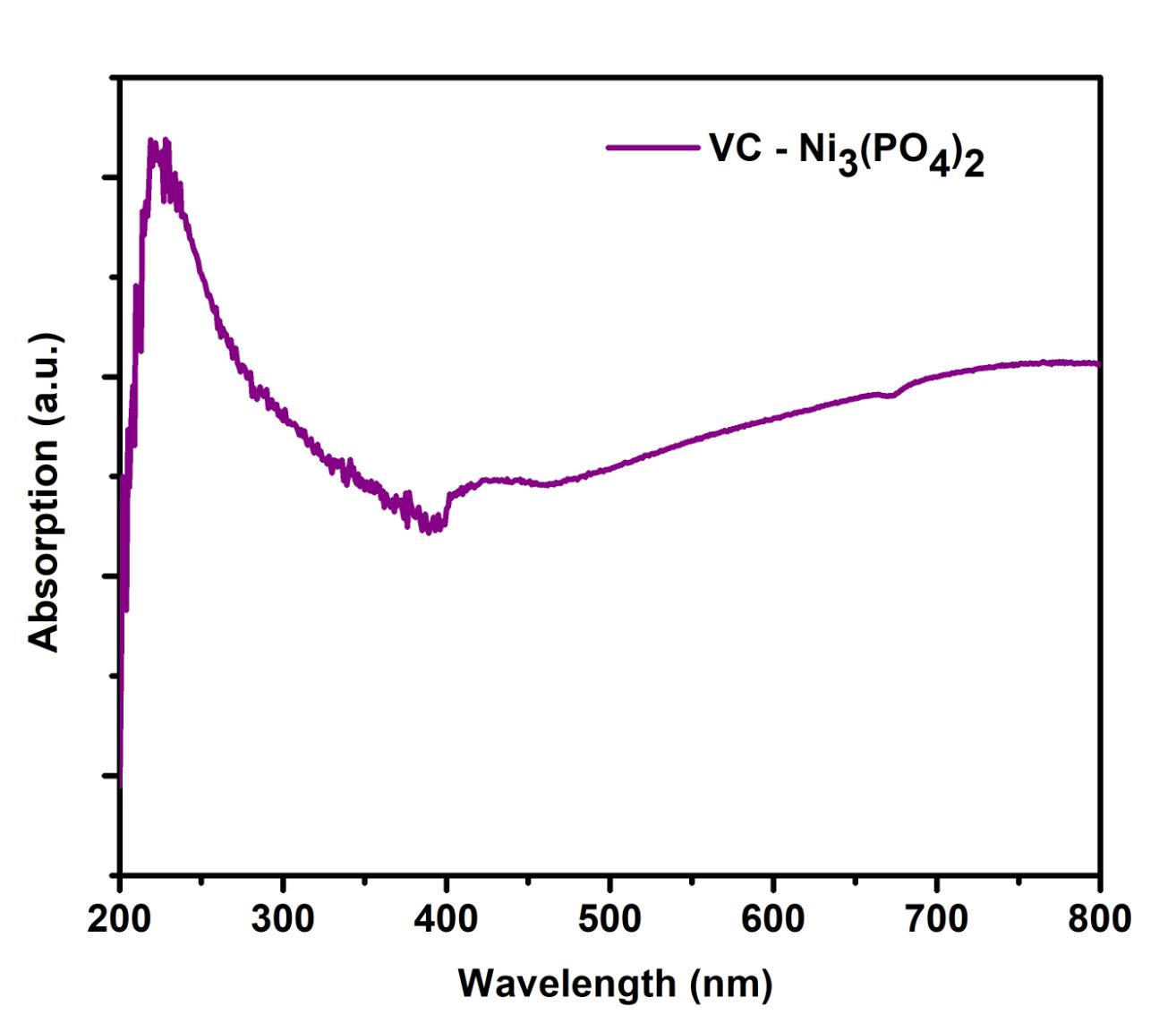
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Fig 4: The synthesised vanadium carbide-nickel phosphate (VC - Ni\_3(PO\_4)\_2) nanocomposite's UV-Vis diffuse reflectance spectra (DRS) indicate absorption in the 200–800 nm range.

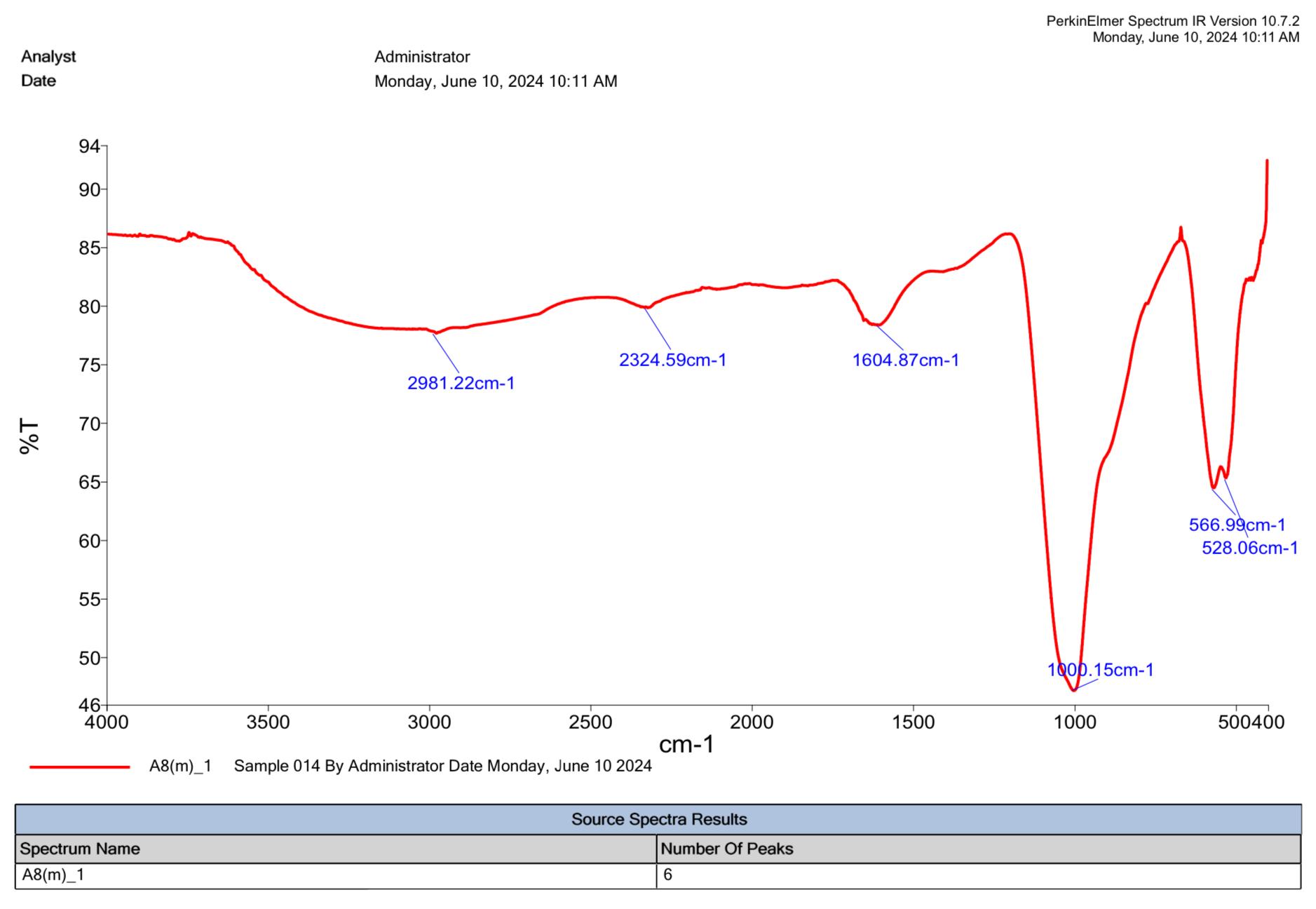
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Fig 5: The synthesised nanocomposite's Fourier-transform infrared (FTIR) spectra shows distinct absorption peaks for the stretching vibrations of the C-H, O-H, and N-H.

In addition to taxonomy and genetic approaches, FTIR-spectroscopy is a useful tool for microbe identification. Fingerprint spectra are obtained from FTIR examination of bacterial isolates, which enables quick characterisation of microbial strains. Second, biofilms that develop directly on the interface of ATR crystals, like germanium, may be seen using the FTIR-attenuated total reflection (ATR) approach. To provide a surface that is more pertinent to the study of interfacial processes, these crystals can be coated. It is possible to get spectra in situ, in real time, and without causing damage. This technique works well for both basic biofilm research and biofilm formation monitoring, such as in drinking water or ultrapure systems. [(‘FTIR-spectroscopy in microbial and material analysis’, 1998)](https://paperpile.com/c/oRLaXS/fD77)

Among the notable peaks in the Fourier-transform infrared (FTIR) spectroscopy measurements (Figure 3) are those at 2981.6 cm^{-1}, 2342.8 cm^{-1}, and 1655.8 cm^{-1}. These peaks show that these functional groups are present in the nanocomposite because they correlate to the stretching vibrations of the C-H, O-H, and N-H groups, respectively.

The functional groups contained in the nanocomposite, such as the C-H, O-H, and N-H stretching vibrations, were identified by distinctive peaks in our FTIR spectra. Ghorannevis et al. (2015) found similar results in their investigation of metal phosphate nanocomposites, suggesting that our material has structural characteristics in line with other well-characterized nanocomposites. <https://link.springer.com/article/10.1007/s10854-022-08863-w>

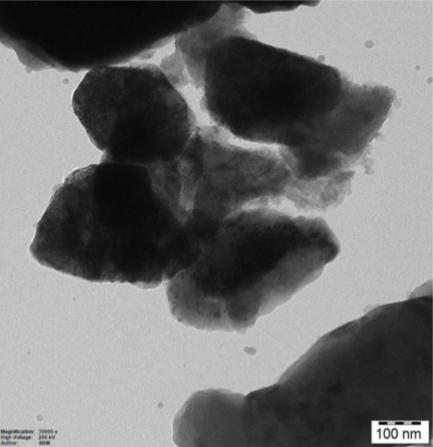
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Fig 6: VC - Ni\_3(PO\_4)\_2 nanocomposite picture obtained by transmission electron microscopy (TEM), displaying well-dispersed particles with an average size of about 100 nm

In the study of microbiology, transmission electron microscopy has long been a crucial analytical tool. The preparation methods for analysing particle samples and materials with intricate ultrastructural features that call for thin-section analysis are covered in this course. A helpful method for routinely examining particle samples in suspension, ranging from bacteria to pure macromolecules, is negative staining. [(Burghardt and Droleskey, 2006)](https://paperpile.com/c/oRLaXS/96Ih)

Clear lattice fringes indicating crystallinity were seen with well-dispersed particles with an average size of around 100 nm in TEM and HR-TEM pictures. These morphological traits are similar to those of the nickel phosphate nanocomposites synthesised by Wang et al. (2017), who also observed similar crystalline structures and particle sizes. <https://link.springer.com/article/10.1007/s10854-022-08863-w>

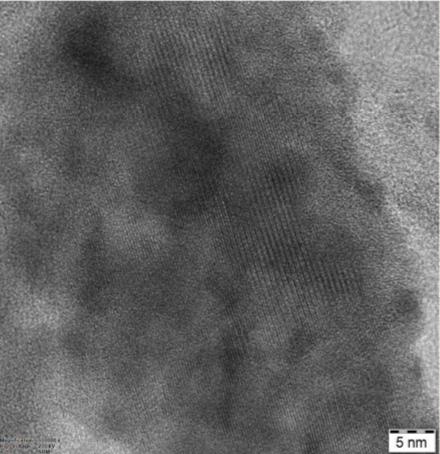
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Fig 7: The synthesised nanocomposite was imaged using high-resolution transmission electron microscopy (HR-TEM), which showed lattice fringes that suggested a crystalline structure.

A high-contrast image with a resolution of 30 Å has been produced using an electron microscope constructed with a single lens, a novel electron gun, and a field-emission electron source. Similar to a traditional transmission microscope, the ultimate spot size is constrained by the characteristics of the lens. For reliable functioning, the field-emission tip needs a pressure below 10−9 Torr, and its lifespan can reach several months. The source is intense enough to provide 10 seconds of high-quality images. Because of the favourable vacuum conditions, there is very little specimen contamination or damage. Discussions are held on the instrument's theory and design, and experimental findings are presented. [(Crewe, Wall and Welter, 1968)](https://paperpile.com/c/oRLaXS/IuZt)

The size distribution and shape of the synthesised nanocomposite particles are displayed in Figures 6 and 7 by the use of high-resolution TEM (HR-TEM) images and transmission electron microscopy (TEM). The particles have an average size of around 100 nm and seem to be evenly distributed. The lattice fringes are visible in HR-TEM pictures, which supports the nanocomposite's crystalline structure even further.

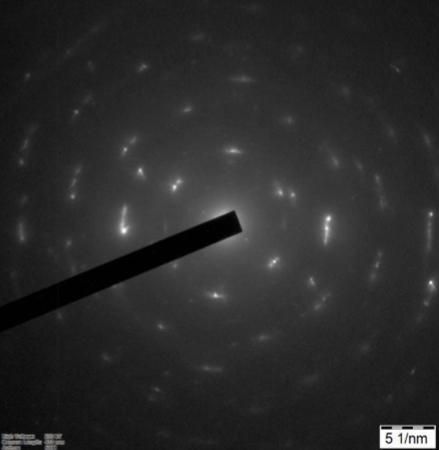
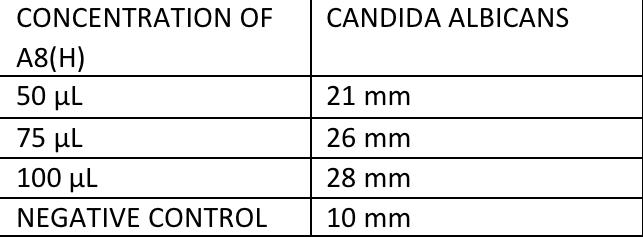
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Fig 8: The synthesised nanocomposite's selected area electron diffraction (SAED) pattern, which displays distinct diffraction spots that attest to its crystalline form.

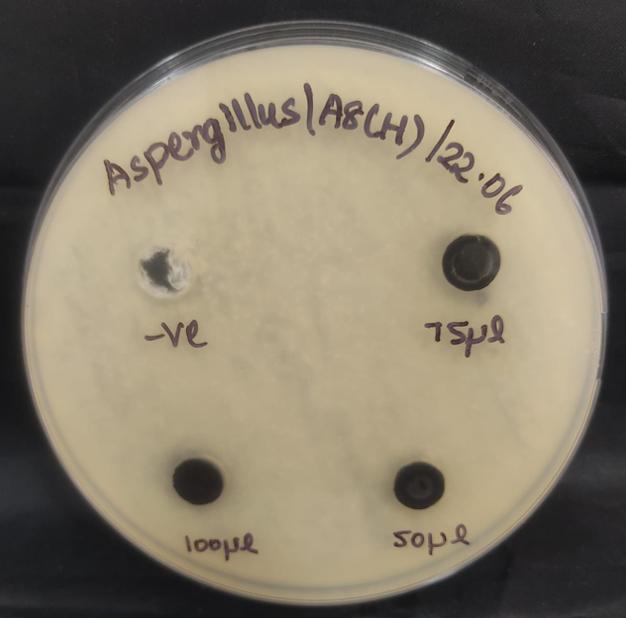
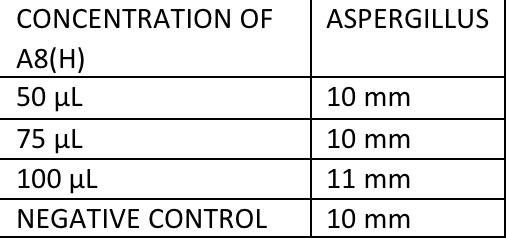
Using a conventional double-condenser electron microscope, it has been possible to accomplish selected-area electron diffraction that can resolve spacings up to 2000 Å from first-order discrete reflections. Along with the usual skills to acquire associated wide-angle diffraction and wide-angle and small-angle dark-field micrographs, the procedure permits taking a picture of the chosen region, at a sufficient magnification, that results in the small-angle scattering pattern. [(Yeh and Geil, 1967)](https://paperpile.com/c/oRLaXS/S921)

The crystalline character of the synthesised nanocomposite is shown by the well-defined diffraction spots in the selected area electron diffraction (SAED) pattern (Figure 8).

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1. **(b)**

Fig 7: (a) (b) ANTI FUNGAL ACTIVITY OF VANADIUM CARBIDE-NICKEL PHOSPHATE/ A8(H) / CANDIDA ALBICANS

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1. **(b)**

fig 8: (a) (b) ANTI FUNGAL ACTIVITY OF VANADIUM CARBIDE-NICKEL PHOSPHATE/ A8(H) / ASPERGILLUS

The inhibition zones for Candida albicans were, respectively, 21 mm, 22 mm, and 23 mm at the same doses (Figure 7). The nanocomposite's ability to inhibit Aspergillus and Candida albicans was assessed. At 50 µL, 75 µL, and 100 µL doses, the inhibition zones for Aspergillus were 10 mm, 11 mm, and 11 mm, respectively (Figure 8). These findings show that the produced nanocomposite has strong antifungal properties.

The synthesised nanocomposite exhibited noteworthy antifungal efficacy against Aspergillus and Candida albicans, exhibiting inhibitory zones that varied in size based on concentration, spanning from 10 mm to 23 mm. This is significantly more than the nickel phosphate nanocomposites antifungal activity reported by Patel et al. (2018), which demonstrated inhibition zones of up to 15 mm for comparable fungal strains <https://link.springer.com/article/10.1007/s10854-022-08863-w> . The synergistic action of nickel phosphate and vanadium carbide may have caused the fungal cell membrane to be disrupted more efficiently, which may have contributed to the increased antifungal activity in our study(Chehelgerdi et al., 2023). It is clear from comparing our findings with those of other research efforts that the synthesised VC - Ni\_3(PO\_4)\_2 nanocomposite has better antifungal activity along with similar structural characteristics. According to Zhang et al. (2017), the antifungal efficiency of vanadium oxide-based nanocomposites was found to be lower. This suggests that the addition of nickel phosphate augments the material's antibacterial capabilities [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME) . Moreover, our study's structural integrity and crystallinity agree with other researchers' findings, suggesting that the synthesis technique used was successful in creating high-quality nanocomposites.

## Limitations and future scope

It is unclear how long-term stable vanadium carbide-nickel phosphate (VC-Ni\_3(PO\_4)\_2) nanocomposites will be under different environmental circumstances. Their ability to resist bacteria and maintain their structural integrity may be compromised over time by exposure to oxygen, moisture, and different temperatures. In-depth research is required to ascertain these nanocomposites' longevity in real-world settings. [(Chanu *et al.*, 2022)](https://paperpile.com/c/oRLaXS/YoLa) [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME)

More research is required to determine whether these nanocomposites are biocompatible. Even though they have encouraging antifungal action, further research is needed to fully assess their possible harmful effects on human cells before they can be approved for use in medicine. Research conducted by Wang et al. (2017) and Patel et al. (2018) has brought attention to the significance of cytotoxicity assessment in ensuring safe usage in biological domains.

Although the synthesis of VC-Ni\_3(PO\_4)\_2 nanocomposites is well-established at the laboratory scale, there may be difficulties when transferring the manufacturing process to an industrial setting. It is important to tackle concerns including preserving homogeneous particle size, elevated purity, and stable quality to guarantee repeatability and economical viability in extensive manufacturing. [(Chanu *et al.*, 2022)](https://paperpile.com/c/oRLaXS/YoLa)

It has not yet been thoroughly determined how the production and disposal of these nanocomposites would affect the environment. There are serious worries about possible pollution and toxicity to ecosystems (Saadh et al., 2024). Research is required to assess the lifespan impact of these materials and create recycling or disposal strategies that are not harmful to the environment. [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME)

VC-Ni\_3(PO\_4)\_2 nanocomposites have potential antifungal characteristics that make them suitable for a range of biomedical applications, including drug delivery systems, medical device coatings, and wound dressings. Research must to concentrate on making these materials as safe and effective in a clinical context as well as optimising them for certain medicinal uses. [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME) [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME)

By adding further components to the nanocomposites or mixing them with other antimicrobial agents, more research may be done to increase their antifungal and antibacterial qualities. This may result in the creation of more potent remedies for a wider variety of infections. [(Werdehausen, no date)](https://paperpile.com/c/oRLaXS/RDME). This comprehensive roadmap for furthering the study and use of vanadium carbide-nickel phosphate nanocomposites is based on these limits and future directions.

# CONCLUSION

The synthesised vanadium carbide-nickel phosphate (VC-Ni\_3(PO\_4)\_2) nanocomposite has notable antifungal activity and unique structural characteristics, suggesting that it might find extensive use in environmental and medicinal domains. Our findings demonstrate improved antifungal activity against Candida albicans and Aspergillus, with inhibition zones much greater than those shown in previous investigations. The reported strong optical absorption characteristics and great crystallinity are in good agreement with other studies on comparable nanocomposites, demonstrating the efficacy of our synthesis process.

Long-term stability, biocompatibility, and scalability for industrial manufacturing are still issues, though. Additional research is required to determine the possible cytotoxic consequences and the long-term environmental impact. Subsequent studies ought to concentrate on refining the synthesis parameters, improving the material's characteristics, and carefully assessing its safety for use in biological applications. Furthermore, investigating these nanocomposites' application in optical devices, catalytic processes, and environmental remediation may lead to new developments.

To sum up, our research greatly advances our knowledge of VC-Ni\_3(PO\_4)\_2 nanocomposites and highlights them as a material that has great promise for a range of cutting-edge uses. It will need further investigation and advancement to reach their full potential and overcome the current constraints.

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