



Article

Synthesis, Spectroscopic Characterization, and Antibacterial Evaluation of Zinc(II) Complexes Incorporating a Heterocyclic Carbonyl Ligand and Phosphine Co-Ligands

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Abstract: Three complexes of zinc(II) that have TAC as their heterocyclic carbonyl ligand, namely $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$, $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$, and $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$, were prepared and studied by means of Fourier-transform infrared (FT-IR) and nuclear magnetic resonance (NMR) spectroscopies. They were isolated with yields of 78%, 69%, and 74% and their melting point ranges were found to be 44-47, 153-155, and 171-173 °C. It was found out by FT-IR study that there is a shift of the carbonyl stretching vibrations from 1708 cm^{-1} for the TAC ligand to 1680.77, 1677.91, and 1679.70 cm^{-1} in the respective complexes. Antibacterial activity of the complexes was tested against *Escherichia coli* and *Staphylococcus aureus* using the agar well diffusion technique where amoxicillin was used as a reference drug. From among the synthesized complexes, $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ had the highest consistency in inhibiting *E. coli*, with inhibition zone diameters of 3.5 to 3.9 cm when tested at different concentrations ranging from 0.1 to 0.001 mg/mL. With *S. aureus*, amoxicillin yielded higher inhibition zones compared to the three complexes tested at the same concentrations. All antibacterial tests were done in triplicate, and the results were found to be the same for each replicate.

Keywords: Zinc(II) complexes; triphenylphosphine; antibacterial activity.

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1. Introduction

The coordination complexes of zinc(II) have received wide attention in coordination and bioinorganic chemistry due to the biological significance of zinc and structural flexibility of its complexes. Zinc participates in the catalytic and structural roles of many proteins and enzymes, and the (d^{10}) electron configuration makes it possible for Zn(II) to form various coordination geometries based on the character of the ligands bound to it. Due to these features, Zn(II) provides a good metal center for studying relationships between structure, coordination environment and biological activity of coordination compounds [1]. It is worth mentioning that the complexes of Zn(II) with nitrogen- and oxygen-bearing ligands have been studied regarding their antimicrobial action; the activity of the complexes varies depending on the nature of the ligands and coordination of the metal [2,3]. Choosing the proper organic ligand is one of the key factors determining the structure and properties of a metal complex. Nitrogen-containing heterocyclic compounds possessing the carbonyl group are expected to act as coordination sites due to their donor atoms availability, according to their molecular and electronic structure. Coordination of these molecules with Zn(II) will lead to changes in the electronic environment of the donor

atoms, affecting stability, geometry, and physicochemical properties of the corresponding complexes. Previous research on zinc complexes with heterocyclic ligands revealed that coordination of the ligands is usually accompanied by some spectroscopic changes and different biological activity of the complexes in comparison with the corresponding free ligands [4,5]. Nevertheless, the presence of coordinating nitrogen and oxygen atoms does not prove that they really coordinate with the metal ion, and this fact should be determined spectroscopically. Phosphine compounds are also widely used in coordination chemistry as they are powerful phosphorus-donors and are capable of changing the electronic and steric environments of metal centers. Triphenylphosphine (PPh_3) is a monodentate phosphine compound consisting of three phenyl fragments, while 1,2-bis(diphenylphosphino)ethane (dppe) is a diphosphine ligand being able to coordinate with two phosphorus atoms [6,7]. In addition, the effect of phosphine ligands on zinc complexes was explored in scientific works based on the joint use of spectral analysis and biological tests that showed how the antibacterial activity changes due to the presence of a certain phosphine co-ligand [8]. The study of metallic compounds as possible agents for the treatment of resistant bacterial infections is still a topical issue because the problem of antimicrobial resistance exists nowadays. According to the reports of the World Health Organization, there is a need to develop new strategies and methods in order to cope with such infections [9]. In this way, coordination compounds make it possible to affect the structure and physicochemical properties of organic ligands by incorporating metals and co-ligands. In particular, the Zn(II) complexes showed their antibacterial activity in respect of Gram-positive and Gram-negative bacteria (*Staphylococcus aureus* and *Escherichia coli*). However, these effects are related to specific compounds and cannot be regarded as universal for all zinc complexes; hence, there is a need to evaluate their activity experimentally [10]. In spite of extensive research on biologically significant Zn(II) coordination compounds and metal complexes incorporating phosphine ligands, additional comparative investigations will help understand the effect of diverse phosphines on spectroscopic properties and antibacterial activity of complexes with similar heterocyclic ligands. More precisely, a comparison of Zn(II) complex with TAC without phosphine co-ligand and its analogues with phosphines PPh_3 and dppe enables one to assess the effect of the type and polydentancy of phosphine on Zn(II) complexes with the same heterocyclic ligand. It is important to note that there is a difference between monodentate PPh_3 and bidentate dppe as these phosphine ligands may result in various coordination spheres and physicochemical properties of Zn(II) complexes. However, antibacterial effects of such dissimilarities should be determined empirically rather than being suggested from phosphine structure. Therefore, the objective of the current study is to synthesize three Zn(II) complexes with TAC, namely $[\text{Zn(TAC)}_2]\text{Cl}_2$, $[\text{Zn(TAC)(PPh}_3)_2]\text{Cl}_2$, and $[\text{Zn(TAC)(dppe)}]\text{Cl}_2$. These compounds will be studied by means of FT-IR spectroscopy, (^1H - NMR), (^{13}C - NMR), and (^{31}P -{H}- NMR). The in vitro antibacterial activity of each compound was determined against the *E. coli* and *S. aureus* bacteria by the use of the agar well diffusion technique with amoxicillin as the control antibiotic. Through the comparison of their spectroscopic data and inhibition zones for the three compounds, this study aims to determine the possible structure-activity relationship and how the use of the various phosphines in the metal complexes affects their antibacterial activity.

2. Experimental Part

2.1. Materials: All chemicals and reagents used in this study were obtained from Dreg and DBH and were used as received, without further purification, unless otherwise specified.

2.2. Instruments Used: The melting points of the prepared ligands and complexes were measured by the Stuart SMP30 instrument. FT-IR spectroscopy was performed on a

Bruker Tensor 27 spectrometer within the region of 400–4000 cm^{-1} . (^1H -NMR), (^{13}C -NMR), and (^{31}P -[H]-NMR) spectroscopies were carried out on a Bruker BioSpin GmbH 400 MHz spectrometer with DMSO as solvent and TMS as the standard reference. These measurements were done in the chemistry departments of Kirkuk, Tikrit, and Basrah Universities in Iraq.

2.3. Synthesis of $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ [11]: The TAC ligand (98.49 mg, 0.8 mmol) and ZnCl_2 (54.52 mg, 0.4 mmol) were then added to a suitable flask that contained ethanol and stirred for 1.5 h at 60 °C. After the reaction was completed, the solid obtained was then separated and washed, then dried. The crude was later purified by recrystallization using tetrahydrofuran (THF) solvent, yielding white, translucent needle-like crystals in a yield of 78%, with a melting point range of 44–47 °C.

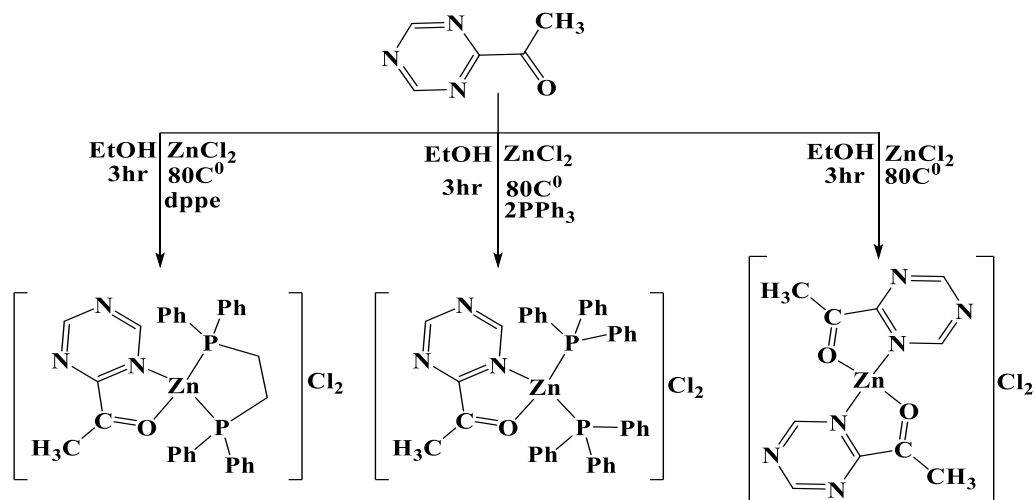
2.4. Synthesis of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$ [12]: The ligand TAC (12.31 mg, 0.1 mmol) and ZnCl_2 (13.63 mg, 0.1 mmol) were taken in an appropriate round bottom flask along with ethanol and heated at 65 °C under constant stirring for 1 hour. Then a solution of triphenylphosphine (PPh_3 , 52.46 mg, 0.2 mmol) in ethanol was added and the mixture was again heated at 65 °C for 3 hours under constant stirring. After completion of the reaction, the precipitate thus formed was filtered, washed and dried. The product obtained was then recrystallized from tetrahydrofuran (THF). The compound formed is of dark yellow colour with a yield of 69% (54.10 mg, calculated theoretically) and melting point range 153–155 °C.

2.5. Synthesis of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ [13]: TAC ligand (12.31 mg, 0.1 mmol) along with zinc chloride (ZnCl_2 , 13.63 mg, 0.1 mmol) were taken in an appropriate flask with ethanol and the mixture was stirred at 65 °C for 1 h. Then dppe (1,2-bis(diphenylphosphino)ethane, 39.84 mg, 0.1 mmol) in ethanol was added to the reaction mixture and stirred at 65 °C for 3 h. After the completion of the reaction, the product obtained was isolated via filtration, and the product was dried and recrystallized from tetrahydrofuran (THF) to obtain a pale-orange solid, with a yield of 74% and melting point of 171–173 °C.

2.6. Evaluation of Biological Efficacy: Antibacterial properties of the synthesized Zn(II) complexes were determined against the Gram-negative bacteria *E. coli* and Gram-positive bacteria *S. aureus* by the agar well diffusion technique. MHA was prepared following standard protocol, sterilized, and poured into the sterile Petri dishes [14]. Bacterial suspensions were freshly prepared and standardized by adjusting their turbidity to approximately 1.5×10^8 CFU/mL. Synthesized Zn(II) complexes and the standard antibiotic amoxicillin were diluted with DMSO in the concentrations of 0.1, 0.01, and 0.001 mg/mL [15]. Inoculation with standardized bacterial suspensions was evenly distributed over the surface of the agar plates, and the wells were subsequently made [16]. Wells were filled with the aliquot solutions (40 μL) of the test samples [17]. Plates were incubated for 24 h at 37 °C, and the inhibition zones' diameters were measured in mm [18]. All experiments were carried out in triplicates. Same values were received for the measurement of the inhibition zone in all three trials; hence, no statistical evaluation was required.

3. Result and Discussion

The synthetic routes employed for the preparation of the target Zn(II) complexes are presented in Scheme 1.



Scheme 1. All synthesized complexes.

3.1. FT-IR spectrum [19]:

The FT-IR spectrum of $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ shown in Figure 1 below indicates the vibrational behavior of the coordinating TAC ligand. Notable here is the carbonyl stretching frequency that changes from 1708 cm^{-1} for the free ligand to 1680.77 cm^{-1} for the coordination compound, which is a downshift of 27.23 cm^{-1} . The observed shift in the carbonyl region is an indication that the electronic environment of the carbonyl group changes as a result of the coordination process and is thus an indication that the oxygen of the carbonyl can participate in the coordination to the metal ion. Other absorption bands seen at 1573.97 and 1539.25 cm^{-1} can be related to the stretching vibrations of the nitrogen hetero ring, while those at 1496.81 and 1427.37 cm^{-1} can be attributed to the ring vibrations and coupled vibrations. Absorptions at 1388.79 , 1367.58 , 1300.07 , and 1197.83 cm^{-1} could be due to coupled C-N stretching and other vibrations while those at 1093.67 and 1010.73 cm^{-1} could be attributed to extra ring vibrations. The absorptions at 617.24 , 520.80 , and 476.43 cm^{-1} could correspond to skeletal vibrations and metal-ligand vibrations, but more proof is needed to assign them correctly. In general, the lowering of the carbonyl vibration indicates that there is a change in the coordination of the TAC ligand when it is complexed, although more analysis must be done using the rest of the spectroscopic results.

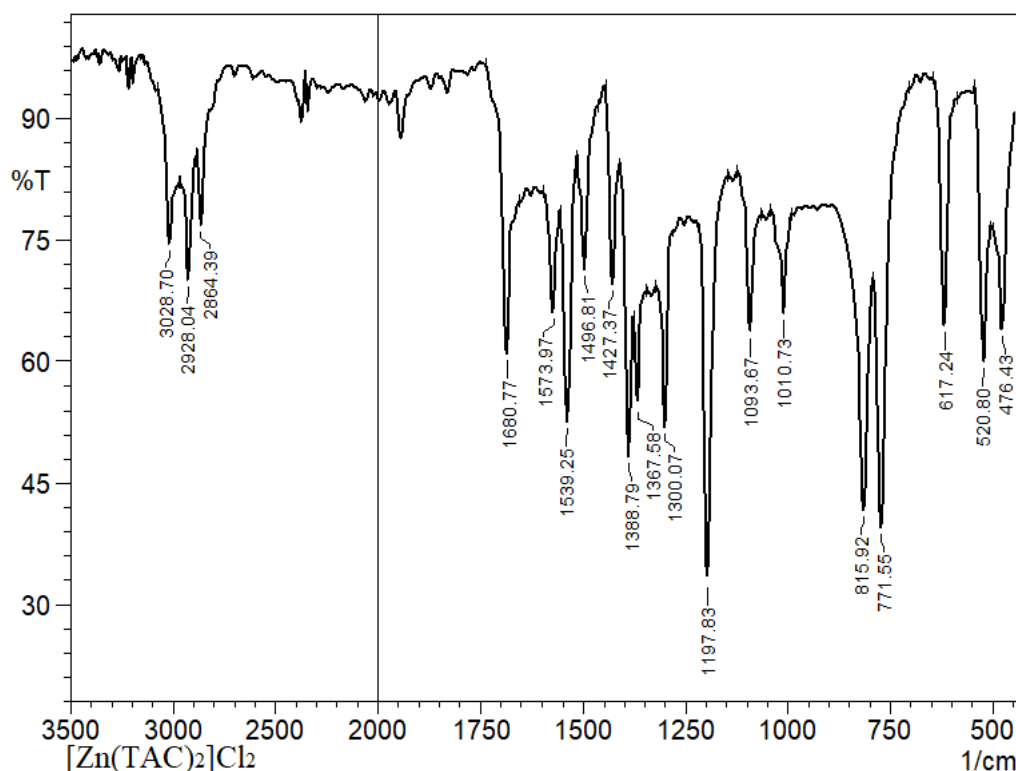


Figure 1. FT-IR from $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$

The FT-IR spectrum of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$, shown in Figure 2 below, shows a number of characteristic absorption peaks corresponding to the vibrations of the coordinated ligand and the triphenyl phosphine groups. The peak assigned to the vibration of the carbonyl stretch appears at 1677.91 cm^{-1} , as opposed to 1708 cm^{-1} in the free TAC ligand, which corresponds to a red shift of 30.09 cm^{-1} . The shift in wavenumber suggests a difference in the electronic environment of the carbonyl group and might suggest that the oxygen in the carbonyl group can possibly coordinate with the zinc(II) center. The peaks observed at 1577.82 and 1539.25 cm^{-1} could be due to the nitrogen heterocyclic ring stretching vibrations, while the peaks observed at 1504.53 and 1458.23 cm^{-1} could be due to the aromatic ring vibrations. The peaks appearing at 1396.51 , 1363.72 , and 1321.28 cm^{-1} have been tentatively attributed to the coupled ring and C-N vibrations. The additional peaks at 1278.85 , 1188.19 , 1143.83 , 1105.25 , and 1072.46 cm^{-1} in the fingerprint region may be due to the vibrations involving aromatic and ligand skeletal structures. The peaks seen at 937.44 and 902.72 cm^{-1} along with the peaks at 817.85 , 761.91 , 727.19 , and 692.47 cm^{-1} can be attributed to aromatic C-H out-of-plane bending and ring deformations related to the phenyl containing phosphine ligand. The peak at 553.59 cm^{-1} may represent low frequency skeletal or metal-ligand vibrations; but further spectroscopic information is needed for the definitive assignment. The spectral changes seen in the present study, especially the change in carbonyl stretching peak, indicate a modification in the coordination environment in complex formation. Nonetheless, to verify the proposed coordination and the role of phosphorus in metal coordination, a comparative study with the free ligand and phosphine is essential.

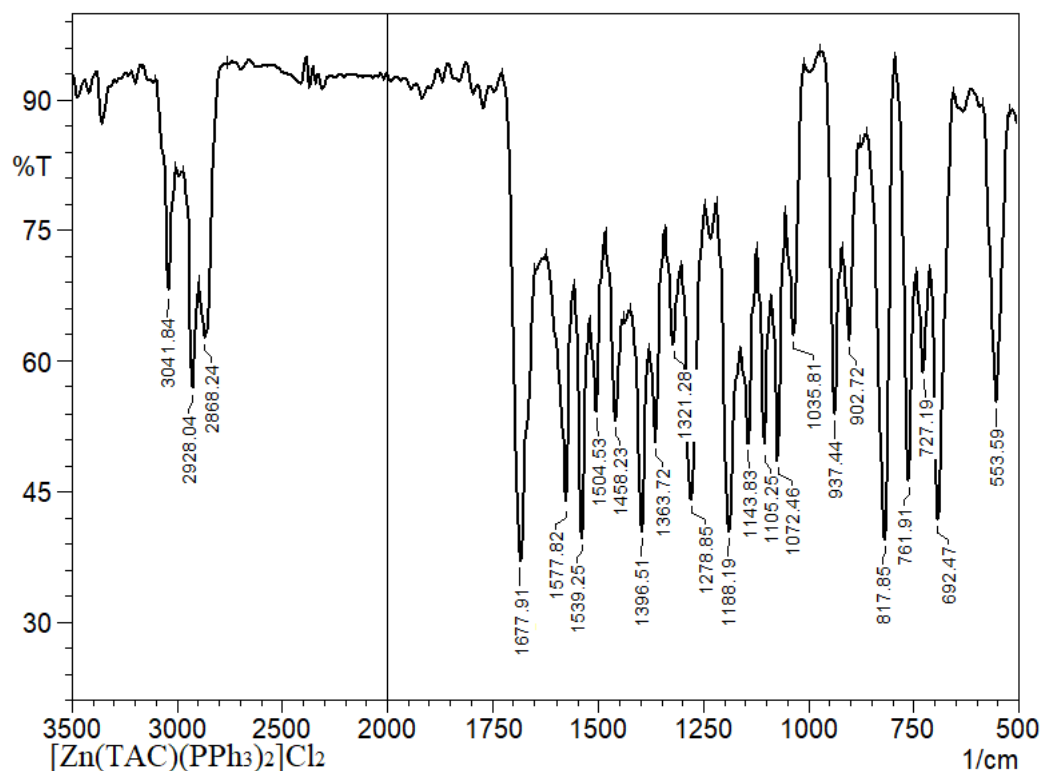


Figure 2. FT-IR from $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$

Figure 3 below shows the FT-IR spectrum of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$, which has several distinct bands due to the TAC ligand and dppe phosphine ligand. The carbonyl ($\text{C}=\text{O}$) stretch band has been observed at 1675.70 cm^{-1} against 1708 cm^{-1} of the free TAC ligand, giving a shift of 28.30 cm^{-1} downwards. This implies that the electronic environment of the carbonyl group has changed with complexation and this can be explained by the possibility of the carbonyl oxygen forming a coordinate bond with the $\text{Zn}(\text{II})$ ion. The absorption bands at 1575.89 and 1518.03 cm^{-1} could be due to the vibrations of the nitrogen-containing heterocyclic ring while those at 1448.59 and 1410.01 cm^{-1} could be due to vibrations of the aromatic ring. Bands at 1143.83 , 1105.25 , and 1070.53 cm^{-1} can be attributed to aromatic and phosphine vibrations, respectively. The absorption at 3055.35 cm^{-1} can be attributed to aromatic C-H stretching. The absorption bands at 2926.11 and 2852.81 cm^{-1} are probably due to aliphatic C-H stretching vibrations of the ethylene group in dppe. Additional bands at 991.44 , 856.42 , 823.63 , 783.42 , 763.84 , 732.97 , 694.40 , and 650.03 cm^{-1} can be attributed to aromatic C-H out-of-plane bending and aromatic ring deformation vibrations. The low frequency absorption at 538.16 cm^{-1} could be due to skeletal and/or metal-ligand vibrations; however, a specific assignment of this band to Zn-P vibrations needs more investigation. Generally speaking, the shift of carbonyl stretching band to lower frequencies can be attributed to changes in the coordination environment of TAC on complex formation.

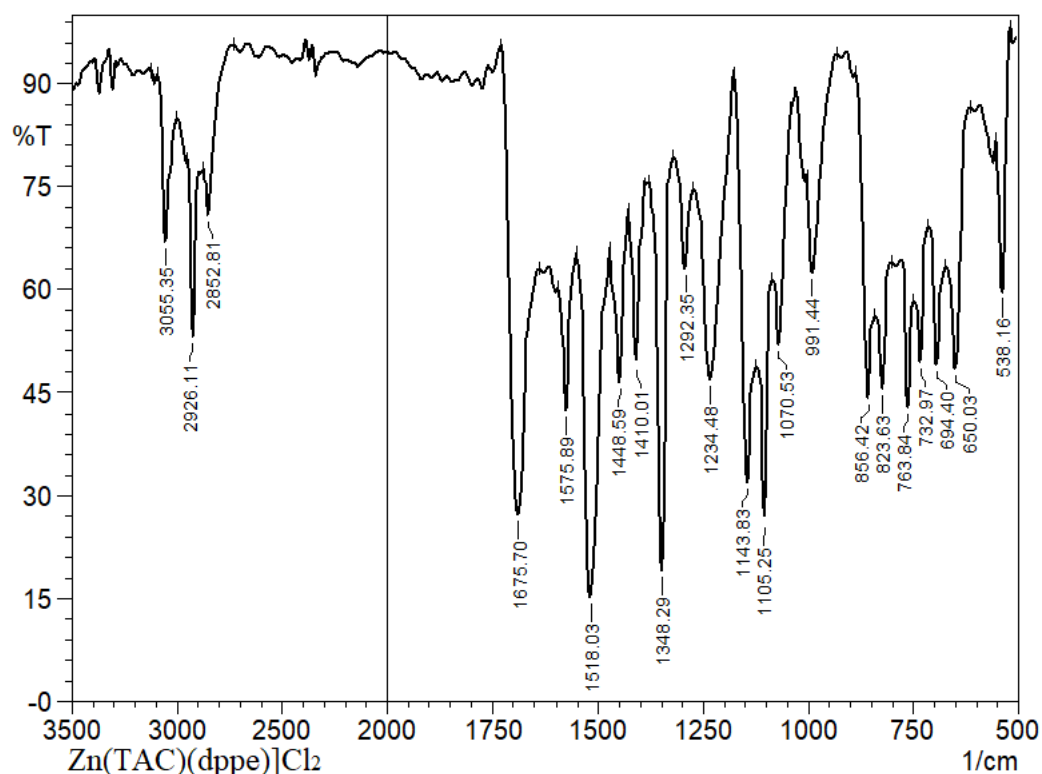


Figure 3. FT-IR from $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$

3.2. ^1H -NMR spectrum [20]:

The ^1H NMR spectrum of $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ is shown in Figure 4. A resonance at δ 7.93 ppm has been recorded in the downfield region and could correspond to protons belonging to the heterocyclic ring having a nitrogen atom in the TAC ligand. Resonances found in the upfield region should be considered with caution since there is the possibility of overlapping between ligand resonances and solvent residues. Specifically, the resonances in the range δ 2.50-3.56 ppm could contain contributions from DMSO and water solvent residues, depending on the solvent chosen for the synthesis of the complex. These resonances cannot be unambiguously assigned to the complex. An accurate interpretation of the proton environment and the induced chemical shift by the coordination should be made through a comparison of the ^1H NMR spectrum of the free TAC ligand.

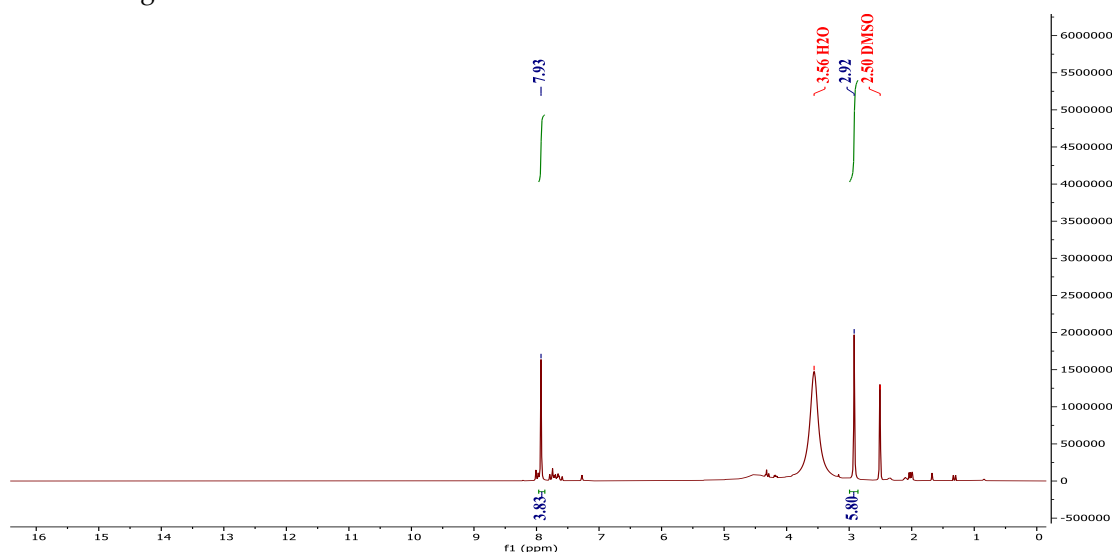


Figure 4. ^1H -NMR spectra of $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$

The ^1H NMR spectrum of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$ is given in Figure 5. It displays a set of overlapped peaks in the aromatic region of the spectrum in the range of δ 7.35–7.59 ppm. These peaks are due mainly to the aromatic hydrogens of two triphenylphosphine ligands (PPh_3) of the proposed complex, but could also originate from the protons of the heterocyclic TAC ligand. The high degree of overlap of these peaks is justified by the presence of many aromatic environments in the proposed complex. Peaks observed at δ 2.51 and 3.37 ppm can be due to residual DMSO and water, respectively. Therefore, these peaks should not be considered when assigning complex-related proton peaks. The predominance of peaks in the aromatic region justifies the use of phosphine ligands in the product of the reaction. However, the validation of the proposed structure will require the integration of the peaks and comparison of the peaks with the peaks of the free TAC and PPh_3 ligands.

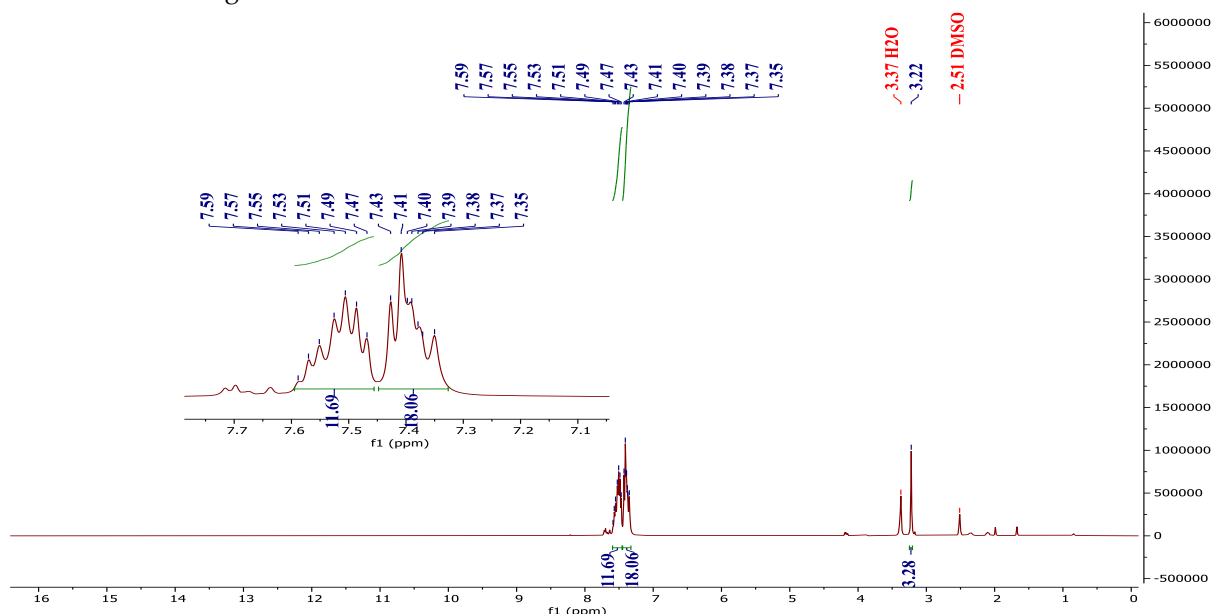


Figure 5. ^1H -NMR spectra of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$

The ^1H NMR spectrum of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ is shown in Figure 6. The spectrum shows a number of resonances in the aromatic region of approximately δ 7.39–7.71 ppm and these resonances are most likely due to the phenyl protons of the dppe ligand and may be due to the heterocyclic TAC ligand as well. The superposition of these peaks indicates that there are many aromatic proton environments present in the proposed complex. There is an additional resonance peak present in the aliphatic region at δ 2.02–2.04 ppm which might be due to the ethylene bridge of dppe but this needs further confirmation through comparing the spectrum with that of the free dppe ligand. There are signals at δ 2.51 and 3.27 ppm which are most likely due to the residual solvent $\text{DMSO}-d_6$ and water respectively. These are not to be assigned to the compound. These aromatic peaks are consistent with the presence of phenyl phosphine groups in the isolated compound. However, confirmation of the proposed structure and the mode of coordination of the dppe ligand will need careful analysis of the signal integrations.

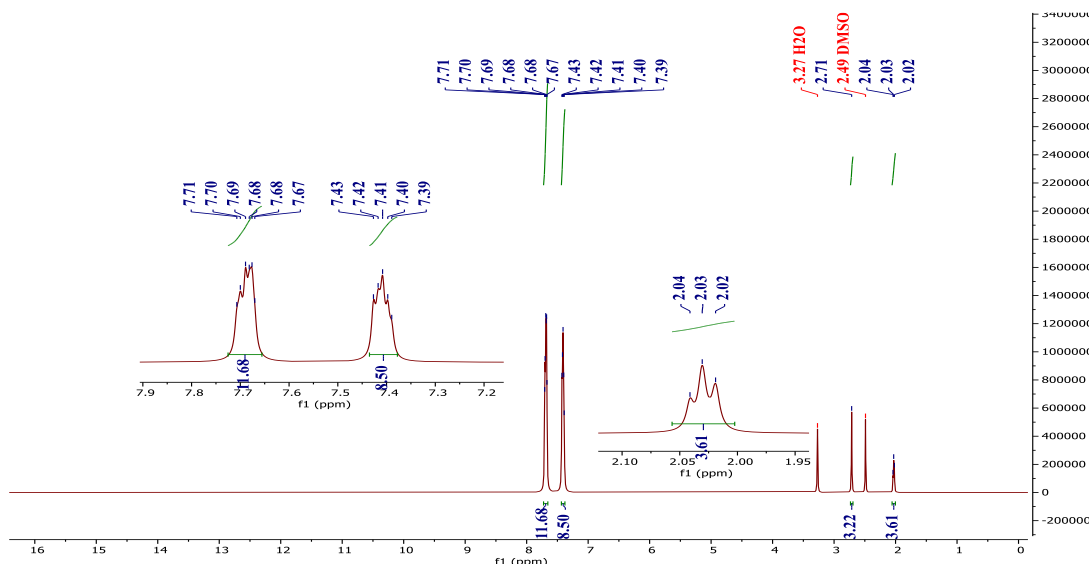


Figure 6: ^1H -NMR spectra of $[\text{Zn}(\text{TAC})(\text{dppp})]\text{Cl}_2$

3.3. $^{31}\text{P}\{-^1\text{H}\}$ -NMR [21]:

Figure 7 displays the $^{31}\text{P}\{-^1\text{H}\}$ -NMR spectrum of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$. A primary peak is observed in the range δ 20.10 ppm, suggesting that phosphorus exists in a different chemical environment in the studied complex. This peak may be attributed to the phosphorus atoms in the coordinated triphenylphosphine ligands. The presence of one major peak suggests that the phosphorus centers may have an identical chemical environment. However, this statement cannot be proven by the number of peaks. The $^{31}\text{P}\{-^1\text{H}\}$ -NMR spectrum of free PPh_3 in similar experimental conditions needs to be compared with the one obtained in order to evaluate the change in chemical shift caused by the coordination of the phosphorus atoms.

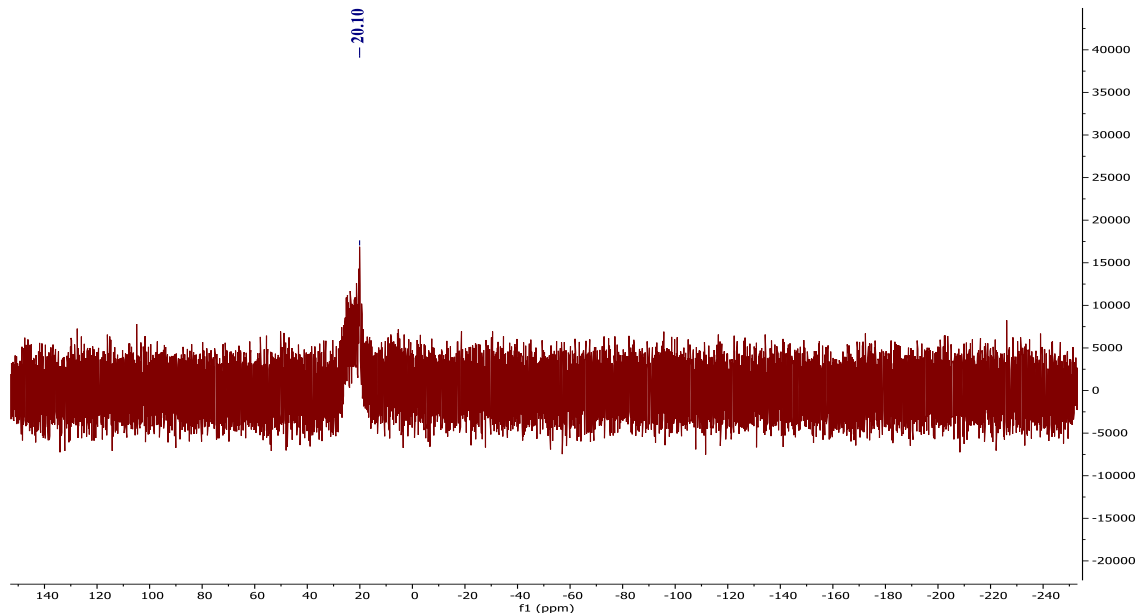


Figure 7. $^{31}\text{P}\{^1\text{H}\}$ -NMR spectra of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$

The $^{31}\text{P}\{-^1\text{H}\}$ -NMR spectrum of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ is illustrated in Figure 8. In particular, the spectrum exhibits a main phosphorus signal located at δ 50.18 ppm, which shows a unique phosphorus environment in the studied compound. This signal might belong to the phosphorus atoms of the dppe ligands in the complex with zinc. The chemical shift might occur due to changes in the phosphorus atom electronic environment as a result of complexation; however, this hypothesis should be supported by comparing the obtained $^{31}\text{P}\{-^1\text{H}\}$ -NMR spectrum with the $^{31}\text{P}\{-^1\text{H}\}$ -NMR spectrum of the free dppe

ligand measured under similar experimental conditions. The presence of one main signal might imply equivalent or unresolved phosphorus environments; however, it cannot prove that the two phosphorus atoms have identical environments. Therefore, additional analysis of the original spectrum and its proper referencing should be performed.

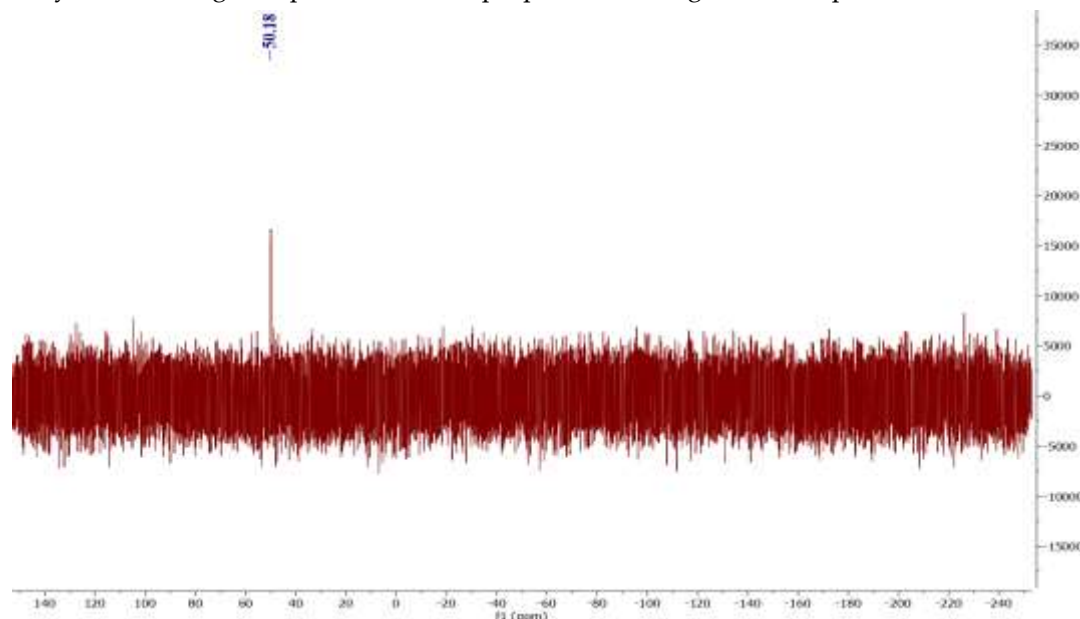


Figure 8. $^{31}\text{P}\{^1\text{H}\}$ -NMR spectra of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$

3.4. Biological Activity Discussion:

The antibacterial activity of the zinc(II) complexes was assessed on the basis of Gram-negative bacteria *Escherichia coli* and Gram-positive bacteria *Staphylococcus aureus* through the application of agar well diffusion technique with amoxicillin as the reference antibiotic. As illustrated in Table 1 below, the antibacterial activities of the compounds under study differed significantly based on their structure, types of bacteria and concentrations used [22].

For *E. coli*, $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ proved to be the most potent compound with inhibition zones of 3.5, 3.9 and 3.8 cm at concentrations of 0.1, 0.01 and 0.001 mg/mL, respectively. The obtained results were similar to or even exceeded those of amoxicillin except at concentration of 0.1 mg/mL when amoxicillin gave the largest inhibition zone (4.6 cm). In case of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$, maximum activity was observed at concentration of 0.1 mg/mL giving inhibition zone of 3.6 cm and then decreasing to 1.8 and 1.0 cm at lower concentrations. In contrast, $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ demonstrated relatively stable activities with zone diameters of 2.0, 2.2 and 1.8 cm [23]. In the case of *S. aureus*, the complex $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ formed inhibition zones with values of 2.1 and 2.3 cm for the concentrations of 0.1 and 0.01 mg/mL, respectively. Both values were greater than the ones of $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ and $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$ for the concentration of 0.01 mg/mL. For the concentration of 0.001 mg/mL, the value of the inhibition zone was 0.9 cm. The complex $[\text{Zn}(\text{TAC})_2]\text{Cl}_2$ formed inhibition zones with values of 2.0, 2.0, and 1.0 cm, while the complex $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$ had values of 1.0, 2.1, and 0.5 cm for the corresponding concentrations. Amoxicillin formed zones with values of 4.0, 3.1, and 2.4 cm, being greater than those of the synthesized complexes against this bacterial strain [24].

The images of the plates can serve as additional visual support to the inhibition zones that have been described quantitatively before. In this regard, Fig. 9 shows the antibacterial assay plates of $[\text{Zn}(\text{TAC})(\text{PPh}_3)_2]\text{Cl}_2$, while Fig. 10 demonstrates the antibacterial assay plates of $[\text{Zn}(\text{TAC})(\text{dppe})]\text{Cl}_2$ [24]. Each experimental treatment was conducted in three replicates and the same measurements of inhibition zones were made in all of them. Therefore, the data is presented as the diameter of observed inhibition zones without any further statistics, as there were no variations between the replicates. The method of

presenting data corresponds to the collected information and does not indicate the absence of biological variability in other experiments.

Table 1. Inhibition zones (cm) of complexes.

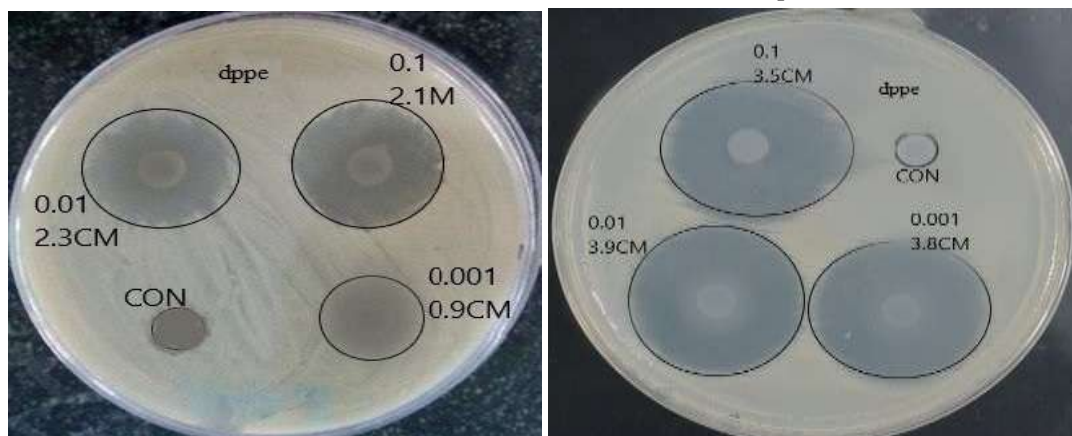


Figure 9. Inhibitory activity of the $[Zn(TAC)(dppe)]Cl_2$ complex against bacteria.

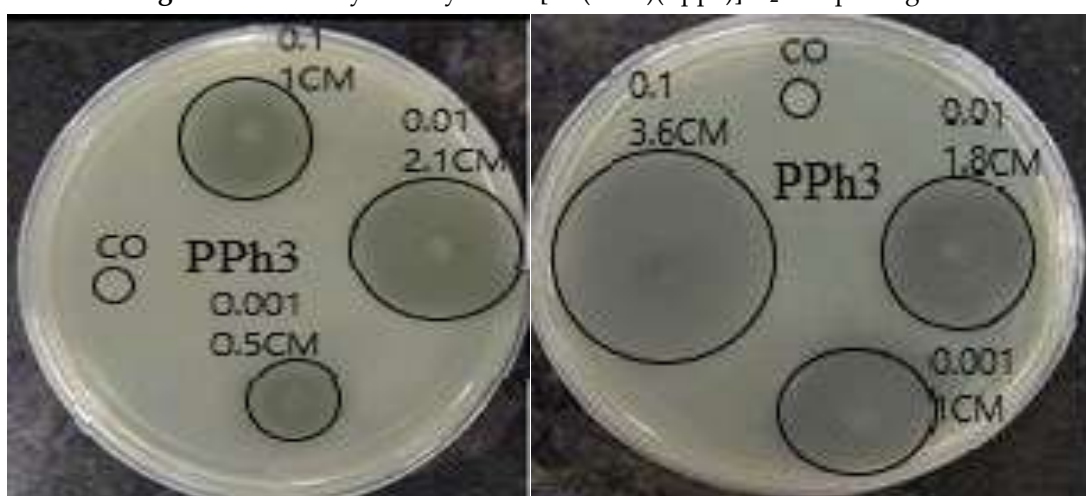


Figure 10. Inhibitory activity of the $[Zn(TAC)(PPh_3)_2]Cl_2$ complex against bacteria.

4. Conclusions

Three different Zn(II) complexes with the TAC ligand, $[Zn(TAC)_2]Cl_2$, $[Zn(TAC)(PPh_3)_2]Cl_2$, and $[Zn(TAC)(dppe)]Cl_2$, were prepared in 78%, 69%, and 74% yield, respectively. Spectroscopic studies by FT-IR and NMR confirmed alterations in the ligand surroundings due to the formation of complexes. Antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* revealed varying inhibitions depending on the compounds screened. The complex with dppe ligand was found to be more active against *E. coli* while amoxicillin was found to have larger inhibitions against *S. aureus* as compared to the synthesized complexes. The findings show that there may be some effect on antibacterial activity due to the identity of the phosphine ligands used.

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