Review Article

Journal of Pharmaceutical and Medicinal Chemistry
Volume 3 Number 1, January - June 2017
DOI: http://dx.doi.org/10.21088/jpmc.2395.6615.3117.4

Studies on the Conducting Polymer Nanocomposites & it's Antimicrobial Activities: An Overview

M. Mubarak Ali*, D. John Williams**

*Assistant Professor **PhD Scholar, Department of Chemistry, Chikkaiah Naicker College, Erode-638004, Tamil Nadu, India.

Abstract

In this review article the conducting polymer nanocomposites are highlighted as innovative material for the treatment against bacteria, fungi, microbes, etc. Conducting polymer nanocomposites have received a high interest due to the combination of unique properties of organic and inorganic components in one material which have been studied extensively by the scientific community for its antimicrobial properties. The present study investigates the antimicrobial activity of conducting polymer nanocomposites against the species such as S.aureus, P.aeruginosa, E.coli and its zone of inhibition, minimum inhibition concentration were reported. So an attempt was taken to establish the consolidated review on the significance of nanocomposite and its antimicrobial activities.

Keywords: Nanocomposites; Antimicrobial; Antibacterial.

Introduction

The present work is aimed to provide a brief overview on the conducting polymer nanocomposites and its activity against pathogenic agents such as bacteria, virus, fungi, etc. Since, some of the pathogens are harmful to the humans as well as to control the bioactivity is critical. Recently the conducting polymer nanocomposites have attracted the medicinal field due to its applications as an effective antimicrobial agent [1-5]. Dorel Feldman presented a review on the application of polymer nano composites especially in the field of medicine and revealed that the polymer nano composites opened new opportunities in the modern medicine to synthesize more products for antibacterial treatment, tissue engineering, cancer therapy, medical imaging, dental applications, drug delivery etc [6]. The detailed review of literature about the conducting polymer nanocomposites and its applications, particularly its antimicrobial activities is not reported so far upto the knowledge of authors. Hence this article is aimed to review the different kinds of conducting polymer nanocomposites.

Reprint Request: M. Mubarak Ali, Assistant Professor, Department of Chemistry, Chikkaiah Naicker College, Erode-638004, Tamil Nadu, India.
E-mail: mubarakscience@gmail.com

(Received on 06.01.2017**, Accepted on** 23.01.2017**)**

Antimicrobial Studies

Various conducting polymer nanocomposites such as natural, synthetic and biopolymer nanocomposites etc., were investigated for the antimicrobial activity and presented in this review paper.

A review on the synthetic metal polymer nanocomposite was reported. Its biomedical applications especially the antibacterial activity against pathogenic bacteria was studied in terms of the synthesizing techniques (Ex-situ & in-situ). It is reported that the in-situ procedure was the optimal technique upto the report of the literature survey due to its maximum dispersion [7]. An integrated study on the antimicrobial activity of Copper - Poly aniline(Cu-PANI) and polymer-Ag nano composite were investigated. It is found that the Copper - Poly aniline(Cu-PANI) nano composite [8] showed higher antimicrobial activity and inhibited the microbial growth, whereas the polymer-Ag nano composite was effective in killing the gram positive, negative bacteria. It is concluded that this new nano composite can act as an antimicrobial material with better cyto compatability which recommends the healing of infected wounds in diabetic rats and also considered as a potential material for the treatment of various diseases [9].

Polyaniline and cellulose (C)/Polyaniline (PANI) [10] and the ZincOxide (ZnO)-Polycarbonate (PC) nanocomposite were investigated simultaneously for its in-vitro antibacterial activity on the same species by different studies. The zone of inhibition for PANI-C was 16±0.43 mm in diameter against S.aureus and for E.coli 13±0.45 mm in diameter and for Pristine PANI it showed 11±0.5 mm and 10±0.43 mm against the S.aureus and E.coli respectively. The ZincOxide (ZnO)-Polycarbonate (PC) nanocomposite was studied in terms of turbidity by using the various samples (0.2-1wt%). The ZnO/PC (0.05%) nanocomposite against the S.aureus and E.coli were 124 NTU(Nephelometric Turbidity Unit) and 196 NTU. But for the high wt% (around 1%) the turbidity for the S.aureus and E.coli were 08 NTU and 41 NTU respectively. The result for both the nanocomposites were analysed. It was reported that the PANI-C was the best antibacterial material than the Pristine PANI. The PC/ZnO nanocomposites showed an enhanced antibacterial activity even at a very low wt%. [11].

A study on the antibacterial properties of the Polypyrrole (PPy)/ZincOxide (ZnO)/Chitosan (CS) bionanocomposite and the various wt% of the Novel Chitosan/Cloisite 10A nanocomposite was analysed against the four pathogens. It was reported that the 20% PPy/ZnO/CS have showed a superior antibacterial activity than the 5%, 10% & 15wt%. The average zone of inhibition for the gram positive S.aureus and Bacillus cereus were 28.63 ± 0.010 and 20.83 ± 0.017 and for the gram negative P.aeruginosa and E.coli were 29.60 ± 0.010 and 17.70 ± 0.026 respectively [12]. On the other hand the zone of inhibition for Novel Chitosan/Cloisite 10A nanocomposite against the same species were 23mm, 23mm, 20mm, 20mm respectively [13].

$CoFe_2O_4$ /Polyaniline/Ag nanocomposite and Polyaniline (PANI) based ZnO (Zinc Oxide) - ZrO_2 (Zirconium dioxide)(PANI-ZnO-ZrO_2) nanocomposites were studied together for the antibacterial activity against four pathogens at a different concentration. The zone of inhibition for the gram positive S.aureus and B.subtilis were 17mm and 12mm respectively. For the (PANI-ZnO-ZrO_2) nanocomposite, the zone of inhibition were 13mm and 14mm respectively. The zone of inhibition for $CoFe_2O_4$/PANI/Ag nanocomposite against the gram negative E.coli and P.aeruginosa were 16mm and 11mm and also 12mm and 11mm for the PANI-ZnO-ZrO_2 nanocomposite respectively. From the above results it was reported that the nanocomposites were potential candidates for antibacterial agent [14-15].

A combined study of Poly aniline/Au-Pd (Gold-palladium), PANI(Polyanilie)/Pt-Pd(Platinum-Palladium) nanocomposite were examined and found that the nano composite showed an enhanced antibacterial activity against four pathogens. Its high antibacterial activity result obtained against E.coli, Staphylococcus sp, Streptococcus sp, Klebsiella sp for the PANI/Au-Pd (Bacterial strains at micromolar [25-150 μg/ml] concentration) were 25±0.87mm, 22±0.35mm, 21±0.33mm, 21±0.31mm and for PANI/Pt-Pd nanocomposite were 22±0.36mm, 28±0.70mm, 21±0.30mm, 25±0.85mm respectively [16-17].

Polyaniline/Polyvinyl alcohol/Ag novel nanocomposite and Polypyrrole Silver nanocomposites were observed together against gram positive staphylococcus aureus and gram negative E.coli and presented the zone of inhibition for different concentrations of nanocomposite. It was reported that the best result obtained were 12mm and 9.8mm for the E.coli and 15mm and 11.2mm for S.aureus respectively. Further study concluded that 15% Ag nanoparticle exhibited an improved antibacterial activity for the Polyaniline/Polyvinyl alcohol/Ag novel nanocomposite [18-19].

Chitosan-Poly (vinyl alcohol)-Silver nano-composite was investigated for its antimicrobial properties and reported that these material when incorporated into a natural compound (curcumin) exhibited a high antimicrobial properties. Its bacterial growth inhibition was evaluated for almost 7 hrs using the O.D(Optical Density) measurement. The result was reported for every 1 hour and in the last hour the absorbance was almost 0.4 a.u(Absorbance Units). The result was reported that the nanocomposite has high possibility of potential in antimicrobial packaging as well as wound dressing [20].

Silver–Polyaniline(Ag-PANI) and Polystyrene-silver(PS-Ag) nanocomposite were observed unitedly for its antibacterial effect against Escherichia coli, the (Ag-PANI) nanocomposites was studied by turbidimetric method at the optical absorbance of 620nm of 0.4±0.02, the number of bacteria was measured spectrophotometrically at 620nm

(A620nm). The PS-Ag nanocomposite was analysed and reported the average diameter of inhibition for the concentration of 0.007, 0.013 and 0.020 w%, and the result were 4.3, 5.0 and 6.2cm respectively. By examining the measured values, both the nanocomposites were exhibited a superior antibacterial activity and found that the antibacterial activity increased with the concentration of the Polystyrene-silver nanocomposite [21-22].

The detailed antimicrobial activity of various conducting polymer nanocomposites and its clear zone diameter for the various species is reported in the Table. 1.

Table 1: Antimicrobial activity of the polymer nanocomposites

S. No	Name of the polymer Anocomposite	Species	Clear zone diameter (mm)	Ref
1	Ag/PLA-NC films	E.Coli	1.43 to 10.33	[23]
2	Ag/PLA-NC films	S.aureus	4 to 9.3	[23]
3	Ag/PLA-NC films	V.Parahaemolyticus	4 to 15	[23]
4	PLA/MCC/5wt%/Ag	E.Coli	1.53 to 7.36	[24]
5	Poly(Ani-co-oAs)/ZnO	S.aureus	20 to 0.4	[25]
6	Poly(Ani-co-oAs)/ZnO	P.aeruginosa	17 to 0.3	[25]
7	Poly(Ani-co-oAs)/ZnO	E.Coli	24 to 0.6	[25]
8	Poly(Ani-co-oAs)/ZnO	A.niger	13 to 0.2	[25]
9	Poly(Ani-co-oAs)/ZnO	A.flavus	21 to 0.5	[25]

Abbreviations

* *Ag /PLA-NC films - Silver /Poly lactic acid-Nanocomposite*
* PLA /MCC/Ag - Poly lactic acid / Micro Crystalline Cellulose-Silver nanocomposites
* Poly(Ani-co-oAs)/ZnO - Conjugated Poly(aniline-co-o-anisidine)/ZincOxide nanocomposites)

Poly(O-toluidine)-titanium dioxide(POT-TiO_2) nanocomposite and its in-vitro antimicrobial activity has been evaluated. It was reported that the zone of inhibition of POT-TiO_2 nanocomposite for different species against gram positive S.aureus and S.epidermis were 19.47±0.27 and 20.36±0.76mm. The gram negative P.mirabilis and E.coli were 16.54±0.72 and 21.74±0.21mm respectively. The minimum inhibitory concentration (μgml^{-1}) against the species S.aureus, S.epidermis, P.mirabilis and E.coli were 6.20,3.122,12.0,12.3μgml^{-1} respectively. From the results obtained it was concluded that the POT-TiO_2 nanocomposite considered as a good antibacterial candidate [26]. Polycarbazole-Titanium dioxide (PCz/TiO_2) nanocomposite was also investigated for the in-vitro antimicrobial activity and reported the % area of inhibition for the PCz/TiO_2 nanocomposite against Basillus megaterium, B.subtilis, P.vulgaris and Pseudomonas aeruginosa. The results were approximately 85mm, 80mm, 80mm and 100mm respectively. From the result obtained the nanocomposite showed a superior antibacterial activity [27].

MtCu (Copper modified Montmorillonite/PLA (Poly lactic acid) nanocomposite was examined for the antibacterial activity at a different concentration of the nanocomposites against E.coli ATCC 25922 and L.innocua ATCC 33090. The sample which have 5% $MtCu^{2+}$/PLA against E.coli and 5% $MtCu^{0}$/PLA against L.innocua have showed an enhanced activity. The zone of inhibition and log reduction for E.coli and L.innocua were 0.15±0.07, 5.75 and 0.40±0.14, 5.79 respectively. From the analysed result these samples were found as a potential candidate for antibacterial activity [28]. Chitosan-Montmorillonite clay/TiO_2 nanocomposite was evaluated for its antibacterial activity and reported the antibacterial assessment values for E.coli and Bacillus Cereus. The results were 20mm and 16mm respectively. From the reported values the nanocomposite was found to be an excellent antibacterial material [29].

Poly (methyl methacrylate) supported TiO_2 (Titanium dioxide) photocatalyst film nanocomposite was investigated for the antibacterial activity against negative clinical isolate klebsiella sp bacteria and found the zone of inhibition for different samples. The superior antibacterial activity was discovered for the 0.01wt% which was 20±0.72. It was reported that this sample showed high efficieny against antibacterial activity [30]. PPy (Poly pyrrole)-MA(Methyl Anthranilate)/TiO_2(Titanium dioxide) nano composite was studied for the in-vitro antibacterial activity against staphylococcus aureus (ATCC 29213) streptococcus mutans (ATCC 25175) etc., using ciprofloxacin and gentamicin as standard drugs [31].

Polyethylene glycol (PEG)/hydroxyapatite (HAP) nano composite was analysed for its biological studies such as antimicrobial and anti-inflammatory etc. It was reported that the nano PEG-20/HAP exhibited the highest antifungal and antibacterial activity and favourable inhibition of human cell hemolysis [32]. The biopolymer, Chitosan-Graphene Oxide (CS-GO) nano composite was studied for its antimicrobial activity against Escherichia Coli, a gram negative bacterium and Bacillus subtilis, a gram positive bacterium. It was reported that the CS-GO nano composite with 2 wt% GO content had higher antibacterial activity against both the samples than the activity of CS and GO separately [33].

PANI (Polyaniline)/Ag-Pt (Silver-Platinum) nanocomposite was examined for the antibacterial activity. It was reported that the nanocomposite exhibited an enhanced activity against staphylococcus aureus with a maximum zone diameter of 30±1.25mm [34]. In a similar manner the nanowires of silver (Ag)-Polyaniline (PANI) nanocomposite was tested for the antibacterial activity against gram positive Bacillus Subtilis NCIM 6633. It was found that the Ag-PANI nanocomposite exhibited a superior antibacterial activity. Its zone of inhibition was 10-18mm diameter [35].

Silver-chitosan nanocomposite and its antibacterial properties was analysed. The result was reported for the different particle size such as low, medium, High. Zone of inhibition for the low, medium and high were 19±0.5mm,18.3±0.4mm and 20.7±0.5mm respectively. From the studies it was reported that the particle size can increase the antimicrobial activity [36]

Poly (3-hydroxybutyrate)/ZnO bionanocomposite was examined for its antibacterial properties with different wt% of ZnO loadings. It was reported that the best antibacterial activity was obtained for 10.0 wt% loading against the species E.coli and S.aureus. Its growth inhibition was almost 97% and 94% respectively. From the measured values it was reported that the nanocomposite can be used in food packaging applications [37].

The biocidal properties of Poly(lactic acid)/TiO_2 nanocomposite against E.coli with PLA/TiO_2 (8wt% of TiO_2) nanocomposite under the UV light bacterial reduction % was reported as ~94.3%. From the result it was reported that these nanocomposites can be used as a good biocidal agent [38]

Conclusion

It has been reported in this review article that the incorporation of metal or metaloxide into polymer matrix can be a versatile method for the applications in the biological field. Among the research papers reviewed in this literature the PANI and chitosan based nanocomposite was reported by many researchers as a good antimicrobial material against the species such as S.aureus, E.coli, B.subtilis, Streptococcus sp, Staphylococcus sp, klebsiella sp and Staphylococcus aureus. On the other hand, the others such as poly pyrrole, poly carbonate, poly ethylene glycol, poly vinyl alcohol, poly methyl metha acrylate were also studied in significant level. In terms of species the E.coli and S.aureus bacteria were studied by most of the authors. Ag (silver) based polymer nanocomposites were reported by many authors. Very few papers have been reported on the different conducting polymer nanocomposites and its antimicrobial activities against the species such as B.cereus, P.aeruginosa, Streptococcus mutans, L.innocua, S.epidermis, P.mirabilis, B.megaterium and P.vulgaris. Since the conducting polymer nanocomposites have been considered as a potent material for biological applications, the further research on this field can be fully exploited.

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