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Nanospheres caped Pt(II) and Pt (IV): synthesis and evaluation as antimicrobial and Antifungal Agent

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Antimicrobial and antifungal polymers are gaining the attention of pharmaceutical makers and industrial design. Nanospheres-Polymers attached Platinum(II) / (IV) complexes have been synthesized to investigate antimicrobial activities. Firstly, nanospheres involving Schiff bases were synthesized from (aminomethyl) polystyrene and four substitute salicylaldehyde (2-hydroxy benzaldehyde, 5-fluoro-2-hydroxy benzaldehyde, 5-kloro-2-hydroxy benzaldehyde, 5-bromo-2-hydroxy benzaldehyde). Secondly, polymers attached Platinum(II) / (IV) complexes have been prepared by means of template method. The IR spectra show that the ligands act in a monovalent bidentate fashion all nanospheres involving Schiff bases. Square-planar and octahedral structures are proposed for Pt(II) and Pt(IV), respectively. All these substances have been examined for antibacterial activity against pathogenic strains, and antifungal activity. In particular, Pt(IV) complexes were more potent bactericides than all of the synthesized substances.

Keywords: antimicrobial agent, antifungal agent, poly(styrene), caped platinium.

INTRODUCTION

The appropriate polymers have been designed and used for the drug delivery technology. Especially, biodegradable polymers are important for drug delivery. Over the past few decades, polymeric-materials with bioactive agents have been preferred in the pharmaceutical industry[1]. Materials have nanoscale formats from polymeric--materials is important for drug delivery technology. The efficiency of drug delivery to various parts of the body is directly affected by particle size[2]. Nanoscale drug carriers are helping to efficient drug distribution. Kohli and Alpar[3] have noted that the efficiency of delivery into gastrointestinal absorption is achieved for the particle diameter of 100 nm. Advantages of nanostructure-mediated drug delivery include the ability to deliver drug molecules directly into cells.

Platinum is an essential trace element in the anti--cancer research. So, numerous derivatives of Pt(II)/ Pt(IV)-complexes have been prepared in recent years[4–7]. Since 2000, increased research on Platinum-complexes linked with polyamine ligands[8–10]. The amine groups of the polyamine linkers are groups capable of hydrogen bond formation with DNA atoms such as the O6 of guanine or the O3 of thymine[11]. According to literature, the first study on Platinum-nanoparticles with the linear polymer has been reported by Ahmadi et al. in 1996[12]. And then, Pt nanowires were synthesized by Fenske et al. using dodecyl amine as ligands[13]. Hence, the synthesis of Pt-nanostructure has been intensively reported on cytotoxicity, genotoxicity and protein expression[14, 15].

Antimicrobial polymers have the advantage that they are chemically stable and do not permeate through the skin. Furthermore, they play an important role in reducing the incidences of infections caused by biomaterial implant. As far as we know, no studies have been carried out on nanosphere including Platinium-Schiff bases complexes. This study aimed to fill in this gap. Novel Platinum-Schiff bases derivatives were investigated to find out the antibacterial properties of Schiff bases and their Pt(II) / Pt(IV) complexes.

MATERIAL AND METHODS

Materials and physical measurements

All other materials were reagent grade (Sigma-Aldrich Company). ^{1}H-NMR spectra of the modified polymers were recorded with a Bruker Spectrospin Avance DPX-400 instrument using TMS as internal standard and DMSO-d_6 as the solvent. Elemental analyses were carried out with an LECO, CHNS-932 instrument. Metal contents were determined by using a Philips PU 9285 atomic absorption instrument at Tübitak, Ankara, Turkey. IR spectra were recorded on a Mattson-5000 FT-IR instrument in KBr pellets. Scanning electron microscopy of the Au-Pd-coated compounds was done by using a JEOL JEM 100 CX II scanning electron microscope (JEOL, Peabody, MA) equipped with a Link analytical system. The electron energy used was 20 keV.

STUDIES ON SYNTHESIS

Synthesis of nanospheres capped Schiff Bases (APS-SchX, X: -F, -Cl, -Br)

The nanospheres capped-Schiff bases (APS-SchX) were prepared by reacting of (aminomethyl) polystyrene (APS) (1 g, 50–100 mesh (or 0.15–0.1 nm), 2.0 mmol/g –NH_2 loaded, 1% cross-linked (Sigma-Aldrich) in hot DMF (15 mL) with 2-hydroxybenzaldehydes and its derivatives (5-fluoro-2-hydroxy benzaldehyde, 5-chloro-2-hydroxy benzaldehyde and 5-bromo-2-hydroxy benzaldehyde) in DMF (10 mL) (Fig. 1A). 2-hydroxybenzaldehydes and its derivatives were added dropwise to (aminomethyl) polystyrene solution while stirring for 30 min. This reaction mixture was stirred under reflux condenser *ca*. 3 *h*, at 70°C. After the mixture cooling to room temperature, nanospheres were poured into the acetone. The result-

ing nanospheres were filtered and dried in the oven and kept with desiccator over anhydrous $CaCl_2$.

Synthesis of Polymer capped Pt(II) / Pt(IV) (APS-SchX-M)

Polymer Attached Pt(II) / Pt(IV) complexes were synthesized by applying the same method. The polymeric-Schiff bases (APS-SchX) were prepared by reacting of (aminomethyl) polystyrene (APS) (1 g, 50–100 mesh (or 0.15–0.1 nm), 2.0 mmol/g $-NH_2$ loaded 1% cross-linked (Sigma-Aldrich) in hot DMF (15 mL) with 2-hydroxy-benzaldehydes and it's derivatives 5-fluoro-2-hydroxy benzaldehyde, 5-chloro-2-hydroxy benzaldehyde and 5-bromo-2-hydroxy benzaldehyde) in DMF (10 mL). Then, a solution was stirred for 2 *h* under a reflux condenser at 50°C. Platinium salts (1.0 mmol $PtCl_2$ / $PtCl_4$) in DMF (5 mL) were added to upon the mixture through 30 min and mixing process was continued 4 *h*. Thus nanosphere polymeric-Pt(II) / Pt(IV) complexes were obtained (Fig. 1). After the mixture cooling to room temperature, nanosphere attached Pt(II) / Pt(IV) complexes were poured into the acetone and washed by adding acetone. The products (brown /dark brown) were filtered then dried.

Detection of antimicrobial and antifungal activity

Antifungal activities of polymer attached Schiff bases and their Pt(II) / Pt(IV) complexes were checked against two fungal strains such as *Aspergillus fumigatus* (*A. fumigatus)*, and *Candida albicans* (*C. albicans)*. For the bacterial subcultures, *Listeria monocytogenes* (*L. monocytogenes) 4b* ATCC19115, *Staphylococcus aureus* (*S. aureus)* ATCC25923, *Escherichia coli* (*E. coli)* ATCC1230, *Salmonella typhi* (*S. typhi) H* NCTC-901.8394, *Brucella abortus* (*B. abortus)* RSKK03026, *Staphylococcus epidermis (S. epidermis sp.), Micrococcus luteus (M. luteus)* ATCC 9341, *Shigella dysenteriae type* (*S. dysenteria* type*)* 10 NCTC 9351 and *Bacillus cereus (B. cereus sp.),* were chosen. For activities measurement, the media used were Mueller--Hinton agar for bacteria and Potato Dextrose agar for the fungi. Fifteen milliliters of the molten agar (45°C) was aseptically mixed with either 100 μl of a bacterial suspension (10^6 CFU/ml) or 1 ml fungal suspension (10^6 CFU/ml) and poured into 100 mm x 15 mm sterile Petri dishes and allowed to solidity. Once the agar was hardened, 6 mm wells were bored using a sterile cork borer and entirely filled with the test solutions. And then the plates were incubated for 24 *h* at 37°C for bacteria and 72 *h* at room temperature for the fungi. At the end of the incubation period, the diameter of the zone of inhibition around the wells was measured.

RESULTS AND DISCUSSION

The analytical data for the ligand and its complexes together with some physical properties are summarized in Table 1. The elemental analyses can be considered compatible with the chemical formulas of the compounds due to polymers of different chain lengths[16]. The weight average molecular weight (Mw) and was suggested from element analyses. Molecular weight and molecular weight distribution (Mw/Mn) were determined by GPC (Gel permeation chromatography). According to GPC, modified polymers have a very narrow molecular weight distribution (PDI, polydispersity index): 1.09, 1.15, 1.30, 1.08, 1.89, 1.80, 1.10,1.74, 2.10, 2.20, 2.20 and 2.10 for

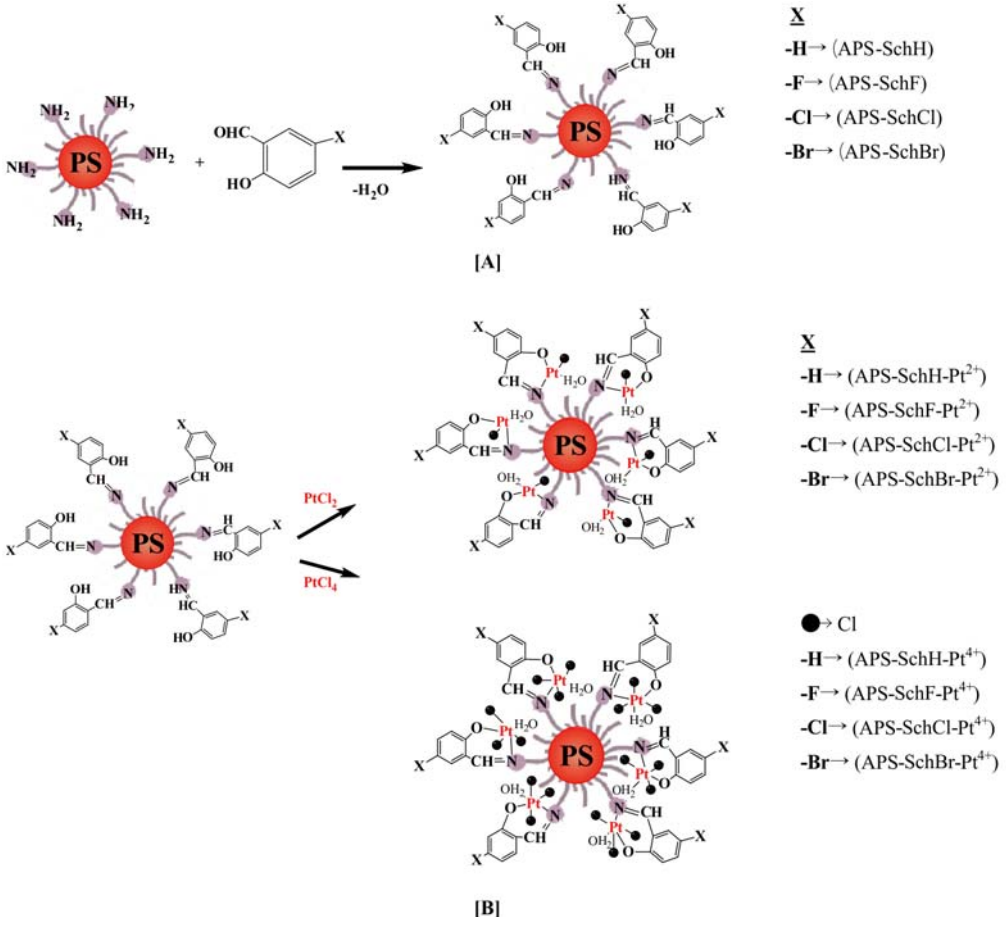


Figure 1. Synthesis rotation of Polymer attached Schiff bases [A] and Pt(II) / Pt(IV) [B]

Table 1. Analytical and physical data for Polymer attached Schiff bases and Pt(II) / Pt(IV) complexes

Compound	Empirical Formula [Formula Weight, g]	Elemental Analysis, [Found[Calc] %]			
		C	H	N	M
[APS-SchH]	$[(C_8H_8)_6(C_{16}H_{17}NO_2)]$	87.37	7.39	1.59	–
mustard color	(879)	(87.42)	(7.21)	(1.34)	
[APS-SchF]	$[(C_8H_8)_9(C_{16}H_{16}NO_2F)]$	87.34	7.28	1.16	–
brick red	(1209)	(87.47)	(7.03)	(0.96)	
[APS-SchCl]	$[(C_8H_8)_6(C_{16}H_{14}NO_2Cl)]$	84.26	6.80	1.54	–
yellow	(911.5)	(83,78)	(7.02)	(1.21)	
[APS-SchBr]	$[(C_8H_8)_6(C_{16}H_{14}NO_2Br)]$	80.33	6.49	1.46	–
dark yellow	(956)	(79.89)	(6.02)	(0.97)	–
[APS-SchH-Pt^{2+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2)$-$Pt(H_2O)Cl]$	68.11	5.94	1.24	17.30
orange	(1127.58)	(68.52)	(6.25)	(1.03)	(16.94)
[APS-SchF-Pt^{2+}]	$[(C_8H_8)_6(C_{16}H_{16}NO_2F)$-$Pt(H_2O)Cl]$	67.04	5.76	1.22	17.03
yellow	(1145.58)	(66.87)	(5.31)	(0.99)	(16.58)
[APS-SchCl-Pt^{2+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2Cl)$-$Pt(H_2O)Cl]$	66.03	5.76	1.20	16.77
dark brown	(1163.08)	(65.56)	(5.47)	(0.87)	(16.58)
[APS-SchBr-Pt^{2+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2Br)$-$Pt(H_2O)Cl]$	63.60	5.55	1.16	16.15
orange	(1207.58)	(63.21)	(5.21)	(0.91)	(15.69)
[APS-SchH-Pt^{4+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2)$- $Pt(H_2O)Cl_3]$	64.13	5.59	1.16	16.29
dark mustard color	(1197.58)	(63.89)	(5.43)	(0.78)	(15.89)
[APS-SchF-Pt^{4+}]	$[(C_8H_8)_6(C_{16}H_{16}NO_2F)$-$Pt(H_2O)Cl_3]$	63.18	5.43	1.15	16.05
mustard color	(1215.58)	63.61)	(5.79)	0.83)	(15.58)
[APS-SchCl-Pt^{4+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2Cl)$-$Pt(H_2O)Cl_3]$	62.28	5.43	1.14	15.82
brown	(1233.08)	(62.71)	(5.12)	(0.76)	(15.49)
[APS-SchBr-Pt^{4+}]	$[(C_8H_8)_6(C_{16}H_{17}NO_2Br)Pt(H_2O)Cl_3]$	60.11	5.24	1.10	15.27
dark brown	(1277.58)	(60.57)	(5.02)	(0.64)	(14.84)

(APS-SchH), (APS-SchF), (APS-SchCl), (APS-SchBr), [APS-SchH-Pt^{2+}], [APS-SchF-Pt^{2+}], [APS-SchCl-Pt^{2+}], [APS-SchBr-Pt^{2+}], [APS-SchH-Pt^{4+}], [APS-SchF-Pt^{4+}], [APS-SchCl-Pt^{4+}] and [APS-SchBr-Pt^{4+}]; respectively.

IR Spectra of Polymer-Bound Azomethine and their Pt(II) and Pt(IV) Complexes

The characteristic peaks of IR spectra of all modified polymers including Schiff bases are given in Table 2. As in our previous studies, in the present study, three overtone peaks showed in 1941, 1872, 1798 cm^{-1} all of the modified polymers. For modified polymer, the vibrations of azomethine are observed between 1618 and 1621 cm^{-1} [17].

In the spectra of modified a polymers (APS-SchH-Pt^{2+}), (APS-SchF-Pt^{2+}), (APS-SchCl-Pt^{2+}), (APS-SchBr-Pt^{2+}) appearing new bands at 1625, 1628, 1624 and 1627 cm^{-1}, (APS-SchH-Pt^{4+}), (APS-SchF-Pt^{4+}), (APS-SchCl-Pt^{4+}), (APS-SchBr-Pt^{4+}) appearing bands at 1628, 1627, 1623, 1625 cm^{-1} respectively are assigned to $\upsilon(CH=N)_{imine\ group}$ stretching vibrations. This situation was evaluated as participation Platinum atom to the polymer (Fig. 2)[18]. As distinct from polymers including Schiff bases, new weak bands emerged at 427–438 and 490–520 cm^{-1} due to coordination of Platinum atoms with N and O atoms[19].

The IR spectra of all coordination polymer including Pt(II) and Pt(IV) atoms exhibit characteristic bands of coordination water at *ca*. 3350, 840 (weak) and 770 (weak) cm^{-1} assigned to ν(OH), ϱr(OH) and $\varrho_W(OH_2)$ vibrations, respectively (Sarı and Gürkan 2004). These observations clearly suggest that the water molecules are coordinated to the metal ion.

Table 2. Specific FT-IR and UV-GB spectra data of polymer attached Schiff bases and Pt(II) / Pt(IV) complexes (no: not observed)

Compound	υOH υCH=N	υoverton υCH(arom)/aliph	υPt-O /Pt-N	λ_{max}; σ→σ*, n→π*(C-N), π→π*(C-N) μ_{eff}(BM)
[APS-SchH]	3432 1618	1937, 1868, 1796 3013, 2920	– –	227, 306,– –
[APS-SchF]	3410 1621	1936, 1868, 1795 3013, 2920	– –	227, 320,– –
[APS-SchCl]	3414 1618	1937, 1867, 1796 3014, 2923	– –	226, 327, 418 –
[APS-SchBr]	3420 1617	1937, 1868, 1794 3013, 2920	– –	227, 328, 416 –
[APS-SchH-Pt^{2+}]	3421 1625	1936, 1867, 1796 3012, 2921	no/498	227, 304, 423 Diamagnetic
[APS-SchF-Pt^{2+}]	3424 1628	1935, 1868, 1796 3015, 2920	430/514	226, 301, 424 Diamagnetic
[APS-SchCl-Pt^{2+}]	3443 1624	1936, 1868, 1796 3013, 2920	437/520	227, 301, no Diamagnetic
[APS-SchBr-Pt^{2+}]	3424 1627	1937, 1868, 1796 3013, 2920	no/519	225, 304, 427 Diamagnetic
[APS-SchH-Pt^{4+}]	3426 1628	1934, 1866, 1792 3011, 2924	no/ 518	227, 306, no, 474 Diamagnetic
[APS-SchF-Pt^{4+}]	3426 1627	1937, 1868, 1796 3023, 2925	438/ 507	227, 305, 421, 470 Diamagnetic
[APS-SchCl-Pt^{4+}]	3432 1623	1937, 1868, 1796 3025, 2931	436/ 520	226, 307, 420, 475 Diamagnetic
[APS-SchBr-Pt^{4+}]	3426 1625	1937, 1868, 1796 3018, 2923	435/510	227, 301, no, 476 Diamagnetic

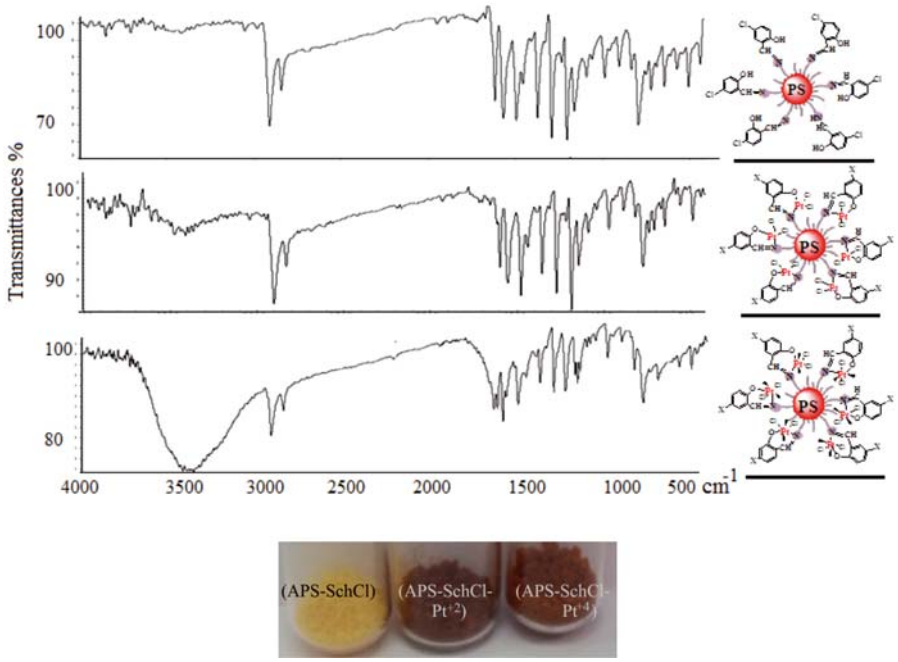


Figure 2. FT-IR spectra of (APS-SchCl) and its Pt(II) and Pt(IV) coordination polymer

UV-Visible and ^{1}H-NMR Spectra of Polymer-Bound Azomethine and their Pt(II) and Pt(IV) Complexes

The ^{1}H NMR spectrum of Polymer-Bound Azomethine and their some Pt(II) Complexes, recorded in DMSO--d_6 showed the following signals: aliphatic -CH, -CH_2 and -CH_3 proton of (APS-SchH), (APS-SchF), (APS--SchCl) and (APS-SchBr) at 1.10–2.90 ppm, 1.15–2.85 ppm, 1.10–2.90 ppm and 1.00–2.90 ppm, respectively. The ^{1}H-NMR spectra of the (APS-SchH), (APS-SchF), exhibit two signals at 10.70 ppm and 10.25 ppm, which are assigned to the –OH and –NH protons, respectively. The spectra strongly suggest that even in solution the keto and enol forms remain as two dominant species in polymeric-Schiff bases. Similar keto-enol tautomerism has been previously reported in other our studies[20]. The ring proton signals appear at 8.00–6.70 ppm, 8.00–6.70, 7.28–6.60 ppm and 7.20–6.61 ppm for (APS-SchH), (APS-SchF), (APS-SchCl) and (APS-SchBr), respectively. [PS-SchH-Pt^{2+}] and [PS-SchCl-Pt^{2+}] from coordination polymer-complexes showed that -OH protons at 11.40 ppm and 11.70 ppm due to coordination water respectively (Table 3 and Fig. 3). At the same time, the aromatic proton moves downfield as a result of the variation in the charge density of molecule via the complex.

UV-Vis spectra of all compounds were taken in DMSO. The band observed in between 226–227 nm and 305 nm which may be considered to $\sigma \rightarrow \sigma^*$ and $\pi \rightarrow \pi^*$ transition for modified polymer, respectively. Furthermore, absorption violence showed an increase in with complexation. The lower bands in the region 324–342

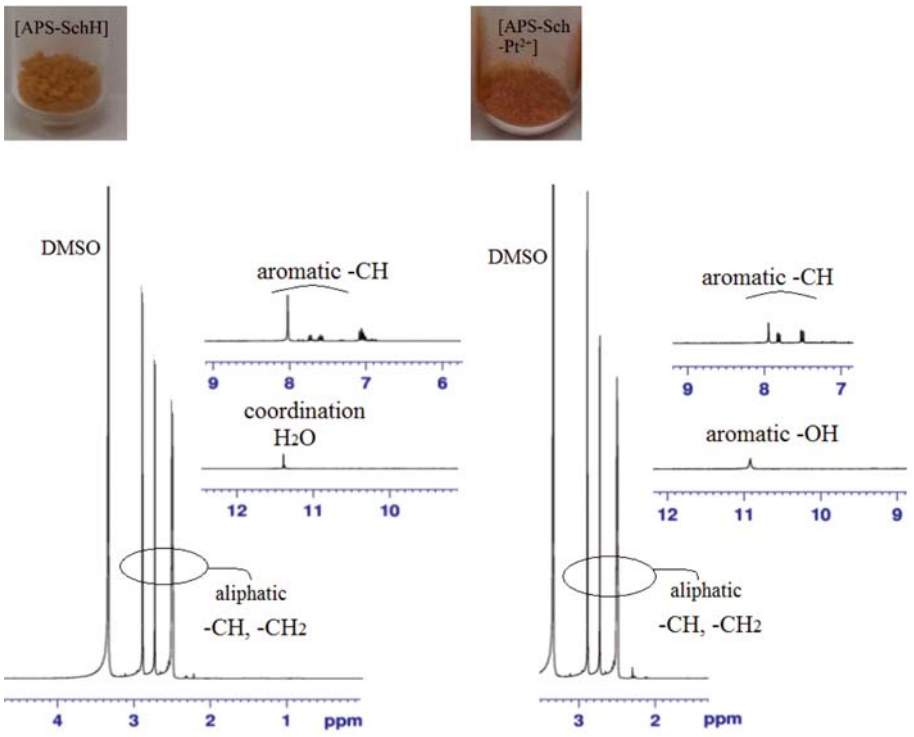
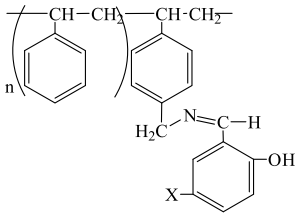
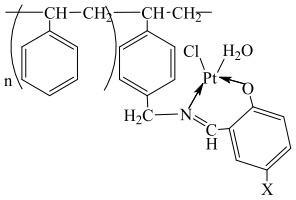


Figure 3. ^{1}H-NMR spectra of (APS-SchH) and its Pt(II) coordination polymer

Table 3. ^{1}H NMR spectra for polymer attached Schiff bases and Pt(II) complexes

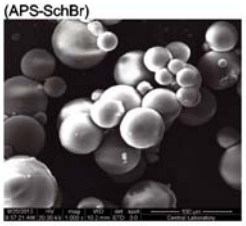
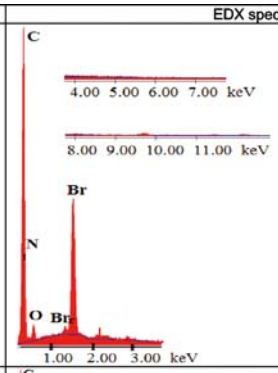
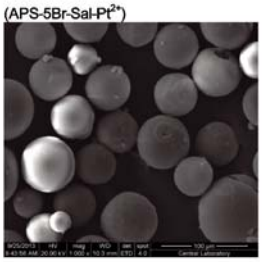
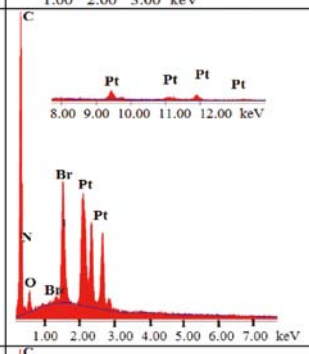
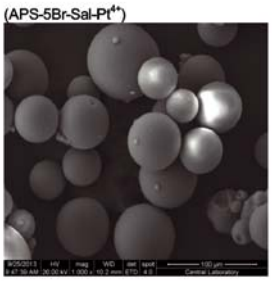
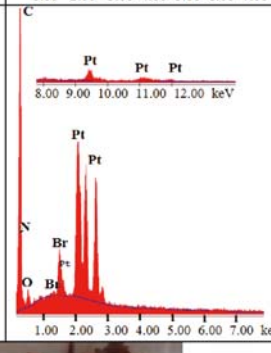
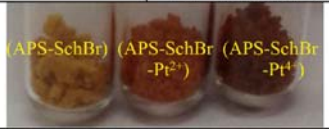
Position	(APS-SchH)	(APS-SchF)	(APS-SchCl)	(APS-SchBr)	[APS-SchH-Pt^{2+}]	[APS-SchCl-Pt^{2+}]
						
–$OH_{(arom)}$ /–NH/-$OH_{(coord)}$	10.70/10.25	10.70/10.25	10.90/–	10.64/–	–/–/ 11.40	–/–/11.70
–CH=N	–	-	7.92	8.02	8.10	8.15
$(–CH)_{arom}$	8.00–6.70	8.00–6.70	7.28–6.60	7.20–6.61	8.00–6.70	7.28–6.60
$(–CH,–CH_2, –CH_3)_{alif}$	1.10–2.90	1.15–2.85	1.10–2.90	1.00–2.90	1.10–2.90	1.10–2.95

nm may be assigned to charge transfer transition which anticipated due to forbidden d-d transitions for square plane platinum(II) complexes. Furthermore, two relatively weak bands observed at 470–475 nm in DMSO for octahedral platinum (IV) complexes[21].

Scanning Electron Microscopy and EDX Analysis of Modified Platinum(II)/(IV) Complexes

SEM images of modified polymers are shown in Table 4. SEM images of platinum coordination polymers were not markedly different from those of (APS-Sch) polymers. This image indicates that protects structure are of modified polymers from (APS-Sch) polymers. Table 4 presents the imaging and EDX spectra of synthesized (APS-SchBr) and its platinum(II) / (IV) complexes.

Table 4. SEM imaging (mag 1000 x) and EDX spectra of (APS-SchBr), (APS-SchBr-Pt^{2+}) and (APS-SchBr-Pt^{4+}) modified polymers

SEM imaging of Compound	EDX spectra
(APS-SchBr) 	
(APS-5Br-Sal-Pt^{2+}) 	
(APS-5Br-Sal-Pt^{4+}) 	
 (APS-SchBr) (APS-SchBr -Pt^{2+}) (APS-SchBr -Pt^{4+})	

Other polymers showed similar properties. EDX analysis shows the presence of platinum ions in the prepared coordination polymer. The combined information from SEM and EDX indicate that the coordination polymer was synthesized with platinum ions.

Antibacterial and Antifungal Studies

The polymers with nano-sphere were screened for antimicrobial activity in DMF solvent as a control substance. The polymers were tested with the same concentrations in DMF solution (10^3 μM). All the synthesized compounds and antibiotic exhibited the varying degree of inhibitory effects on the growth of different tested strains. As shown in Table 5, the results of antifungal and antibacterial screening indicated that the Pt(IV) derivatives with nano-spheres showed more activity than the other studied nano-spheres. All of the polymers with nano-sphere were active against *S.aureus, C. albicans*, and *B. cereus*.

As shown in Figure 1 and Figure 4, Pt(II) and Pt(IV) derivatives with nano-sphere were prepared, containing fluorine, chlorine and bromine substituents. The pharmacology test revealed that their activity order was fluorine substituent < chlorine substituent < bromine substituent for *B. cereus, C. albicans, E. coli and L. monocytogenes 4b.* As shown in Table 5, the [APS-SchH-Pt^{4+}] that showed a significant activity against *C. albicans*. All of the compounds were active against *S. aureus, C. albicans and B. cereus.* [APS-SchH-Pt^{4+}] from all coordination polymer was highly active against studied bacteria. As shown in Table 5, the [APS-SchCl] showed activity against all bacteria; however, *L. monocytogenes 4b* did not display any

Table 5. Antimicrobial activity of polymer attached Schiff bases and Pt(II) / Pt(IV) complexes (0.018 g/ml) (Diameter of zone inhibition (mm))

Compound		[APS-SchH]	[APS-SchF]	[APS-SchCl]	[APS-SchBr]	[APS-SchH -Pt^{2+}]	[APS-SchF -Pt^{2+}]	[APS-SchCl -Pt^{2+}]	[APS-SchBr -Pt^{2+}]	[APS-SchH -Pt^{4+}]	[APS-SchF -Pt^{4+}]	[APS-SchCl -Pt^{4+}]	[APS-SchBr -Pt^{4+}]
Diameter of zone [mm]	*S. aureus*	12	12	11	11	10	10	13	10	22	14	16	17
	S h.dys. typ 10	11	12	–	16	11	11	11	11	21	–	14	–
	L. monocytogenes 4b	15	13	–	15	15	15	13	12	16	17	15	17
	E. coli	13	16	15	15	17	15	14	12	20	11	13	12
	S. typhi H	12	11	–	11	11	–	11	–	15	20	11	12
	S. epidermis	–	–	–	–	–	–	–	–	–	–	–	–
	Br. abortus	–	–	–	12	12	14	20	11	22	–	–	12
	M. luteus	13	12	–	12	–	–	11	–	15	11	–	–
	C. albicans	15	12	13	22	22	24	22	17	27	22	25	25
	B. cereus	15	20	16	20	21	20	19	18	22	17	19	20
	A. fumigatus	19	20	25	18	16	25	23	23	20	20	23	16

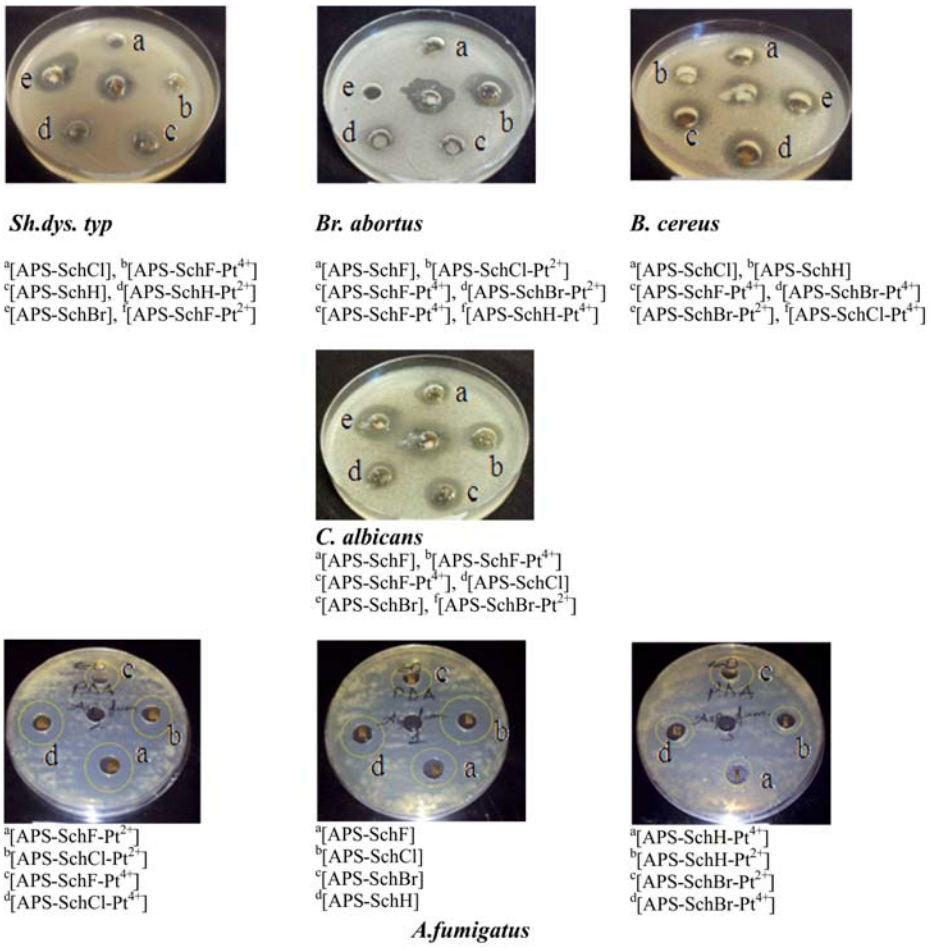


Figure 4. Imaging of antimicrobial affectivities of studied some the polymers with nano-sphere

activity against. Generally, the Pt(II)/Pt(IV) derivatives with nano-spheres are more potent bactericides than the ligand. This enhancement in activity may be explained on the basis of chelation theory[20].

In addition, the Pt(IV) derivatives with nano-spheres are more potent bactericides than the Pt(IV) derivatives with nano-spheres. We know that bacteria needs folic acid to synthesize DNA and repair DNA. Bacteria have to make their own folic acid. Pt(IV) is kinetically more inert than Pt(II). So, Pt(IV) drugs are more stable to acidic media. Pt(IV) derivatives with nano-spheres may have been more active against studied bacteria due to its stable in acidic media[22]. We know that *A. fumigatus* is an emerging worldwide problem with major epidemiological and clinical implications. *A. fumigatus* test results of polymeric-spheres exhibited excellent activity.

CONCLUSIONS

The new Pt(II) / Pt(IV) derivatives with nanospheres compounds prepared in our study seem to have interesting biological activity. Pt(II) and Pt(IV) complexes were prepared by the template method. The structures of the prepared compound were confirmed by elemental analysis, IR, ^{1}H spectral analysis. The antibacterial and antifungal activities of the prepared compounds were evaluated showing moderate to good activities. The Pt(II) / Pt(IV) derivatives showed much better activity than ligands. We can say that this compound merits further investigation as an alternative drug. *A. fumigatus* test results of Pt(II) / Pt(IV) derivatives with nanospheres compounds are especially noteworthy.

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