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Synthesis, Characterization and Antimicrobial Investigation of Mixed Ligand Complexes of Cobalt(II) and Nickel(II) with P-Dimethylaminobenzaldehyde Thiosemicarbazone

Sonia Khanna[1]*, Pooja Singh[2], Harsimrut Kau[1] and Antima Joon[2]
[1]Department of Chemistry and Biochemistry, School of Basic Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh, India.
[2]Department of Chemistry and Biochemistry,
Sharda University, Greater Noida, India.
*Corresponding author (e-mail: sonia.khanna@sharda.ac.in)

A series of cobalt(II) and nickel(II) complexes were prepared by reactions with p-dimethylaminobenzaldehyde thiosemicarbazone (Hdmbtsc) in stoichiometric ratio of 1:2 and in the presence of co-ligands pyridine, 1,10 phenanthroline and PPh_3, which yielded octahedral complexes (**1-8**). The ligand acted as uninegative and neutral bidentate ligands coordinating through its N, S donor atoms. Dimethylaminobenzaldehyde thiosemicarbazone (Hdmbtsc) is reported to form complexes with mercury and zinc [14]. The ligand and complexes were characterized using spectroscopic techniques (UV-Vis, FTIR). They were screened for antibacterial activity against Gram +ve (*Listeria*) and Gram –ve (*E. coli*) bacteria and antifungal activity against *Candida albicans* using agar diffusion method. Cobalt complexes **1, 2** and **4** and nickel complex **8** were found to be active against Gram -ve bacteria (*E. coli*), while cobalt complexes **1-5** and nickel complex **6** showed moderate activity against fungi (*Candida albicans*). $[Co(dmtsc)_2(phen)]Cl_2$ (**4**), $[Co(dmtsc)_2(PPh_3)_2(NO_3)_2]$ (**5**) and $[Ni(Hdmtsc)_2(Cl)_2]$ (**6**) were found to be the most effective against tested bacterial and fungal strains.

Key words: Dimethylaminobenzaldehyde thiosemicarbazone; UV-Vis.spectra; antibacterial, antifungal activity, octahedral complexes

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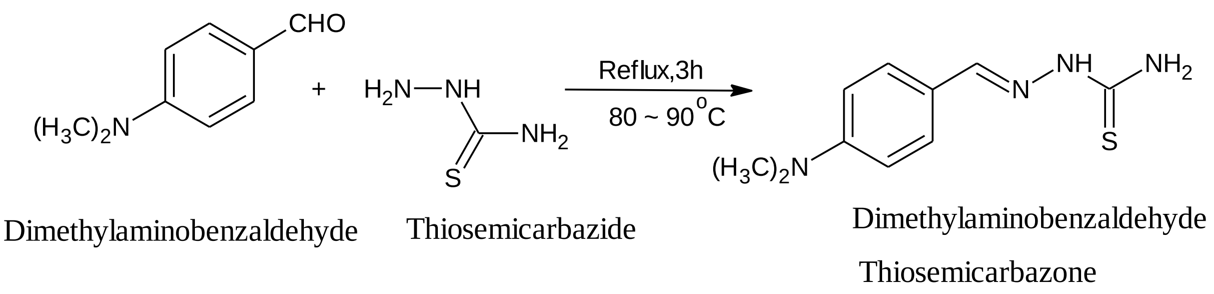
Thiosemicarbazone and its complexes have received substantial attention over the past few decades due to their multiple pharmacological properties, such as antibacterial, antifungal, antimalarial and antitumor [1-3]. This may be attributed to the flexibility of thiosemicarbazones to adopt different bonding modes forming complexes such as mononuclear, dinuclear as well as polynuclear complexes. Thiosemicarbazones are known to exhibit thione-thiol tautomerism by coordinating to a metal ion through the azomethine nitrogen either in the neutral thione form or in the anionic thiolate form [4-8].

Dimethylaminobenzaldehyde is a bifunctional aromatic compound having aldehyde group (CHO) para to dimethylamino group. It is also reported to have analytical properties [9-11]. The ^{1}H-NMR of Hdmbtsc and its Zn(II), Cd(II), Hg(II) and Cu(II) complexes are reported in literatures [12-14]. It also acts as a selective fluorosensor for detection of Hg(II) [15]. In an extension to the study, we report the synthesis and characterisation of Ni(II) and Co(II) complexes with p-dimethylaminobenzaldehyde thiosemicarbazone and co-ligands (py, phen, PPh_3), not reported earlier. All these complexes were characterised by spectroscopic methods (IR, UV). They were also tested for their antibacterial and antifungal activities to see their application as drugs.

MATERIALS AND TECHNIQUES

Thiosemicarbazide and p-dimethylaminobenzaldehyde were used without any further purification. Pyridine, 1,10 phenanthroline, triphenylphosphine, cobalt chloride, nickel chloride and cobalt nitrate were procured from Sigma Aldrich. All other reagents and solvents were purchased from commercial sources and were of analytical grade. The IR spectra were recorded on Agilent Carey 630 FTIR Spectrometer. The electronic spectra were recorded on UV-Visible Spectrophotometer (UV-1800).



Scheme 1. Preparation of p-dimethylaminobenzaldehyde thiosemicarbazone (Hdmbtsc).

EXPERIMENTAL

1. Synthesis of p-dimethylaminobenzaldehyde thiosemicarbazone (Hdmbtsc)

The ligand Hdmbtsc was prepared by suspending thiosemicarbazide (0.01 mol, 0.91 g) in methanol (30 ml) at 50°C. To it, p-dimethylaminobenzaldehyde (0.01mol, 2 ml) in methanol (5 mL) was added followed by the addition of a few drops of glacial acetic acid. The solution was refluxed for 3 hours, resulting in the formation of a yellow-coloured crystalline substance (Figure 1). The compound was filtered and rinsed with methanol and dried in the desiccator. The compound was soluble in THF and DMSO but insoluble in water.

M. pt. 187°C. % yield 87%. IR (cm^{-1}): v(N^{1}H) 3471(b), 3244(m); (-NH) 3147(m); v(C-H) 2907(w); v(C=N) + v(C=C) + δNH$_2$ 1571(m), 1592(m), 1369(m) ; v(C=S) 821(m).

2. Synthesis of metal complexes

Co(II) and Ni(II) complexes with Hdmbtsc were prepared by using two reaction schemes: i) with two moles of Hdmbtsc; and ii) with two moles of Hdmbtsc and co-ligands.

2.1. Synthesis of Complexes

The complexes were prepared by refluxing aqueous solutions of cobalt/nickel salts (20 ml) and THF solution (10mL) of Hdmbtsc in the stoichiometric ratio of 1:2 for 3 hours. It was cooled, filtered and kept undisturbed for 4-5 days. Coloured crystalline products (**1**, **2**, **6**) were obtained. Mixed ligand complexes were prepared by first refluxing aqueous solutions (EtOH: H$_2$O- 1:1) metal salts and Hdmbtsc (10 ml THF) in the stoichiometric ratio of 1:2 for 2 hours followed by the addition of co-ligands, such as pyridine (**3**, **7**), PPh$_3$ (**5**) and phenanthroline (**4**, **8**). The solutions were further refluxed for 1-2 hours, cooled, filtered and washed with ethanol. All the complexes were crystalline and soluble in DMSO. Many attempts were made to crystallize the complexes using different solvent mixtures but no suitable crystals were obtained. The reaction schemes used are as follows:

CoX$_2$ + 2Hdmbtsc → [Co(dmbtsc)$_2$X$_2$] X = Cl (**1**), NO$_3$ (**2**)

NiCl$_2$ + 2Hdmbtsc → [Ni(Hdmbtsc)$_2$]Cl$_2$ (**6**)

CoX$_2$ + 2Hdmbtsc + Y → [Co(dmbtsc)$_2$XY] (X = NO$_3$, Y= py (**3**); X= Cl;Y= phen (**4**)

Co(NO$_3$)$_2$ + 2Hdmbtsc + 2PPh$_3$→ [Co(dmbtsc)$_2$ (PPh$_3$)$_2$](NO$_3$)$_2$ (**5**)

NiCl$_2$ + 2Hdmbtsc+ 2py → [Ni(Hdmbtsc)$_2$(py)$_2$] Cl$_2$ (**7**)

NiCl$_2$ + 2Hdmbtsc + phen → [Ni(dmbtsc)$_2$ (phen)$_2$]Cl$_2$ (**8**)

i) **[Co(dmbtsc)$_2$Cl$_2$] (1):** M. pt. 200°C, % yield 67%. IR (cm^{-1}): v(N^{1}H) 3407(b); *v*(C-H) 2907(w); *v*(C=N) + *v*(C=C) + δNH$_2$ 1571(m), 1510(m), 1369(m) ; *v*(C=S) 803(m). The complex was soluble only in DMSO.

ii) **[Co(dmbtsc)$_2$(NO$_3$)$_2$]** (**2**): A crystalline brown product was obtained. It was recrystallised with ethanol. M. pt. 370°C, % yield 65%. IR (cm^{-1}): *v*(N^{1}H) 3502(b); *v*(C-H) 2907(w); *v*(C=N) + *v*(C=C) + δNH$_2$ 1611(m), 1514(m), 1264(m); *v*(C=S) 803(m). The complex was soluble only in DMSO.

iii) **[Co(dmbtsc)$_2$(py)(NO$_3$)].2NO$_3$** (**3**): To an aqueous solution (10 ml) of Co(NO$_3$)$_2$.6 H$_2$O (0.457 g, 2.5 mmol) was added a solution of the ligand Hdmbtsc (1.11 g, 5.0 mmol) in THF(15 ml) and refluxed for about 2 hours 30 minutes. It was followed by the addition of aqueous solution of pyridine (0.12 g, 2.5 mmol) and further refluxing for 1 hour, resulting in a dark red coloured solution. It was cooled at room temperature, filtered and kept undisturbed for 10-15 days. A crystalline maroon powder was obtained and recrystallised with ethanol. The complex was soluble only in DMSO. M. pt. 165°C, % yield 72%. IR (cm^{-1}) *v*(N^{1}H) 3461(m); *v*(C-H) 2918(s), 2847(w); *v*(C=N) + *v*(C=C) + δNH$_2$ 1603(m), 1521(m), 1439(m); *v*(C=S) 821(m).

iv) **[Co(dmbtsc)$_2$(phen)]Cl$_2$** (**4**): To an aqueous solution of $CoCl_2.6H_2O$ (0.594 g, 2.5 mmol) was added a solution of Hdmbtsc (1.11 g, 5.0 mmol) dissolved in THF (15 ml). The solution was refluxed for 2 hours 30 minutes, followed by the addition of 1,10 phenanthroline (0.450 g, 2.5 mmol) and further refluxed for 1 hour. The resulting dark red solution was cooled at room temperature, filtered and kept undisturbed for 10-15 days. A crystalline brown powder was obtained, which was recrystallised with ethanol. The complex was soluble only in DMSO. M. pt. 90ºC. % yield 72%. IR (cm^{-1}): $v(NH_2)$ 3480(w), 3200(m); v(C-H) 2918(s), 2847w; v(C=N) + v(C=C) + δNH_2 1598(m), 1514(m) 1164(m); v(C=S) 817(m).

v) **$[Co(dmbtsc)_2(PPh_3)_2](NO_3)_2$ (5):** To an aqueous solution of $Co(NO_3)_2.6\ H_2O$ (0.457 g, 2.5 mmol) was added a solution of Hdmbtsc (0.555 g, 5.0 mmol) in THF (15 ml) and the solution was refluxed for about 2 hours 30 minutes. It was followed by the addition of triphenylphosphine (1.311 g, 5.0 mmol) and the solution was further refluxed for 1 hour. The resulting dark reddish brown solution was cooled at room temperature, filtered and kept undisturbed for 4-5 days. A crystalline maroon powder was obtained and recrystallized with ethanol. The complex was soluble only in DMSO. M. pt. 168ºC, % yield 72%. IR (cm^{-1}): $v(NH_2)$ 3480(m), 3320 (m); v(C-H) 2918 (s), 2847(w); v(C=N) + v(C=C) + δNH_2 1611 (m), 1511 (m), 1264 (m); v(C=S) 817 (s).

2.2. **Synthesis of Nickel(II) Complexes**: Nickel(II) complexes were prepared by refluxing an ethanolic solution (15 ml) of nickel chloride with Hdmbtsc in THF (10 mL) in a stoichiometric ratio of 1:2 to form $[Ni(Hdmbtsc)_2]Cl_2$ (**6**) and followed by the addition of pyridine **(7)** and 1,10 phenanthroline (**8**).

i) **$[Ni(Hdmbtsc)_2]Cl_2$ (6):** To an ethanolic solution (15 ml) of $NiCl_2.6H_2O$ (0.5 g, 0.002 mol) was added THF solution (10 mL) of Hdmbtsc (0.933 g, 0.004 mol) and refluxed for about 3 hours. The solution was cooled, filtered and kept undisturbed for 4-5 days. The crystalline brown compound obtained was filtered and recrystallized with ethanol and acetonitrile (1:3). The complex was soluble only in DMSO. M. pt. 189ºC, % yield 65% IR(cm^{-1}): $v(N^1H_2)$ 3372 (m), 3244 (m); $(-N^2H)$ 3123 (m); v(C-H) 2903 (s), 2714 (s), v(C=N) + v(C=C) + δNH_2 1592(s), 1529 (m), 1372 (s); v(C=S) 818 (s).

ii) **$[Ni(dmbtsc)_2(py)_2]Cl_2$ (7):** To an ethanolic solution of $NiCl_2.6H_2O$ (0.9010 g, 0.002 mol) was added Hdmbtsc (0.324 g, 0.004 mol) dissolved in THF (10 ml) and the resulting solution was refluxed for about 3 hours. It was followed by the addition of pyridine (0.354 ml, 0.004 mol) and further refluxed for 1 hour, resulting in a dark brown solution. It was filtered and rinsed with ethanol. Complex was soluble only in DMSO. M. pt. 130ºC, % yield 62%. IR (cm^{-1}): $v(-N_1H_2)$ 3418m, 3272m (s); $v(N^2H)$ 3130m; v(C-H) 2916m, v(C=N) + v(C=C) + δNH_2 1592s, 1515m, 1369m; v(C=S) 814 (s).

iii) **$[Ni(dmbtsc)_2(phen)]Cl_2$ (8):** To an ethanolic solution (15 ml) of $NiCl_2.6H_2O$ (0.324 g ,0.0025 mol) was added 1,10 phenanthroline (0.9010 g, 0.025 mol) and the solution was stirred for 45 minutes. It was followed by the addition of Hdmbtsc (0.555 g, 0.005 mol) dissolved in THF (10 mL) and further stirring was done for one hour. The resulting orange-coloured solution was filtered and kept undisturbed for 10 days. The crystalline reddish orange compound obtained was filtered and dried. It was recrystallised with ethanol. Complex was soluble only in DMSO. M. pt. 90ºC, % yield 68%, IR (cm^{-1}): $v(N^1H_2)$ 3398 (m); v(C-H) 2915 (s), 2847 (m); v(C=N) + v(C=C) + δNH_2 1592 (s), 1515 (m), 1424 (m) ; v(C=S) 851 (s).

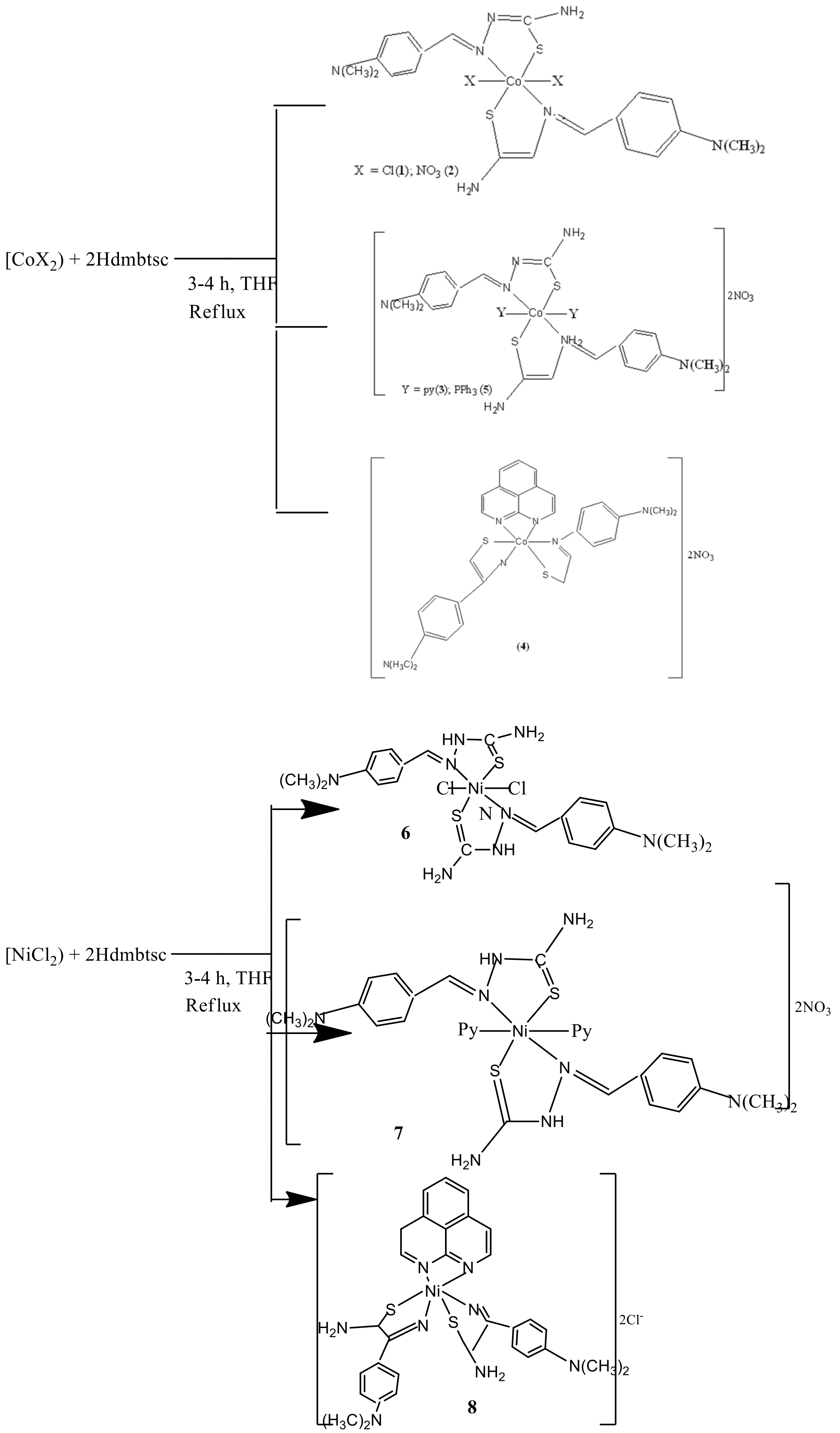
RESULTS AND DISCUSSION

1. Physical Characteristics

The physical characteristics, melting point and colour of Hdmbtsc and its metal complexes are listed in Table 1.

Table 1. Physical Characteristics of Hdmbtsc and its complexes.

Compounds	Colour	Solubility	Melting Point
Hdmbtsc	Yellow	DMSO, THF	~187ºC
$[Co(dmbtsc)_2Cl_2]$ **(1)**	Maroon	DMSO	~200ºC
$[Co(dmbtsc)_2(NO_3)_2]$ **(2)**	Brown	DMSO (partially)	Beyond 370ºC
$[Co(dmbtsc)_2(Py)(NO_3)]$**(3)**	Maroon	DMSO, THF	~165ºC
$[Co(dmbtsc)_2(Phen)]Cl_2$(**4**)	Brown	DMSO	~89ºC
$[Co(dmbtsc)(PPh_3)_2(NO_3)_2]$ (**5**)	Maroon	DMSO	~168ºC
$[Ni(Hdmbtsc)_2Cl_2]$ (**6**)	Brown	DMSO	189ºC
$[Ni(Hdmbtsc)_2(py)_2]Cl_2$ (**7**)	Black	DMSO	130ºC
$[Ni(dmbtsc)_2(phen)_2]Cl_2$(**8**)	Orange	DMSO	76ºC



Scheme 2. Proposed structures of cobalt(II) and nickel(II) complexes of p-dimethylaminobenzaldehyde thiosemicarbazone (Hdmbtsc).

In complexes **1-5** and **8**, Hdmbtsc is proposed to act as a uninegative bidentate ligand, coordinating through azomethine N and thiol group in the complexes, and a neutral bidentate coordinating through azomethine (C=N) and S atom of C=S group in **6** and **7**. The proposed structures of the complexes are shown in Scheme 2. All the formed complexes were stable in atmospheric conditions and insoluble in water and common organic solvents.

2. Infra Red Spectroscopic analysis of Hdmbtsc and complexes

The most significant IR bands of Hdmbtsc and the nickel and cobalt complexes are given in Table 2. The IR spectra of ligand Hdmbtsc showed medium to broad peaks at 3471 cm^{-1}, 3244 cm^{-1} assigned as *v*(-NH$_2$); 3147 cm^{-1} as *v*(-NH); 1592 cm^{-1} as *v*(C=N); and 821 cm^{-1} as *v*(C=S). Medium stretching vibrations of ν(NH$_2$) appeared in the range of 3400 – 3200 cm^{-1} in cobalt and nickel complexes **1-8**. The stretching vibration of 3147 cm^{-1} assigned as ν(-NH) was absent in metal complexes **1-5**, **8**. This may be due to the deprotonation of $-N^2H$ proton upon complexation, suggesting that Hdmbtsc acted as a mononegative bidentate, coordinating through azomethine N and thiol group in these complexes. It acted as a neutral bidentate, coordinating through azomethine (C=N) and S atom of C=S group in **6** and **7**. The sharp peaks at 1592$cm^{-1}$and 1510 cm^{-1}, corresponding to ν(C=N) in Hdmbtsc, shifted to lower wave numbers in the spectra of cobalt complexes **1-5** and **8**, indicating the coordination of the metal ions to azomethine group, similar to the reported value [15]. A strong band observed at 821 cm^{-1}, assigned as *v*(C=S) in the spectra of Hdmbtsc, showed a shift to lower wave numbers in the complexes, indicating the involvement of thiol sulphur in bonding. This shift can be assigned to the thiocarbonyl ν(C = S) stretching and bending modes of vibrations and to the coordination of the sulfur atom to metal ions [16, 17]. The amount of the shifts suggests that the ligand coordinated as a neutral, bidentate (through the azomethine nitrogen and thiocarbonyl sulfur) ligand in **6** and **7**. The bands in the region of 1500-1100 cm^{-1} refers to *v*(C=C) and δNH$_2$. The negligible effect on these bands in the complexes, rules out their participation in bonding.

3. Electronic Spectra of Hdmbtsc and complexes

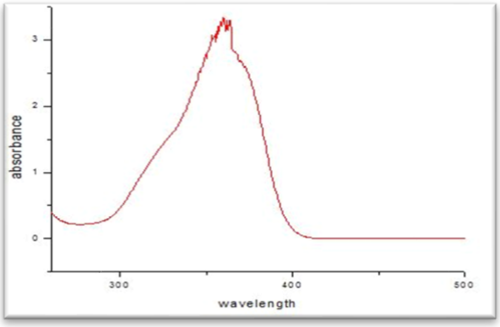
The electronic spectra data of Hdmbtsc and the metal complexes are given in Table 3. The spectra of Hdmbtsc and the complexes were recorded in DMSO. Hdmbtsc showed two bands at 320 nm, 359 ($n \rightarrow \sigma^*$) and 380nm ($\pi \rightarrow \pi^*$). In octahedral cobalt(II) complexes with ^4F ground state term, three bands were expected. Upon coordination with Co(II), these bands shifted to either high or low energy regions. These bands may be attributed to the d-d transitions: $^4T_1g(F) \rightarrow {}^4T_2g(F)$; $^4T_1g(F) \rightarrow {}^4A_2g(F)$ and $^4T_1g(F) \rightarrow {}^4T_1g(P)$. In complexes **1- 6**, two bands were observed due to merging of the second and third bands. Charge transfer bands were observed in the region of 409-550 cm^{-1}. A blue shift was seen in the $\pi \rightarrow \pi^*$ band as a result of the coordination of azomethine through donation of lone pairs of electrons in the nitrogen atom. In octahedral Ni(II) complexes, three spin-allowed transitions were expected with ^3F ground state term and ^3P excited state term due to the d-d transitions: $^3A_2g(F) \rightarrow {}^3T_2g(F)$; $^3A_2g(F) \rightarrow {}^3T_1g(F)$ and $^3A_2g(F) \rightarrow {}^3T_1g(P)$ (Figure 1). The electronic spectra of the complexes have been discussed in light of earlier studies [18, 19]. These bands also supported the geometry of the complexes. All the complexes displayed similar bands corresponding to the intra-ligand transitions, and an expected blue shift was observed. A broad band was observed near 400 nm, corresponding to the ligand to metal charge transfer transition similar to the literature [20].

Table 2. IR bands of Hdmbtsc and its complexes.

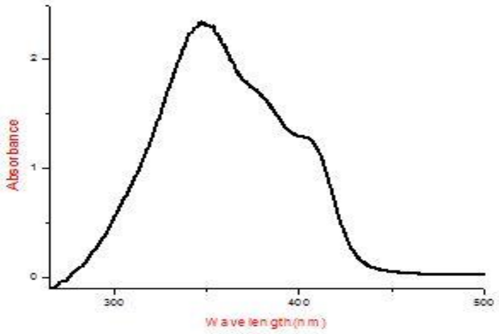
	v(NH$_2$) (cm^{-1})	*v*(-NH-) (cm^{-1})	*v*(C=S) (cm^{-1})	*v*(C=N) (cm^{-1})	*v*(C-N) (cm^{-1})
Hdmbtsc	3471, 3244	3147	821	1592	1184
$[Co(dmbtsc)_2]Cl_2$ **(1)**	3407	-	803	1571	1167
$[Co(dmbtsc)_2(NO_3)_2]$ **(2)**	3502	-	803	1611	1104
$[Co(dmbtsc)_2(py)2](NO_3)_2$ **(3)**	3461	-	821	1603	
$[Co(dmbtsc)_2(phen)]Cl_2$ **(4)**	3480, 3200	-	817	1598	1164
$[Co(dmbtsc)(PPh_3)_2](NO_3)_2]$ **(5)**	3480, 3320	-	817	1611	1264
$[Ni(Hdmbtsc)_2]Cl_2$ **(6)**	3372, 3244	3123	817	1592	1164
$[Ni((Hdmbtsc)(py)_2]Cl_2$ **(7)**	3418, 3272	3130	814	1592	1182
$[Ni(dmbtsc)_2(phen)]Cl_2$ **(8)**	3398	-	732	1592	1167

Table 3. Electronic spectra data of Hdmbtsc and its complexes **1-8**.

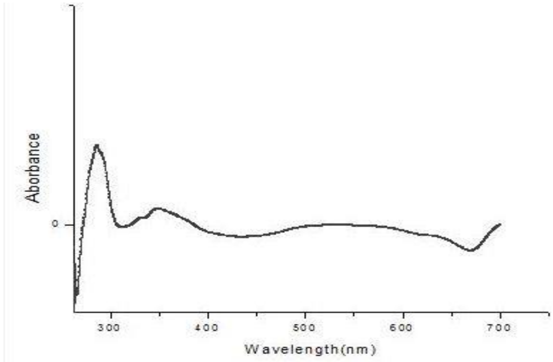
	n→ σ*	π→π*	Charge transfer	Geometry
Hdmbtsc	320, 359	380		
$[Co(dmbtsc)_2]Cl_2$ **(1)**	348	380	450	Octahedral
$[Co(dmbtsc)_2(NO_3)_2]$**(2)**	280	360	550	Octahedral
$[Co(dmbtsc)_2(py)(NO_3)]$**(3)**	282	370	400	Octahedral
$[Co(dmbtsc)_2(phen)]Cl_2$ **(4)**		361	411	Octahedral
$[Co(dmbtsc)(PPh_3)_2(NO_3)_2]$ **(5)**	279	360	409	Octahedral
$[Ni(Hdmbtsc)_2]Cl_2$ **(6)**	350	383		Octahedral
$[Ni((Hdmbtsc)(py)_2Cl_2]$ **(7)**	358	370		Octahedral
$[Ni(dmbtsc)_2(phen)Cl_2]$ **(8)**	335	350		Octahedral



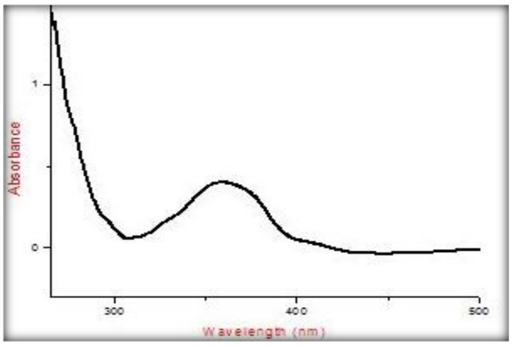
Hdmbtsc



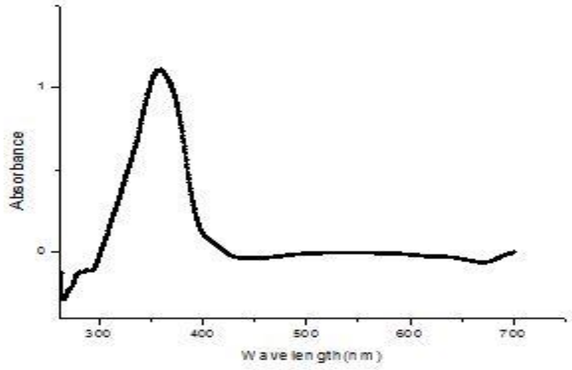
$[Co(dmbtsc)_2Cl_2]$ (1)



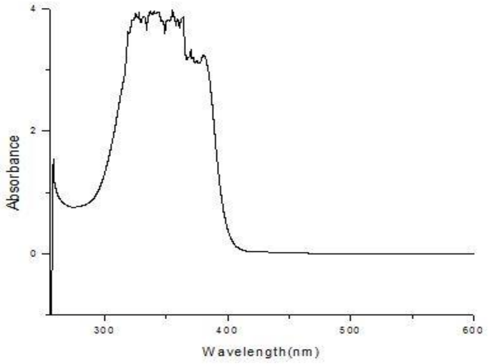
$[Co(dmbtsc)_2((NO_3)_2]$ (2)



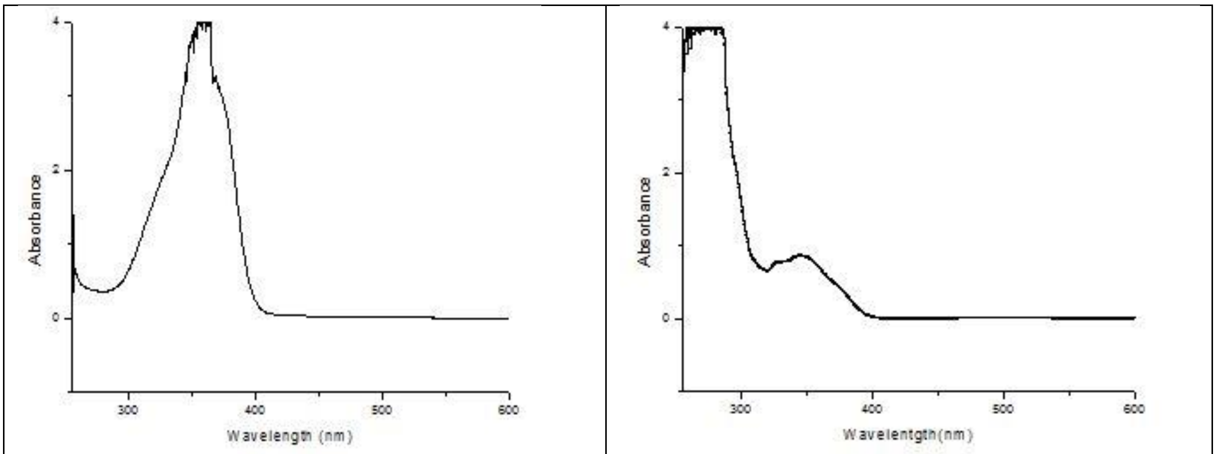
$[Co(dmbtsc)_2(phen)]Cl_2$ (4)



$[Co(dmbtsc)_2(PPh_3)_2]Cl_2$ (5)



$[Ni(dmbtsc)_2Cl_2]$ (6)



[Ni(dmbtsc)$_2$(py)$_2$]Cl$_2$ (7)

[Ni(dmbtsc)$_2$(phen)$_2$] (8)

Figure 1. Electronic spectra of Complexes 1-8.

4. Microbiological Investigations: Antibacterial and Antifungal Activities

Hdmbtsc and the complexes were tested against the bacteria *Escherichia coli* (*E. coli*) and *Listeria* and the fungus *Candida albicans* using the agar plate method. The antimicrobial activity was tested by using (Kirby Bauer) agar disc/well diffusion method [21]. The test strains of *E. coli* and *Candida albicans* were subcultured on specific LB (Luria Bertani) and SD (Sabouraud Dextrose) media respectively and further incubated aerobically at 37ºC for 24 hr. Gentamicin (stock 10 mg/ml) was taken as the positive control for the bacterial strain, while for the fungal strain, it was Amphotericin B. The negative control used was DMSO solvent.

To test the effect of the synthesized chemical compounds on microorganisms, specific media were prepared - 250 ml media and 50 ml broth. In each labelled plate that contained the medium, 40 µl of standardized broth culture of the bacteria was inoculated. A spreader was used to ensure uniform distribution of the microorganisms on the surface of the agar. This method of agar disc/well diffusion was described by Kirby-Bauer [21]. To study the effectiveness of antibacterial and antifungal activities of the synthesised compounds, the compounds were dissolved in a suitable solvent (DMSO). Wells of a suitable size were made by using the end of sterile disposable pipette tips. The wells were filled with the various synthesized compounds, and then they were aseptically placed over the media with specific bacteria. The plates were incubated in an upright position at 37°C for 24 hours. Ranking of the antimicrobial activity results was done according to Clinical Laboratory Standards Institute (CLSI, 2010), according to which the zone of inhibition less than 15 mm is less active, 16-20 mm is moderately active and 21 mm and above is highly active [22].

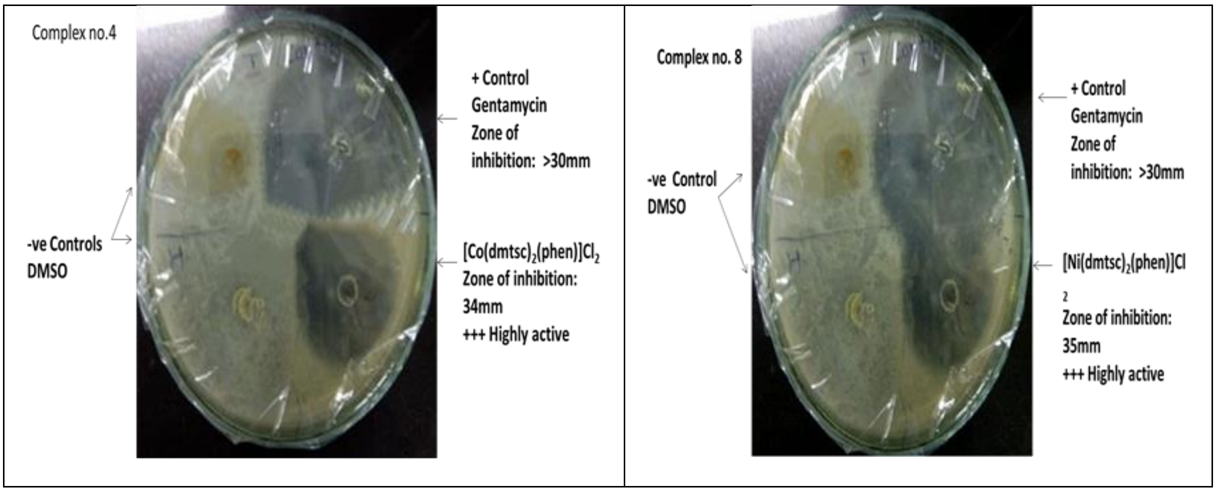
Table 4. Antimicrobial activity in terms of zone of inhibition for Hdmbtsc and cobalt(II) and nickel(II) complexes.

Test samples	**Gram +ve bacteria**	**Gram –ve bacteria**	**Fungus**
	Listeria	*E. coli*	*Candida albicans*
Hdmbtsc	0	0	0
[Co(dmbtsc)$_2$Cl$_2$] **(1)**	0	+	++
[Co(dmbtsc)$_2$(NO$_3$)$_2$] **(2)**	0	+	+
[Co(dmbtsc)$_2$(py)(NO$_3$)] **(3)**	0	0	+
[Co(dmbtsc)$_2$(Phen)]Cl$_2$ **(4)**	0	+++	++
[Co(dmbtsc)(PPh$_3$)$_2$(NO$_3$)$_2$] **(5)**	0	0	++
[Ni(Hdmbtsc)$_2$Cl$_2$] **(6)**	0	0	++
Ni(Hdmbtsc)$_2$(py)$_2$Cl$_2$] **(7)**	0	0	0
[Ni(dmbtsc)$_2$(phen)$_2$Cl$_2$] **(8)**	0	+++	0

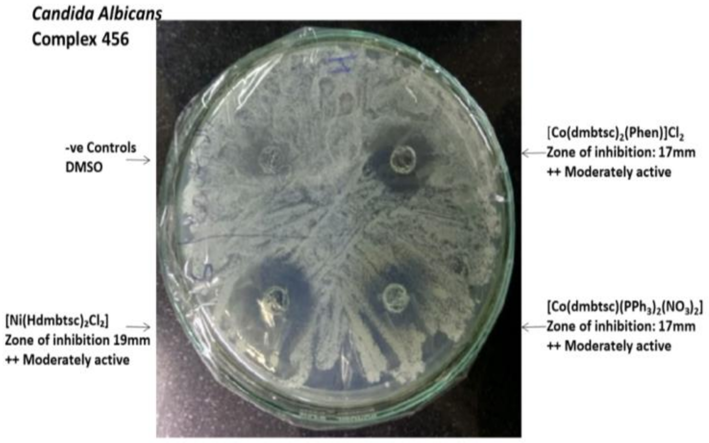
Table 5. Zone of inhibition (mm) for Hdmbtsc and cobalt(II) and nickel(II) complexes.

Test sample	**Gram +ve bacteria**	**Gram –ve bacteria**	**Fungus**
	Listeria	*E. Coli*	*Candida albicans*
Hdmbtsc	0	0	0
$[Co(dmbtsc)_2Cl_2]$ **(1)**	0	≤13	19
$[Co(dmbtsc)_2(NO_3)_2]$ **(2)**	0	≤13	10
$[Co(dmbtsc)_2(py)(NO_3)]$ **(3)**	0	0	15
$[Co(dmbtsc)_2(Phen)]Cl_2$ **(4)**	0	34	17
$[Co(dmbtsc)(PPh_3)_2(NO_3)_2]$ **(5)**	0	0	17
$[Ni(Hdmbtsc)_2Cl_2]$ **(6)**	0	0	19
$Ni(Hdmbtsc)_2(py)_2Cl_2]$ (**7**)	0	0	0
$[Ni(dmbtsc)_2(phen)_2Cl_2]$ (**8**)	0	35	0

Hdmbtsc did not show any inhibition of growth for E. coli and Listeria as well as Candida albicans, but growth inhibition was observed in some complexes. Cobalt complex [Co(dmbtsc)2Cl2] (1) showed less activity against E. coli and Candida albicans with zone of inhibition less than 13 mm, whereas [Co(dmbtsc)2(phen)]Cl2 (4) was highly active against E. coli and moderately active against Candida albicans, as depicted in Table 4. Out of all the nickel complexes, only [Ni(Hdmbtsc)2Cl2] (6) showed maximum inhibitory activity against E. coli (35 mm zone of inhibition) (Table 2). The rest of the complexes were inactive. None of the test compounds were active against Gram +ve bacteria (Listeria).



(a) Antibacterial study (*E. coli*)



b) Antifungal study (*Candida albicans*) of complexes

Figure 2. Microbiological studies of Co(II) and Ni(II) complexes.

A possible explanation for this increased activity may be related to delocalization of π electron density over the chelate rings, reducing the polarity of the metal ion and increasing lipophilic character of the metal chelate. This favours the permeation of the complex through the lipid layers of the bacterial membranes, thus affecting growth.

CONCLUSION

Cobalt(II) and nickel(II) complexes with p-dimethyl-aminobenzaldehyde thiosemicarbazone (Hdmbtsc) were prepared in the presence/absence of co-ligands and characterised by spectroscopic methods (IR, UV). The absence of *v*(-NH) indicated that Hdmbtsc coordinated as an anionic bidentate in cobalt complexes **1-5** and nickel complex **8** and a neutral bidentate in nickel complexes **6** and **7** (Scheme 2). The structures of all the complexes were proposed in light of the spectroscopic studies. Antibacterial and antifungal activity studies were carried out on Hdmbtsc and the complexes against the Gram -ve bacterium *E. coli* and the fungus *Candida albicans*. Hdmbtsc was not found to have any inhibitory effect against bacterial and fungal strains while its few complexes were effective. Cobalt complex $[Co(dmbtsc)_2(phen)]Cl_2$ (**4**) and $[Ni(Hdmbtsc)_2(phen)_2Cl_2]$ (**8**) showed the highest activity against *E. coli* . Cobalt complexes showed moderate activity against *Candida albicans* (Table 5). Complexes **1**, **4** and **8** are potential candidates to be applied in medical formulations. This study can be extended to anticancer activity of other metal complexes with Hdmtsc. Hdmbtsc has been reported as selective and sensitive sensor for mercury(II)[15], such activity may be extended on other metals of importance.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animal studies performed by the authors.

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