Journal of the Serbian Chemical Society
JSCS@tmf.bg.ac.rs • www.shd.org.rs/JSCS

J. Serb. Chem. Soc. 75 (6) 749–761 (2010)
JSCS–4004

UDC 546.795.4+547.72'828'288.3:
543.57:615.277–188
Original scientific paper

Synthesis, thermal and antitumour studies of Th(IV) complexes with furan-2-carboxaldehyde4-phenyl-3-thiosemicarbazone

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(Received 29 July 2009, revised 2 February 2010)

Abstract: Thorium(IV) complexes with the Schiff base furan-2-carboxaldehyde4-phenyl-3-thiosemicarbazone (L) were synthesised and characterized. The composition and structure of the metal complexes were proposed based on elemental analysis, molar conductivity measurements, FTIR and ^{1}H-NMR spectroscopy. The Schiff base behaves as a neutral bidentate ligand coordinating through the azomethine N and the thioketo S atoms. From various studies, complexes were ascertained the general formula $[ThL_2X_4]$ and $[ThL_2Y_2]$, where X represents NO_3^-, NCS^-, CH_3COO^-, $CH_3CHOHCOO^-$, ClO_4^- and Y $SO_4^{2-}$and $C_2O_4^{2-}$. The thermal behaviour of the nitrato and oxalato complexes was studied and kinetic and thermodynamic parameters were calculated using the Coats-Redfern Equation. The ligand and a representative complex $[ThL_2(NO_3)_4]$ were screened *in vitro* for their antitumour activity against the human cervical cancer cell line (HeLa).

Keywords: thorium(IV) complexes; furan-2-carboxaldehyde4-phenyl-3-thiosemicarbazone; antitumour activity; thermal analysis.

INTRODUCTION

Complexes of thiosemicarbazones have been explored for a variety of reasons, such as variable bonding properties, presence of several donor sites, structural diversity and pharmacological aspects.[1] They present a variety of biological activities, including anticancer and anti-inflammatory activities.[2–4] Metal thiosemicarbazonate complexes are emerging as a new class of experimental anticancer and chemotherapeutic agents which exhibit inhibitory activities against most cancer through inhibition of a crucial enzyme obligatory for DNA biosynthesis and cell division, *viz*. ribonucleotide diphosphate reductase (RDR).[5] Some thiosemi-

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doi: 10.2298/JSC090729048R

carbazones even increase their antitumour activity by their ability to form chelates with specific metal ions.[6] It was reported that the anticancer activities of thiosemicarbazones were closely related to the parent aldehyde or ketone group, metal chelation ability and terminal amino substitution. Among them, the parent aldehyde or ketone group was considered critical for the anticancer activity of thiosemicarbazones. Heterocyclic thiosemicarbazone showed higher activity compared with aromatic thiosemicarbazones.[7] Heterocyclic thiosemicarbazones and their metal complexes are among the most widely studied compounds for their potential therapeutic uses, such as antitumoural, fungicidal, bactericidal or antiviral activity.[8] The activity of these compounds is dependent on the nature of the hetroaromatic ring and the position of attachment of the ring as well as on the form of the thiosemicarbazone moiety.[9] There were several studies involving thiosemicarbazones with different metal ions.[10–13] However, only a few reports described studies on thorium thiosemicarbazone complexes. Hence as part of ongoing research regarding thiosemicarbazone complexes of thorium[14,15], the synthesis, characterization and antitumour activity of Th(IV) complexes with furan--2-carboxaldehyde4-phenyl-3-thiosemicarbazone (Fig. 1) are reported herein.

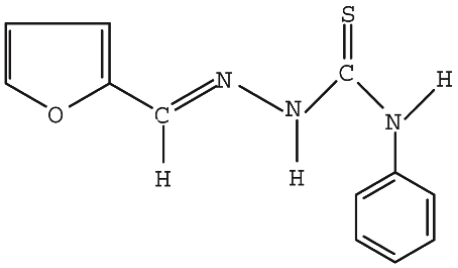

Fig. 1. Schematic view of the ligand.

EXPERIMENTAL

Materials and analytical methods

All employed chemicals were of analytical grade purchased from Merck, Sisco (India), *etc*. Commercial solvents were distilled and used for synthesis, but for the physicochemical studies, they were purified by standard methods.

The IR spectral studies were performed using KBr discs on a Schimadzu 8201 PC FT infrared spectrophotometer. The ^{1}H-NMR spectra were recorded on a Bruker DRX-300 FT NMR spectrophotometer employing TMS as the internal reference and DMSO-d_6 as the solvent. X-Ray diffraction studies were realized using a Philips X-ray PW 1710 diffractometer using K-α1 radiation of wavelength 1.54056 Å. Molar conductance measurements of 10^{-3} M solutions in CH_3CN and $C_6H_5NO_2$ were performed at room temperature using a direct reading Elico conductivity bridge. TG and DTG curves were recorded on a Mettler Toledo 850 C simultaneous TG/DTA thermal analyzer system in dynamic air at a heating rate of 10 °C/min. The TG data was analyzed using the Coats-Redfern Equation for calculating the kinetic and thermodynamic parameters. Elemental analyses were realized using an Elementar Vario EL III Carlo Erba 1108 elemental analyzer at the Central Drug Research Institute, Lucknow, India.

The metal content was estimated gravimetrically by the oxalate–oxide method.[16] Standard gravimetric procedures were adopted for the estimation of the anions in the prepared complexes.[17] The sulphate and thiocyanate present in the complexes were estimated gravimetrically as $BaSO_4$ and AgNCS, respectively, while the perchlorate content was determined by the Kurz method.[18] The nitrate, oxalate, acetate and lactate contents were indirectly fixed by performing elemental analysis for carbon, hydrogen and nitrogen by micro analytical methods.

Synthesis of ligand

The ligand, furan-2-carboxaldehyde4-phenyl-3-thiosemicarbazone, was prepared by the following method. Furan-2-carboxaldehyde (0.010 mol) in methanol (10 ml) was added dropwise to a hot solution of 4-phenyl-3-thiosemicarbazide (0.010 mol) in methanol (30 ml) under constant stirring. The resulting mixture was heated on a water bath for 3 h, concentrated and allowed to cool. The formed dark brown crystals of the ligand were washed, dried and recrystallized from ethanol. Yield: 84 %; m.p. 120 °C ; Anal. Calcd. for $C_{12}H_{11}N_3OS$: C, 58.77; H, 4.49; N, 17.14; S, 13.06 %. Found: C, 58.56; H, 4.54; N, 17.63; S, 13.21 %. IR (KBr, cm^{-1}): 3256, (*m*, –NH), 1623 (*vs*, C=N), 1526 (*m*, C–O furan ring), 1060 (*m*, (N–N), 868 (*s*, C=S).

Synthesis of metal complex

The metal complexes were prepared by refluxing a methanolic solution of the metal salt and the ligand in the stoichiometric ratio 1:2. For the preparation of the nitrato complex, the appropriate amount of the metal salt (0.0020 mol) dissolved in a minimum quantity of methanol (10 ml) was added to a solution of the ligand (0.0040 mol, 0.10 g) dissolved in methanol (25 ml). The pH of the solution was raised to 7 and refluxed on a water bath for about 5 h. It was then concentrated and left standing over night. The separated complex was filtered, washed with a methanol–water mixture (50 % v/v) and then with ether and dried over P_4O_{10} *in vacuo*. The other anionic complexes were prepared from the nitrato complex by the substitution method[19] by refluxing stoichiometric amounts of the nitrato complex with the respective anionic salts of lithium.

Antitumour screening

The *in vitro* antitumour activities of the ligand and a representative complex were examined by the MTT assay method[20,21] against human cervical cancer cell line (HeLa).

The human cervical cancer cell line (HeLa) was obtained from the National Centre for Cell Science Pune, India. The cells were grown in Dulbecco's modified eagles medium (DMEM) containing 10 % foetal bovine serum (FBS), streptomycin (100 μg/ml), penicillin (100 units/ml) and amphotericin B (2.5 μg/ml). The cells were incubated at 37 °C in a 5 % CO_2 incubator in a humid condition and harvested using trypsin–ethylene diamine tetraacetic acid.

The test samples were dissolved in DMSO and diluted to the required concentration for the biological experiments. Studies were undertaken with the test compounds in the concentration range from 10 to 100 μg/ml.

For the determination of the cytotoxic effects, cells harvested from the exponential phase were seeded equivalently (5000 cells/well) in a 96-well plate and incubated for 24 h. Test solutions of different concentrations were added in triplicate to the well plates. Six well plates were maintained in a drug free medium to determine the control, cell survival and the percentage of live cells after culture. Cells with various concentrations of the test samples were incubated at 37 °C for 72 h.

To determine the numbers of live cells, the dye 3-(4,5-dimethylthiazol-2yl)-2,5-diphenyltetrazolium bromide (MTT) was added to the cells, which were then incubated for 2 h

at 37 °C. MTT is metabolized in the presence of the pyridine cofactors NADH and NADPH, to give blue insoluble crystals. The cells were solubilised with 0.1 ml of extraction buffer (20 % sodium dodecyl sulphate in 50 % dimethylformamide) and then incubated for 4 h at 37 °C. Following the solubilisation of the cells, the colour intensity was read at 570 nm using an Elisa plate reader (Bio-Rad). The percentage viability of the cells or cell survival (*CS*) was expressed as mean optical density (drug exposed cell) divided by mean optical intensity (control).

RESULTS AND DISCUSSION

All the prepared complexes were brown coloured, non-hygroscopic solids stable at room temperature. They were soluble in DMSO and DMF but insoluble in water and common organic solvents. The room temperature molar conductivities of 10^{-3} M solutions of the complexes in CH_3CN and $C_6H_5NO_2$ corresponded to those of non-electrolytes.[22] The analytical data revealed that all complexes possessed 1:2 metal to ligand stoichiometry. Based on elemental analysis, the complexes were assigned the composition shown in Table I.

TABLE I. Molar conductance at room temperature and elemental analyses data of the complexes (L = $C_{12}H_{11}N_3OS$)

Complex	Found (Calcd.), %					Molar conductance S cm^2 mol^{-1}	
	Metal	C	H	N	S	$C_6H_5NO_2$	CH_3CN
$[ThL_2(NO_3)_4]$ (**1**)	23.85 (23.92)	29.63 (29.69)	2.16 (2.26)	14.53 (14.43)	6.79 (6.59)	5.7	13.8
$[ThL_2(SO_4)_2]$ (**2**)	25.25 (25.38)	31.45 (31.51)	2.30 (2.41)	9.09 (9.19)	14.15 (14)	7.5	12.1
$[ThL_2(NCS)_4]$ (**3**)	24.21 (24.32)	35.12 (35.22)	2.51 (2.31)	14.47 (14.67)	20.21 (20.13)	8.8	10.8
$[ThL_2(C_2O_4)_2]$ (**4**)	25.64 (25.84)	37.22 (37.42)	2.15 (2.45)	9.55 (9.35)	7.03 (7.13)	6.9	9.6
$[ThL_2(CH_3COO)_4]$ (**5**)	24.30 (24.22)	40.02 (40.08)	3.25 (3.55)	8.17 (8.77)	6.28 (6.68)	7.1	11.1
$[ThL_2(C_3H_5O_3)_4]$ (**6**)	21.27 (21.52)	40.26 (40.07)	3.87 (3.89)	7.81 (7.79)	5.73 (5.93)	7.9	13.6
$[ThL_2(ClO_4)_4]$ (**7**)	20.67 (20.71)	25.76 (25.71)	1.50 (1.96)	7.63 (7.5)	5.49 (5.71)	12.9	17.1

Spectral studies

The IR spectrum of the ligand showed a strong absorption band at 1623 cm^{-1} which was assigned to the azomethine group, ν(C=N).[23] In principle, the ligand can exhibit thione–thiol tautomerism owing to the presence of a thioamide –NH–C=S functionality (Fig. 2). The possibility of thione–thiol tautomerism in the ligand was ruled out as no band around 2700–2500 cm^{-1}, characteristic of the thiol group, was observed in the IR spectrum[24] (Fig. 3). The strong band observed at 868 cm^{-1} in the spectrum was due to the stretching vibrations of

C=S.[7,25] The bands observed at 3256 and 3423 cm^{-1} were assigned to N–H vibrations. This further indicates that the ligand remained in the thione form.

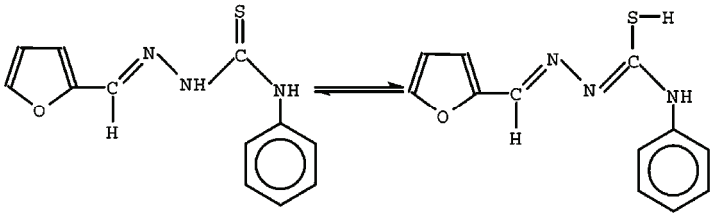

Fig. 2. Tautomeric forms of the ligand.

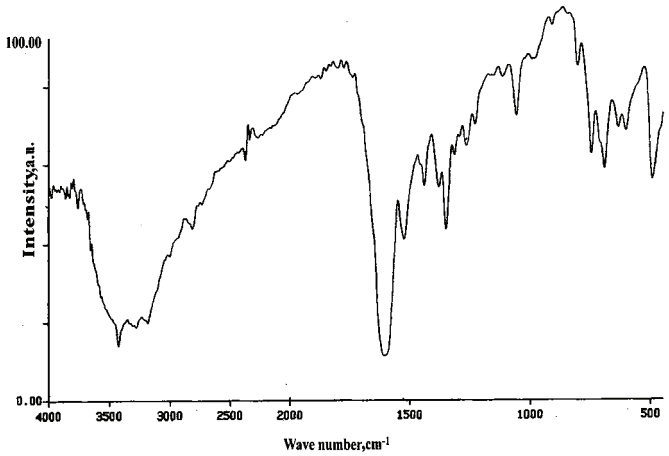

Fig. 3. IR spectrum of furan-2-aldehyde-*N*-phenylthiosemicarbazone.

The diagnostic IR spectral bands of the complexes are presented in Table II, together with their tentative assignments. In the spectra of all the complexes, the band due to the azomethine moiety (C=N) was shifted to a lower frequency by ≈ 20–30 cm^{-1}, indicating its involvement in coordination with metal ion. The ν(C=S) stretching frequency was lowered by ≈20–40 cm^{-1} in the spectra of the complexes, indicating the involvement of the thioketo sulphur in the coordination. These findings are further supported by the appearance of new bands in the far IR region at 495–505 and 359–370 cm^{-1}, which are assignable to ν(Th–N) and ν(Th–S) vibrations, respectively.

The IR spectra of the complexes differed among themselves due to the various coordinating anions and possessed additional non-ligand bands characteristic of the anion present. The spectrum of the complex **1** showed three bands at 1495, 1373 and 1033 cm^{-1}, assignable to the ν_4, ν_1 and ν_2 modes of the coordinated nitrate ions. The magnitude of the separation between the split bands (ν_4 and ν_1) was 120 cm^{-1}, indicating monodentate coordination[26] of the nitrate ion to the metal. In the spectra of complexes **5** and **6**, $\nu_a(COO^-)$ was observed at

1598 and 1596 cm^{-1}, respectively, and $\nu_s(COO^-)$ at 1362 and 1352 cm^{-1}, respectively, apart from the skeletal vibrations of the ligand. The separation between the two frequencies adequately supports the monodentate coordination of the acetate and lactate group.[27] The spectrum of complex **4** showed additional bands at 1665 and 1361 cm^{-1}, which were assigned to $\nu_a(COO)$ and $\nu_s(COO)$ modes of the bidentately coordinated dicarboxylate ion.[28] The IR spectrum of complex **3** had additional non-ligand bands at 2072, 777 and 493 cm^{-1}, assignable to ν(C–N), ν(C–S) and δ(NCS) of thiocyanate.[29] The presence of these bands revealed the N-coordinated nature of the thiocyanate ion.[29] The spectrum of complex **2** exhibited additional non-ligand bands at 1248, 1177 and 1085 cm^{-1}, and the values showed the bridging bidentate coordination of the sulphate group.[30] For complex **7**, the spectral bands at 1110, 1071 and 627 cm^{-1} indicated the monodentate coordination of the perchlorate group.[31] The nature of the bonding of the various anions is further supported by the non-electrolytic nature of all the complexes.

TABLE II. IR spectral data of the complexes (cm^{-1})

Compound	ν(N–H)	ν(C=N)	ν(C–O) Furan ring	ν(N–N)	ν(C=S)	ν(Th–N)	ν(Th–S)
$[ThL_2(NO_3)_4]$ **(1)**	3255 *m*	1598 *vs*	1520 *m*	1064 *m*	827 *s*	503 *m*	364 *m*
$[ThL_2(SO_4)_2]$ **(2)**	3256 *m*	1601 *vs*	1522 *m*	1066 *m*	823 *s*	506 *m*	368 *m*
$[ThL_2(NCS)_4]$ **(3)**	3252 *m*	1590 *vs*	1521 *m*	1062 *m*	834 *s*	507 *m*	363 *m*
$[ThL_2(C_2O_4)_2]$ **(4)**	3524 *m*	1597 *vs*	1522 *m*	1066 *m*	846 *s*	504 *s*	369 *m*
$[ThL_2(CH_3COO)_4]$ **(5)**	3253 *m*	1593 *vs*	1524 *m*	1068 *m*	848 *s*	508 *m*	362 *m*
$[ThL_2(C_3H_5O_3)_4]$ **(6)**	3256 *m*	1596 *vs*	1527 *m*	1067 *m*	848 *s*	506 *m*	360 *m*
$[ThL_2(ClO_4)_4]$ **(7)**	3257 *m*	1591 *vs*	1523 *m*	1061 *m*	846 *s*	498 *s*	359 *m*

The ^{1}H-NMR spectrum of the ligand recorded in DMSO-d_6 showed no peak at 4 ppm attributable to SH protons[8] but showed a peak at 9.87 ppm, which was attributed to the N–H group, indicating that the ligand was in the thione form, which is in conformity with the IR spectrum. A significant azomethine proton signal due to CH=N was observed at 8.98 ppm, while that due to aromatic protons were observed in the region 7.21–7.36 ppm. Signals for the furan ring protons were observed at 6.57, 7.38 and 7.41 ppm.

The ^{1}H-NMR spectrum of the complex $[ThL_2(NO_3)_4]$ recorded in DMSO-d_6 showed proton signals in the expected regions but showed slight shifts compared to the ligand spectrum. In the spectrum of the complex, an azomethine proton signal was observed at 9.12 ppm; the N–H proton signal was observed at 9.98 ppm, the aromatic and furan ring proton signals were observed as multiplets in the region 6.5 to 7.52 ppm. These data are consistent with the IR spectral data. Based on spectral evidence, the proposed geometry for the complex is given in Fig. 4.

X-Ray diffraction study

The structure of $[ThL_2(NO_3)_4]$ evaluated using powder X-ray diffraction indicated the amorphous nature of the complex. The X-ray diffraction pattern is given in Fig. 5.

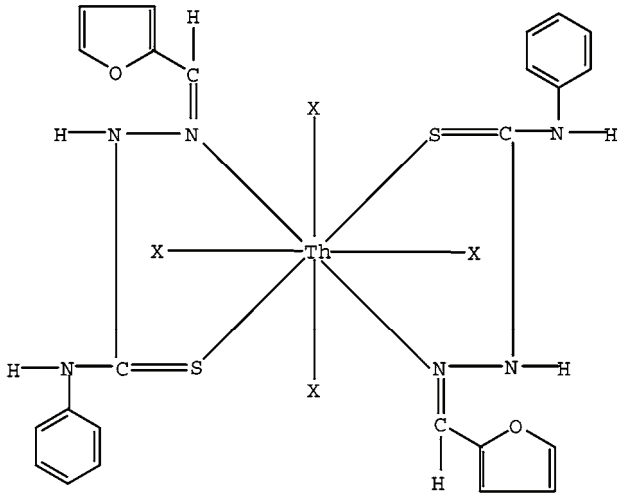

Fig. 4. Proposed geometry of the complexes.

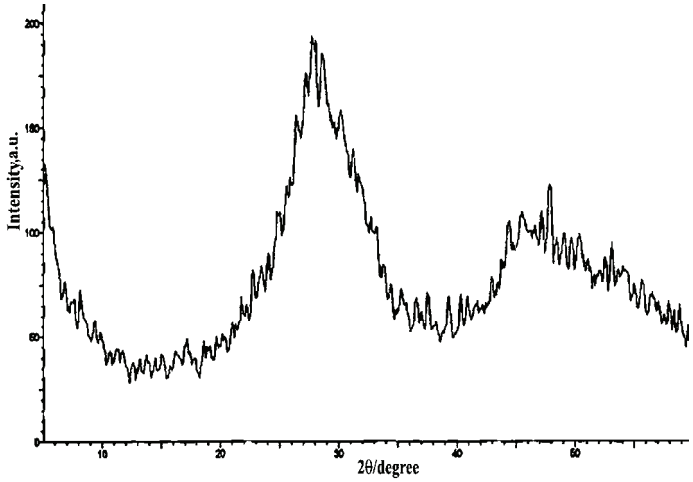

Fig. 5. XRD Pattern of the $[ThL_2(NO_3)_4]$ complex.

Thermal studies

The thermal behaviour of $[ThL_2(NO_3)_4]$ and $[ThL_2(C_2O_4)_2]$ were investigated by the TG and DTG techniques under non-isothermal conditions.

The $[ThL_2(NO_3)_4]$ complex showed a single stage decomposition, as shown by the DTG curve. The TG curve showed the absence of water or any other solvent molecules, as the complex was stable up to 190 °C (Fig. 6). Decomposition started at 190 °C and ended at 270 °C with a peak temperature of 247 °C, indicating the loss of the ligand and nitrate group. The residue 27.57 % (calcd. 27.82 %) showed that the final product formed was ThO_2, which is in agreement with the analytical result for the metal content.

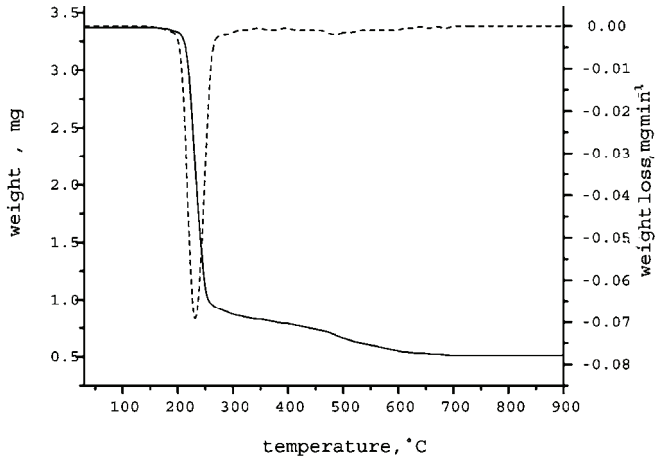

Fig. 6. TG and DTG curves of $[ThL_2(NO_3)_4]$.

For the complex $[ThL_2(C_2O_4)_2]$, the TG plateau up to 220 °C showed the absence of coordinated water or any other solvent molecules and the stability of complex (Fig. 7). Decomposition began at 220 °C and ended at 310 °C. The peak temperature for the decomposition was 265 °C. The complex showed a single stage decomposition, as evident from the DTG curve, and the decomposition occurred with the loss of both ligand and oxalate molecules. The final product formed was ThO_2 and the residue obtained 29.55 % (calcd. 29.40 %) agreed well with the analytical result obtained by an independent pyrolysis experiment.

Kinetic aspects

A kinetic evaluation of the thermal decomposition data of complexes was carried out. The kinetic parameters, *viz*., the activation energy, *E*, and the pre-exponential factor, *A*, were calculated using the Coats-Redfern Equation.[32] Computational data for the evaluation of kinetic parameters are given in Tables III and IV. Here the $\ln g(\alpha)/T^2$ *vs*. $1000/T$ plots (Figs. 8 and 9) gave straight lines, from the slope and intercept of which were calculated the kinetic parameters by the least square method. The goodness of fit was tested by evaluating the correlation coefficient. The entropy of activation ΔS was calculated using the equation:

$$\Delta S = R \ln (Ah/kT_S) \quad (1)$$

where R is the gas constant, A is the pre-exponential factor, k is the Boltzmann constant, T_S is the DTG peak temperature and h is the Planck constant.

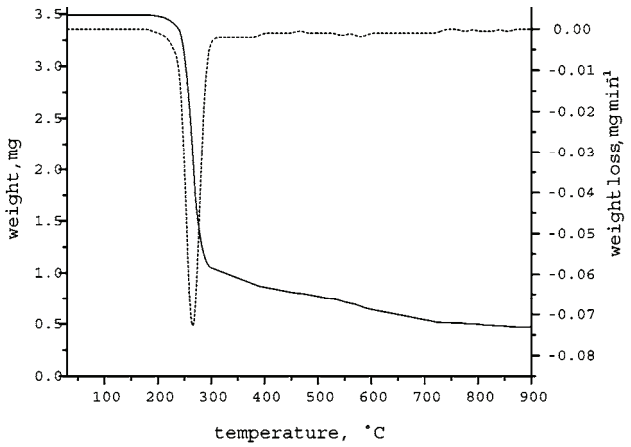

Fig. 7. TG and DTG curves of $[ThL_2(C_2O_4)_2]$.

TABLE III. Computational data for the thermal decomposition of $[ThL_2(NO_3)_4]$ (n = 2; r = 0.99295)

t / °C	m / mg	T/ K	T / 10^{-3} K^{-1}	Weight loss, %	α	$g(\alpha)$	ln $(g(\alpha)/T)^2$
200	3.33	473	–	0	0	0	–
210	3.30	483	2.07039	0.03	0.01240	0.01255	–16.73788
220	3.08	493	2.02840	0.25	0.10331	0.11521	–14.56204
230	2.24	503	1.98807	1.09	0.45041	0.81955	–12.64018
240	1.58	513	1.94932	1.75	0.72314	2.61194	–11.52046
250	1.03	523	1.91205	2.30	0.95041	19.1667	–9.56599
260	0.96	533	1.87617	2.37	0.97934	47.4	–8.69842
270	0.93	543	1.84162	2.40	0.99174	120	–7.80673
280	0.91	553	1.80832	2.42	1	–	–

TABLE IV. Computational data for the thermal decomposition of $[ThL_2(C_2O_4)_2]$ (n = 1.7; r = 0.99566)

t / °C	m / mg	T/ K	T / 10^{-3} K^{-1}	Weight loss, %	α	$g(\alpha)$	ln $(g(\alpha)/T)^2$
220	3.45	493	2.0284	0	0	0	–-
230	3.42	503	1.98807	0.03	0.01240	0.01253	–16.82091
240	3.35	513	1.94932	0.10	0.04132	0.04283	–15.63107
250	3.25	523	1.91205	0.20	0.08264	0.08892	–14.93921
260	2.70	533	1.87617	0.75	0.30992	0.42356	–13.41611
270	1.76	543	1.84162	1.69	0.69835	1.8770	–11.96454
280	1.21	553	1.80832	2.24	0.92562	7.37952	–10.63201
290	1.08	563	1.77620	2.37	0.97934	20.16347	–9.66269
300	1.05	573	1.74520	2.40	0.99174	39.57784	–9.02350
310	1.03	583	1.71527	2.42	1	–	–

The kinetic parameters determined for the thermal decomposition are listed in Table V. The positive value of the entropy of activation in both cases indicates that the activated state was less ordered than the reactants.[33]

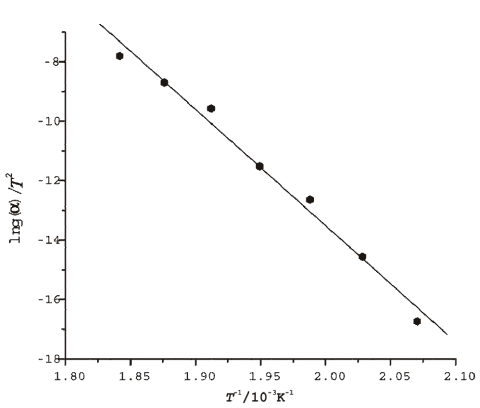

Fig. 8. Coats-Redfern plot for $[ThL_2(NO_3)_4]$.

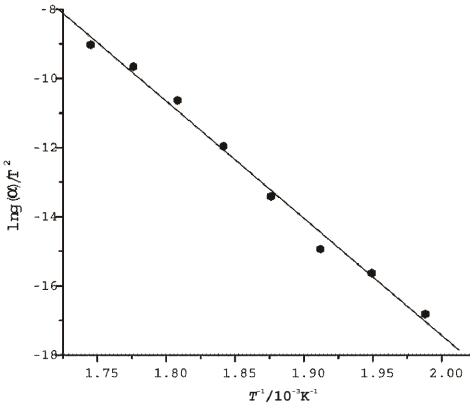

Fig. 9. Coats-Redfern plot for $[ThL_2(C_2O_4)_2]$.

TABLE V. Kinetic parameters for the thermal decomposition of the complexes

Complex	Peak temp. t_s/ °C	Correlation coefficient	Order n	Activation energy E / kJ mol^{-1}	Pre-exponential term A / s^{-1}	Entropy of activation ΔS / J K^{-1} mol^{-1}
$[ThL_2(NO_3)_4]$	247	0.99295	2	325	8.6×10^{31}	362
$[ThL_2(C_2O_4)_2]$	265	0.99566	1.7	282	4.4×10^{25}	241

Antitumour activity

The cell viability over the untreated control was determined using the MTT assay, which is a very convenient method for assessing drug sensitivity even through it does not discriminate between apoptosis and necrosis. The results showed that both the ligand and complex possessed antitumour activity. The results are summarized in Table VI.

The pharmacological properties of the metal complex must primarily be attributed to the thiosemicarbazone ligand since the metal complex shows an activity of the same order of magnitude as that of the ligand. Ribonucleotide reductase, RR, the enzyme that catalyzes the conversion of ribonucleotides to deoxyribonucleotides, is produced as a prerequisite for DNA replication and is highly expressed in tumour cells.[34] A strong positive correlation was established between RR activity and the rate of replication of tumour cells.[35,36] The inhibition of RR prevents the production of deoxyribonucleotides. As a consequence these compounds interfere with DNA synthesis[37] thus decreasing the rate of replication

of tumour cells and inhibiting tumour growth. The antitumour activity seems to be due to an inhibition of DNA synthesis in cancer cells produced by modification in reductive conversion of ribonucleotides to deoxyribonucleotides.[38]

TABLE VI. Antitumour activity of the ligand and complex

Compound	Concentration, μg ml^{-1}	Relative cell viability, %
L	10	88.2
	25	85.5
	50	89.4
	100	83.3
$[ThL_2(NO_3)_4]$	10	85.64
	25	80.6
	50	86.78
	100	82.8

CONCLUSIONS

The coordination sites of the ligand and the coordination number of the metal in the prepared complexes were confirmed by physicochemical studies. Spectral analysis showed that the ligand in the thioketo tatutomer form acts as neutral bidentate with N and S atoms as the coordination sites. All the complexes were neutral, amorphous solids stable at room temperature. From the research findings, the composition of the complexes can be ascertained as $[ThL_2X_4]$ and $[ThL_2Y_2]$, where X represents NO_3^-, NCS^-, CH_3COO^-, $CH_3CHOHCOO^-$ and ClO_4^-, and Y SO_4^{2-} and $C_2O_4^{2-}$. A coordination number of 8 is proposed in all these complexes. Antitumour studies indicated that complexation of the thiosemicarbazone with the metal ion lead to an enhancement of the activity of the thiosemicarbazone.

ИЗВОД

СИНТЕЗА, ТЕРМИЧКА И АНТИТУМОРСКА ПРОУЧАВАЊА Th(IV) КОМПЛЕКСА СА ФУРАН-2-КАРБОКСАЛДЕХИД-4-ФЕНИЛ-3-ТИОСЕМИКАРБАЗОНОМ

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Добијени су и окарактерисани комплекси торијума(IV) са Шифовом базом фуран-2-карбоксалдехид-4-фенил-3-тиосемикарбазоном (L). Састав и структура металних комплекса су предложени на основу елементалне анализе, мерења моларне проводљивости, FT-IR и ^{1}H-NMR спектара. Шифова база се понаша као неутрални бидентатни лиганд координујући се преко азометинског N и тиокето S атома. Из различитих студија комплексима су установљене опште формуле $[ThL_2X_4]$ и $[ThL_2Y_2]$, где X представља NO_3^-, NCS^-, CH_3COO^-, $CH_3CHOHCOO^-$ и ClO_4^-, а Y SO_4^{2-} и $C_2O_4^{2-}$. Проучавано је термичко понашање нитрато и оксалато комплекса, а кинетички и термодинамички параметри су израчунати применом Coats–Redfern-ове једначине. Лиганд и одабрани комплекс $[ThL_2(NO_3)_4]$ су тестирани *in vitro* на антитуморску активноост према ћелијским линијама рака грлића материце (HeLa).

(Примљено 29. јула 2009, ревидирано 2. фебруара 2010)

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