

THE OXIDATIVE-ADDITION REACTIONS OF TRI(META-TOLYL)ANTIMONY AND TRI(ORTHO-TOLYL)ANTIMONY WITH 5-NITROFURFURALDOXIME IN THE PRESENCE OF PEROXIDES. THE MOLECULAR STRUCTURES OF μ_2 -OXO-BIS[(5-NITROFURFURALDOXIMATO)TRI(META-TOLYL)ANTIMONY] AND μ_2 -OXO-BIS[(5-NITROFURFURALDOXIMATO)TRI(ORTHO-TOLYL)ANTIMONY]

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The interaction of tri(meta-tolyl)antimony and tri(ortho-tolyl)antimony with 5-nitrofurfural oxime in the presence of an oxidizing agent (hydrogen peroxide or tert-butyl hydroperoxide) leads to the formation of bis(5-nitrofurfuraldoximato)tri(meta-tolyl)antimony (1), μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(meta-tolyl)antimony] (2), bis(5-nitrofurfuraldoximato)tri(ortho-tolyl)antimony (3) and μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(ortho-tolyl)antimony] (4). The molecular structures of complexes 2 and 4 have been determined by X-ray diffraction analysis.

Keywords: tri(m-tolyl)antimony, tri(o-tolyl)antimony, 5-nitrofurfuraldoxime, tert-butyl hydroperoxide, hydrogen peroxide, oxidation, bis(5-nitrofurfuraldoximato)tri(m-tolyl)antimony, μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(m-tolyl)antimony], μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(o-tolyl)antimony], molecular structures, X-ray diffraction analysis.

Introduction

It is known that some pentavalent antimony derivatives are biologically active compounds. For example, triphenyl- and trimethylantimony dioximates and dicarboxylates were observed to have bactericidal and antitumor activity [1-6]. One of the methods allowing such compounds to be synthesized is the oxidative synthesis. It is interesting to note that two types of triarylantimony dioximates (Ar_3SbX_2 or $(\text{Ar}_3\text{SbX})_2\text{O}$ ($\text{Ar} = \text{Ph}, p\text{-Tol}, o\text{-Tol}$; $\text{X} = \text{ONCHR}, \text{ONCRR}'$) can be obtained, depending on the oxime nature and the reaction conditions [7-10].

Oximes that contain two donor atoms (O and N) are ampolydentate ligands. However, according to X-ray diffraction data, the ligands of such antimony derivatives as $\text{Ar}_3\text{Sb}(\text{ONCRR}')_2$ and $(\text{Ar}_3\text{SbONCRR}')_2\text{O}$ are usually bound to the antimony atom only via the oxygen atom. In this case, short distances between the antimony atom and the nitrogen atoms of iminoxy-groups, which do not lead to the significant distortion of the trigonal-bipyramidal central atom coordination, are observed [11].

Sometimes the oxime ligand coordination method can be dependent on the nature of the aryl radicals at the antimony atom. For example, furfuraldoxime or 2-hydroxybenzaldoxime performs various structural functions in the derivatives of triphenyl- [8] and tri (*o*-tolyl) antimony [10] or triphenyl- and *tris*(5-bromo-2-methoxyphenyl)antimony [9], respectively.

Obviously, the oxidative-addition reactions of triarylantimony with oximes and the structure of the obtained products require further study.

The present work concerns the investigation of the interaction between tri(*m*-tolyl)- or tri(*o*-tolyl)antimony and 5-nitrofurfuraldoxime in the presence of an oxidizing agent (hydrogen peroxide or *t*-butyl hydroperoxide) and the establishment of the product molecular structures.

Experimental

Synthesis of bis(5-nitrofurfuraldoximate)tri(*m*-tolyl)antimony (1).

100 mg of tri(*m*-tolyl)antimony (0.25 mmol) and 79 mg (0.5 mmol) of 5-nitrofurfuraldoxime were dissolved in the mixture of diethyl ether (15 mL) and heptane (15 mL), then 28 mg of 30 % aqueous solution of hydrogen peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. After the solvent evaporation, the light-yellow crystals of **1** were obtained (*m* = 0.132 g (78 %), MP = 78 °C).

IR spectrum, ν , cm^{-1} : 3155, 3138, 3049, 2957, 2922, 2860, 1558, 1520, 1475, 1456, 1377, 1348, 1300, 1244, 1097, 1016, 970, 937, 810, 773, 739, 706, 689, 545, 505, 474, 426.

Synthesis of μ_2 -oxo-bis[(5-nitrofurfuraldoximate)tri(*m*-tolyl)antimony] (2).

a) 100 mg of tri(*m*-tolyl)antimony (0.25 mmol) and 39 mg (0.25 mmol) of 5-nitrofurfuraldoxime were dissolved in the mixture of diethyl ether (25 mL) and heptane (5 mL), then 28 mg of 30 % aqueous solution of hydrogen peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. After the solvent evaporation, the yellow crystals of **2** were obtained (*m* = 0.134 g (96 %), MP = 143 °C).

IR spectrum (ν , cm^{-1}): 3176, 3161, 3049, 2866, 2826, 1570, 1522, 1479, 1381, 1350, 1298, 1246, 1163, 1099, 1018, 966, 914, 860, 810, 775, 739, 689, 552, 484, 426.

b) 100 mg of tri(*m*-tolyl)antimony (0.25 mmol) and 39 mg (0.25 mmol) of 5-nitrofurfuraldoxime were dissolved in the mixture of diethyl ether (15 mL) and heptane (15 mL), then 22 mg of 70 % aqueous solution of *tert*-butyl peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. After the solvent evaporation, the yellow crystals of **2** were obtained (*m* = 0.127 g (91 %), MP = 144 °C).

Synthesis of bis(5-nitrofurfuraldoximate)tri(*o*-tolyl)antimony (3).

a) 100 mg of tri(*o*-tolyl)antimony (0.25 mmol) and 79 mg (0.5 mmol) of 5-nitrofurfuraldoxime were dissolved in diethyl ether (40 mL), then 28 mg of 30 % aqueous solution of hydrogen peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. When the solvent was evaporated, fine-crystalline precipitate was crystallized from benzene with the addition of heptane (5:1 vol.) to give light-yellow crystals of **3** (*m* = 0.139 g (83 %), MP = 154 °C, with destr.).

IR spectrum (ν , cm^{-1}): 1576, 1560, 1526, 1477, 1456, 1375, 1348, 1298, 1242, 1205, 1180, 1159, 1123, 1018, 964, 924, 864, 837, 808, 746, 737, 704, 683, 631, 582, 548, 507, 480, 436, 412.

b) 100 mg of tri(*o*-tolyl)antimony (0.25 mmol) and 79 mg (0.5 mmol) of 5-nitrofurfuraldoxime were dissolved in diethyl ether (40 mL), then 22 mg of 70 % aqueous solution of *tert*-butyl peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. When the solvent was evaporated, fine-crystalline precipitate was crystallized from benzene with the addition of heptane (5:1 vol.) to give light-yellow crystals of **3** (*m* = 0.139 g (83 %), MP = 154 °C, with destr.).

Synthesis of μ_2 -oxo-bis[(5-nitrofurfuraldoximate)tri(*m*-tolyl)antimony] (4).

a) 100 mg of tri(*o*-tolyl)antimony (0.25 mmol) and 39 mg (0.25 mmol) of 5-nitrofurfuraldoxime were dissolved in heptane (40 mL), then 28 mg of 30 % aqueous solution of hydrogen peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. After the solvent evaporation, the colorless crystals of **4** were obtained (*m* = 0.138 g (99 %), MP = 164 °C, with destr.).

IR spectrum (ν , cm^{-1}): 1587, 1570, 1550, 1516, 1473, 1377, 1352, 1304, 1242, 1206, 1178, 1155, 1121, 1031, 1013, 982, 968, 943, 860, 822, 808, 798, 748, 723, 698, 674, 665, 542, 503, 471, 438, 409.

b) 100 mg of tri(*o*-tolyl)antimony (0.25 mmol) and 39 mg (0.25 mmol) of 5-nitrofurfuraldoxime were dissolved in heptane (40 mL), then 22 mg of 70 % aqueous solution of *tert*-butyl peroxide (0.25 mmol) were added. The mixture was kept for 24 hours at 20 °C. After the solvent evaporation, the yellow crystals of **4** were obtained (*m* = 0.138 g (99 %), MP = 164 °C, with destr.).

IR spectra of compounds **1–4** were recorded on a Shimadzu IRAffinity-1S FTIR spectrometer (pellets with KBr; 4000–400 cm^{-1}).

X-ray diffraction analysis of crystalline substances **2, 4** was performed on Bruker D8 QUEST automatic four-circle diffractometer (Mo K_{α} -emission, $\lambda = 0.71073 \text{ \AA}$, graphite monochromator).

Data collection and editing, the refinement of unit cell parameters, and correction for absorption were carried out in *SMART* and *SAINT-Plus* software [10]. All calculations aimed at solving and refining the structures of **2, 4** were performed in *SHELXL/PC* software [11]. The structures of **2, 4** were

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determined using direct methods and refined with LS method in the anisotropic approximation for non-hydrogen atoms. The selected crystallographic data and the structure refinement results are listed in Table 1. Selected bond lengths and bond angles are summarized in Table 2.

The full tables of atomic coordinates, bond lengths, and bond angles were deposited with the Cambridge Crystallographic Data Centre (CCDC 1048763, 1048167, 1048131 for compounds **2** and **4**, respectively; deposit@ccdc.cam.ac.uk; <http://www.ccdc.cam.ac.uk>).

Table 1
Crystallographic data and the experimental and structure refinement parameters for compounds **2**, **4**

Parameter	Value	
	2	4
Empirical formula	C ₅₂ H ₄₈ N ₄ O ₉ Sb ₂	C ₂₆ H ₂₄ N ₂ O _{4.5} Sb
Formula weight	1116.44	558.22
<i>T</i> , K	273.15	273.15
Crystal system	monoclinic	monoclinic
Space group	P2 ₁ /c	C2/c
<i>a</i> , Å	22.472(2)	20.5292(11)
<i>b</i> , Å	13.1397(11)	10.1119(6)
<i>c</i> , Å	21.1657(18)	27.9617(15)
α , deg	90.00	90.00
β , deg	110.646(3)	91.075(2)
γ , deg	90.00	90.00
<i>V</i> , Å ³	5848.3(9)	5803.5(6)
<i>Z</i>	4	8
ρ (<i>calcd.</i>), g/cm ³	1.268	1.278
μ , mm ⁻¹	0.974	0.981
<i>F</i> (000)	2248.0	2248.0
θ Range of data collection, deg	6.5–38.12°	7–49.5°
Range of refraction indices	–20 ≤ <i>h</i> ≤ 20, –12 ≤ <i>k</i> ≤ 12, –19 ≤ <i>l</i> ≤ 19	–24 ≤ <i>h</i> ≤ 19, –11 ≤ <i>k</i> ≤ 11, –32 ≤ <i>l</i> ≤ 31
Measured reflections	32451	9023
Independent reflections	4701	4648
<i>R</i> _{int}	0.0476	0.0428
Refinement variables	610	307
<i>GOOF</i>	1.117	1.078
<i>R</i> factors for $F^2 > 2\sigma(F^2)$	<i>R</i> ₁ = 0.0738, <i>wR</i> ₂ = 0.2106	<i>R</i> ₁ = 0.0792, <i>wR</i> ₂ = 0.2043
<i>R</i> factors for all reflections	<i>R</i> ₁ = 0.0906, <i>wR</i> ₂ = 0.2430	<i>R</i> ₁ = 0.1291, <i>wR</i> ₂ = 0.2323
Residual electron density (min/max), e/Å ³	1.54/–0.41	1.05/–0.47

Table 2
Selected bond lengths and bond angles in the structures of compounds **2**, **4**

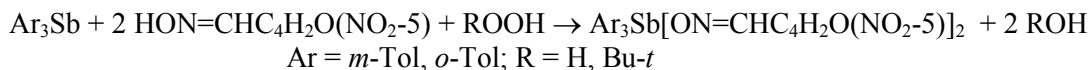
Bond	<i>d</i> , Å	Angle	ω , deg
2			
Sb(1)–C(1)	2.156(17)	O(1)Sb(1)O(2)	176.5(4)
Sb(1)–C(11)	2.107(19)	C(11)Sb(1)C(1)	121.5(7)
Sb(1)–C(21)	2.051(16)	C(21)Sb(1)C(11)	118.3(7)
Sb(1)–O(1)	1.971(9)	C(1)Sb(1)C(21)	119.1(7)
Sb(1)–O(2)	2.130(10)	N(1)O(2)Sb(1)	107.1(9)
O(2)–N(1)	1.409(17)	O(2)N(1)C(35)	108.2(13)
O(6)–N(3)	1.332(17)	Sb(1)O(1)Sb(2)	146.0(5)
N(1)–C(35)	1.267(19)	N(3)O(6)Sb(2)	116.3(8)
N(3)–C(75)	1.206(17)	O(6)N(3)C(75)	113.9(12)

Table 2 (end)

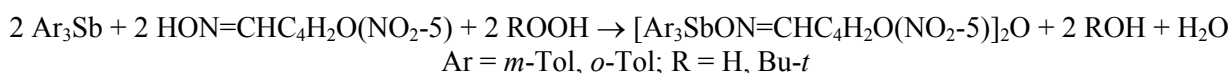
Bond	<i>d</i> , Å	Angle	ω, deg
Sb(2)–C(41)	2.119(15)	C(61)Sb(2)C(51)	120.9(6)
Sb(2)–C(51)	2.088(13)	C(51)Sb(2)C(41)	121.0(5)
Sb(2)–C(61)	2.092(14)	C(41)Sb(2)C(61)	116.9(6)
Sb(2)–O(1)	1.975(8)	O(1)Sb(1)C(11)	92.8(7)
Sb(2)–O(6)	2.127(9)	O(1)Sb(1)C(21)	94.8(5)
Sb(1)–N(1)	2.88(2)	O(1)Sb(2)C(61)	96.6(4)
Sb(2)–N(3)	2.97(1)	O(1)Sb(2)C(41)	91.0(5)
4			
Sb(1)–C(1)	2.097(10)	O(1)Sb(1)O(2)	173.6(2)
Sb(1)–C(11)	2.116(16)	C(11)Sb(1)C(1)	123.3(5)
Sb(1)–C(21)	2.107(17)	C(21)Sb(1)C(1)	122.1(6)
Sb(1)–O(1)	1.960(8)	C(11)Sb(1)C(21)	114.0(6)
Sb(1)–O(2)	2.193(8)	N(1)O(2)Sb(1)	111.3(6)
O(2)–N(1)	1.335(11)	O(4)N(2)C(34)	116.9(14)
O(5)–N(2)	1.187(14)	Sb(1)O(1)Sb(2)	180.00(3)
N(1)–C(35)	1.302(13)	O(5)N(2)C(34)	119.7(13)
N(2)–C(34)	1.395(16)	O(1)Sb(1)C(11)	95.1(3)
Sb(1)–N(1)	2.95(1)	O(1)Sb(1)C(21)	91.4(4)

Results and Discussion

We have studied the reactions of tri(*m*-tolyl) - and tri(*o*-tolyl)antimony with 5-nitrofurfuraloxime at various molar ratios in the presence of an oxidizing agent. It has been found that at molar ratio 1:2 of triarylantimony and 5-nitrofurfuraldoxime the product of the reactions, regardless of the nature of the oxidant, is *bis*(5-nitrofurfuraloximato)triarylantimony: *m*-Tol₃Sb[ON=CHC₄H₂O(NO₂-5)]₂ (**1**) or *o*-Tol₃Sb[ON=CHC₄H₂O(NO₂-5)]₂ (**3**):



At the equimolar ratio of the reagents, in the presence of both hydrogen peroxide and *tert*-butyl hydroperoxide, μ_2 -oxo-bis[(5-nitrofurfuraldoxymato) tri(*m*-tolyl)antimony][*m*-Tol₃SbON=CHC₄H₂O(NO₂-5)]₂O (**2**) or μ_2 -oxo-bis[(5-nitrofurfuraldoxymato)tri(*o*-tolyl) antimony] [*o*-Tol₃SbON=CHC₄H₂O(NO₂-5)]₂O (**4**) is formed:



Compounds **1–4** are crystalline substances, which are resistant to the effect of moisture and air oxygen and freely soluble in aromatic and aliphatic hydrocarbons.

The synthesized triarylantimony dioximates have been identified by infrared spectroscopy and X-ray diffraction analysis.

In the IR-spectrum of compounds **1–4** there are intensive absorption bands, which characterize nitro group vibrations. Thus, the absorption band due to NO₂-group asymmetric vibrations is at 1520, 1522, 1526 и 1516 cm⁻¹, while the band, corresponding to NO₂-group symmetric vibrations appears at 1348, 1350, 1348 и 1352 cm⁻¹ in the spectra of **1–4**, respectively. The C–NO₂ vibrations are characterized by the bands at 810, 810, 808 и 808 cm⁻¹. In addition, there are bands at 426, 426, 436 и 438 cm⁻¹, which have been attributed to the Sb–C(Ar) vibration of the C₃-symmetric [12] SbC₃ fragment. The characteristic bands at 1558–1587 cm⁻¹ (C=N bonds), 964–970 cm⁻¹ (N–O bonds) have also been found.

According to the X-ray diffraction analysis data, the antimony atoms in the molecules of compounds **2** and **4** have distorted trigonal-bipyramidal coordination with oxygen atoms in axial positions (Fig. 1–2). Molecule **4** is centrosymmetric. In binuclear molecules **2**, **4** the Sb (1) and Sb (2) atoms are connected by the bridging oxygen atom, Sb(1)O(1)Sb(2) bond angles are equal to 146.0(3)° и 180.0(0)°, respectively. The oximate ligands in molecules **2**, **4** are monodentate as in the case of μ_2 -oxo-bis[(furfuraloxymat)tri(*o*-tolyl) antimony] [10].

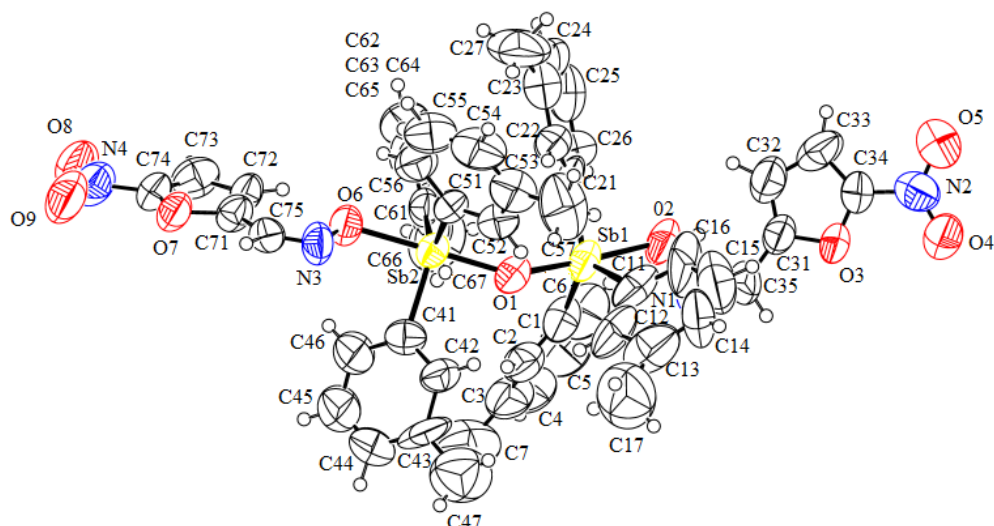


Fig. 1. The structure of compound 2

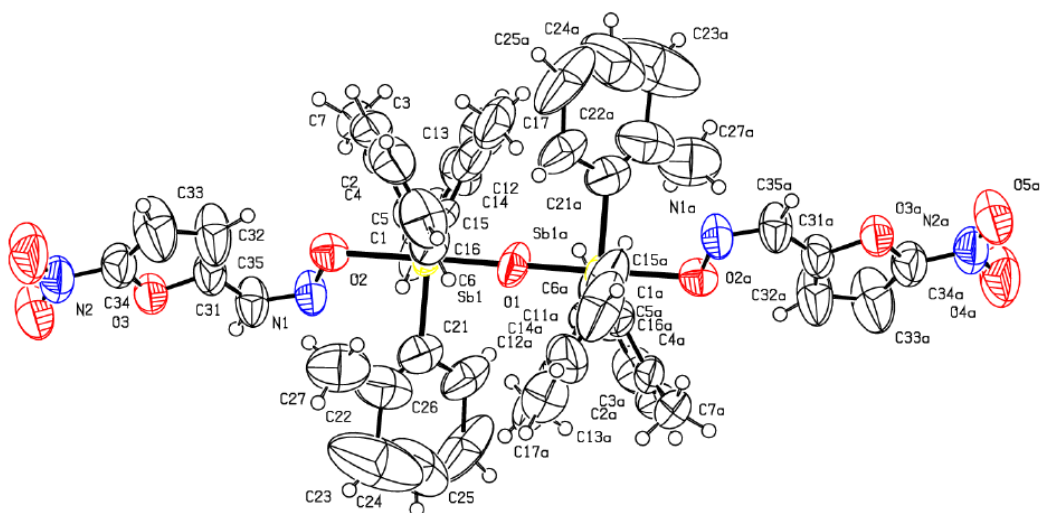


Fig. 2. The structure of compound 4

The sums of CSbC bond angles are equal to $358.9(7)^\circ$, $358.8(6)^\circ$ (**2**), $359.4(6)^\circ$ (**4**), at that the values of the individual angles differ from the theoretical angle not more than by 6° . The Sb atoms are shifted from the correlated planes $[C_3]$ at 0.002 \AA (**1**), 0.091 , 0.098 \AA (**2**), 0.052 \AA (**3**). The axial OSbO angles are equal to $176.5(4)^\circ$, $176.1(3)^\circ$ (**2**), $173.6(2)^\circ$ (**4**). The OSbC angles vary within the ranges $92.8(7)^\circ$ – $94.8(5)^\circ$, $91.0(5)^\circ$ – $96.6(4)^\circ$ (**2**), $91.4(4)^\circ$ – $95.1(3)^\circ$ (**4**).

The lengths of Sb–C bonds lie within the ranges of $2.051(16)$ – $2.156(17) \text{ \AA}$, $2.088(13)$ – $2.119(15) \text{ \AA}$ (**2**), $2.097(10)$ – $2.116(16) \text{ \AA}$ (**4**). The Sb–O bridging bond lengths in **2** ($1.971(9)$, $1.975(8) \text{ \AA}$) are longer in comparison with the same characteristic in **4** ($1.960(8) \text{ \AA}$), which correlates with the previously discovered pattern for the molecules with the similar structure: the closer the angle SbOSb is to linear, the shorter the Sb–O bond is [11]. The lengths of the Sb–O terminal bonds are $2.130(10)$, $2.127(9) \text{ \AA}$ (**2**), and $2.195(8) \text{ \AA}$ (**4**). It should be noted that the values of angles for the antimony atom in molecule **4** are approximately equal to the corresponding values in the fragment of the molecule of μ_2 -oxo-bis[(furfuraloxime)tri(*o*-tolyl)antimony], where the Sb–O–Sb fragment is linear, but the internuclear distances Sb–C and Sb–O in these molecules are different. Thus, the bonds Sb–O ($1.9706(3)$, $2.112(6) \text{ \AA}$ [10]) in the latter compound are shorter than in **4**, which can be explained by the presence of the nitro group in the furan ring of its oximate ligand.

In molecules **2**, **4** the Sb \cdots N distances between the Sb atom and N atoms of iminoxy groups [$2.88(8)$, $2.97(1) \text{ \AA}$ (**2**), $2.95(1) \text{ \AA}$ (**4**)] are considerably less than the sum of Van der Waals radiuses of

the Sb and N atoms (3.8 Å [15]). Obviously, there is no correlation between the Sb–O bond lengths and strength of Sb···N contacts. Thus, in the molecule of μ_2 -oxo-bis[(furfuraloximato)tri(*o*-tolyl)antimony], the distance Sb···N (2.951(1) Å [10]) coincides with the comparable distance in **4**. The decrease of the Sb···N distances does not result in the expected N–O bond lengthening [1.409(17), 1.332(17) Å (**2**), 1.335(11) Å (**4**)].

The structure organization of crystals **2**, **4** is due to weak intermolecular O···H hydrogen bonds between the oxygen atoms of nitro groups and the hydrogen atoms of methyl groups or aromatic rings, as well as due to C–H··· π interactions.

Conclusions

The structure of the products of the reactions of tri(*m*-tolyl)- and tri(*o*-tolyl) antimony with 5-nitrofurfuraldoxime depends on the molar ratio of the reactants. Regardless of the nature of the oxidant, the reaction of triarylantimony with 5-nitrofurfuraldoxime at molar ratio 1:2 leads to the formation of tritolylantimony dioximates. At the stoichiometric ratio of the reagents the antimony-organic product with the bridging oxygen atom is formed.

The structure of molecules is determined by the aryl radical nature, thus, the μ_2 -oxo-bis[(5-nitrofurfuraldoxymato)tri(*m*-tolyl)antimony molecule] has the angular structure of the central fragment, and the μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(*o*-tolyl) antimony] molecule is centrosymmetric and has a linear structure. The oxime ligands are monodentate in both cases; they are bound to the antimony atom via the oxygen atom.

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ОСОБЕННОСТИ ВЗАИМОДЕЙСТВИЯ ТРИ(МЕТА-ТОЛИЛ)СУРЬМЫ И ТРИ(ОРТО-ТОЛИЛ)СУРЬМЫ С 5-НИТРОФУРФУРАЛЬДОКСИМОМ. МОЛЕКУЛЯРНЫЕ СТРУКТУРЫ μ_2 -ОКСО-БИС[(5-НИТРОФУРФУРАЛЬДОКСИМАТО)ТРИ(МЕТА-ТОЛИЛ)СУРЬМЫ] И μ_2 -ОКСО-БИС[(5-НИТРОФУРФУРАЛЬДОКСИМАТО)ТРИ(ОРТО-ТОЛИЛ)СУРЬМЫ]

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Взаимодействием три(мета-толил)сурьмы и три(орто-толил)сурьмы с 5-нитрофурфуральдоксимом в присутствии окислителя (пероксида водорода или третбутилгидропероксида) синтезированы бис(5-нитрофурфуральдоксимато)три(мета-толил)сурьма (1), μ_2 -оксо-бис[(5-нитрофурфуральдоксимато)три(мета-толил)сурьма] (2), бис(5-нитрофурфуральдоксимато)три(орто-толил)сурьма (3) и бис(5-нитрофурфуральдоксимато)три(орто-толил)сурьма (4). Соединения 2, 4 охарактеризованы методом рентгеноструктурного анализа.

Ключевые слова: три(м-толил)сурьма, три(о-толил)сурьма, 5-нитрофурфуральдоксим, третбутилгидропероксид, пероксид водорода, окисление, бис(5-нитрофурфуральдоксимато)три(м-толил)сурьма, μ_2 -оксо-бис[(5-нитрофурфуральдоксимато)три(м-толил)сурьма], бис(5-нитрофурфуральдоксимато)три(о-толил)сурьма, μ_2 -оксо-бис[(5-нитрофурфуральдоксимато)три(о-толил)сурьма], молекулярные структуры, рентгеноструктурный анализ.

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ОБРАЗЕЦ ЦИТИРОВАНИЯ

The oxidative-addition reactions of tri(*meta*-tolyl)antimony and tri(*ortho*-tolyl)antimony with 5-nitrofurfuraldoxime in the presence of peroxides. The molecular structures of μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(*meta*-tolyl)antimony] and μ_2 -oxo-bis[(5-nitrofurfuraldoximato)tri(*ortho*-tolyl)antimony] / E.V. Artemeva, M.S. Makerova, V.V. Sharutin, O.K. Sharutina // Вестник ЮУрГУ. Серия «Химия». – 2017. – Т. 9, № 2. – С. 50–57. DOI: 10.14529/chem170207

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