Synthesis of 4,4′-bis(dichloroamino)- and 4,4′-bis(chloroamino)-3,3′-azofurazans, the first representatives of dichloroamino- and chloroaminofurazans

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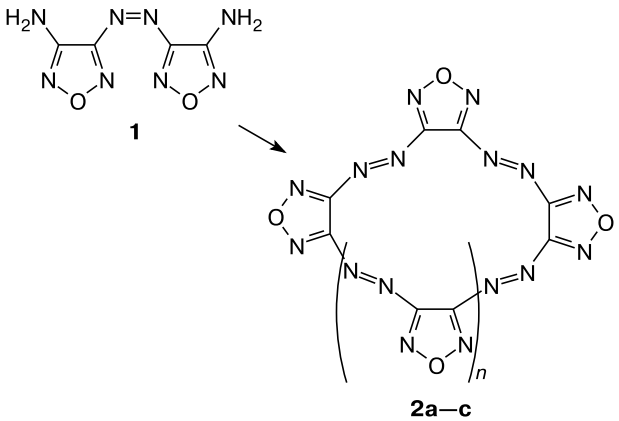
First representatives of dichloroamino- and chloroaminofurazans, *viz.*, 4,4′-bis(dichloroamino)- and 4,4′-bis(chloroamino)-3,3′-azofurazans, were synthesized by the chlorination of 4,4′-diamino-3,3′-azofurazan with sodium hypochlorite in the CH_2Cl_2—H_2O mixture.

Key words: 4,4′-bis(dichloroamino)-3,3′-azofurazan, 4,4′-bis(chloroamino)-3,3′-azofurazan, 4,4′-diamino-3,3′-azofurazan, 4,4′-dinitro-3,3′-azofurazan, NaOCl, AcOCl, oxidation.

Over the years, the scientific interest of our research group is focused on the development of methods for the synthesis and studies of reactivity of 1,2,5-oxadiazole derivatives, *viz.*, furazans and furoxans. These substances are of interest as potential high-energy and biologically active compounds.[1—6] In particular, earlier[7—9] we have shown that 4,4′-diamino-3,3′-azofurazan **1** treated with hypohalites (NaOBr, NaOCl, AcOBr, AcOCl), dibromoisocyanurate (DBI) and mixtures of $Pb(OAc)_4$ with Bu_4NBr, Br_2, or NaBr form macrocyclic compounds **2a**—**c**. In this case, compound **2a** containing 4 azofurazan units was the major isomer, whereas isomers **2b**,**c** with 6 and 8 azofurazan units were formed in the insignificant amounts (Scheme 1). The reactions of **1** with hypohalites were carried out in an organic solvent—water mixture (MeCN—H_2O or AcOEt—H_2O), whereas the reaction with DBI and with the mixtures based on $Pb(OAc)_4$, in organic solvents (CH_2Cl_2, MeCN, or AcOEt).

Scheme 1



2: n = 1 (**a**); 3 (**b**); 5 (**c**)

Reagents and conditions: NaOCl, MeCN—H_2O or AcOEt—H_2O, 5—10 °C.

The present work is devoted to the studies of the reaction of 4,4′-diamino-3,3′-azofurazan **1** with hypohalites (NaOCl, AcOCl) in the two-phase system CH_2Cl_2—H_2O (1 : 1 v/v). The reaction was initially carried out with NaOCl. It turned out that the use of a 40-fold molar excess of NaOCl per 1 mol of diaminoazofurazan **1** and the reaction temperature of 5—10 °C (similarly to the known[7] method for the synthesis of macrocycles **2**) led to a dramatic change in the reactivity of compound **1**. The earlier unknown 4,4′-bis(dichloroamino)-3,3′-azofurazan **3**, the product of the exhaustive chlorination of both NH_2 groups in the starting compound **1**, was unexpectedly isolated as the reaction product (Scheme 2). Under this conditions, compound **3** was formed in almost quantitative yield within 30 min. Its structure was established based on elemental analysis data, ^{13}C NMR spectroscopy and mass spectrometry. The TLC showed that neither products of oxidative cyclocondensation of **2a**—**c**, nor any other products were formed under these conditions even in the minor amounts.

When the reaction time with NaOCl in a CH_2Cl_2—H_2O mixture was increased from 30 min to 24 h, another compound, rather than bis(dichloroamino) derivative **3**, was formed containing only two chlorine atoms according to the elemental analysis and mass spectrometry data. Based on this data and the ^1H NMR spectrum (a singlet with the chemical shift at δ 8.77), the structure of 4,4′-bis(chloroamino)-3,3′-azofurazan (**4**) was assigned to the compound obtained. A ^{13}C NMR spectrum of the isolated product could provide an additional evidence of the structure of this compound, however, during recording the spectrum in acetone-d_6, compound **4** transformed into an un-

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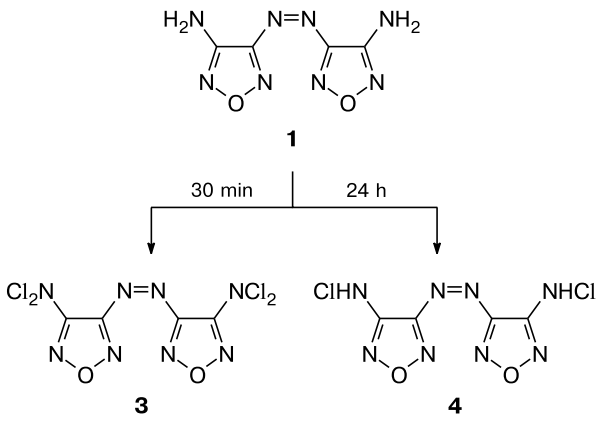
Scheme 2



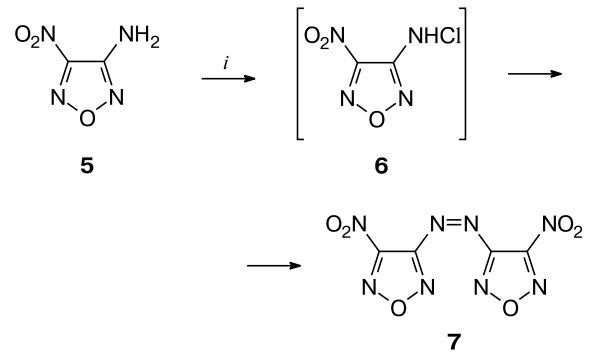
Reagents and conditions: *i*. NaOCl, CH_2Cl_2—H_2O (1 : 1), 5—10 °C, *ii*. 30 min, *iii*. 24 h.

identified orange crystalline product, which sublimed at 175 °C. The TLC showed that compound **3** was also formed when AcOCl was used under the same conditions. However, in this case, besides compound **3**, macrocycle **2a** and, apparently, macrocycles with higher molecular weights, were formed. Therefore, we did not use AcOCl as the reagent in our further studies.

Compounds **3** and **4** are, respectively, orange and bright yellow crystalline substances with m.p. 85—86 °C and 167—169 °C, they are well soluble in most organic solvents and insoluble in water. These compound are fairly stable in the crystalline state, whereas their solutions in CH_2Cl_2, AcOEt, and MeCN are unstable. Lability of compounds **3** and **4** depends on the nature of the solvent, time of their contact with the solvent and drying agent ($MgSO_4$). When tetrachloride **3** was allowed to stand in CH_2Cl_2 over the drying agent during several days, it converted to diaminoazofurazan **1** practically quantitatively. Practically pure cyclic tetramer **2a** was formed from tetrachloride **3** in the solution in MeCN. In other solvents (according to the TLC), complex mixtures of different compositions were formed containing, besides other components, amine **1** and macrocycle **2a**.

The behavior of 3-amino-4-nitrofurazan (**5**) containing one amino group was also studied under conditions selected for the preparation of tetrachloride **3**. Monitoring of the reaction by chromatography showed the formation of a compound with R_f 0.28 (C_6H_6), which possibly was *N*-chloro derivative **6**. However, attempted isolation and characterization of this compound failed because of its rapid conversion to 4,4′-dinitro-3,3′-azofurazan (**7**), which was isolated in 62% yield (Scheme 3). It is interesting that the preparation of compound **7** by this reaction is the first example of its synthesis by the oxidation of 3-amino-4-nitrofurazan **5** by chlorination agents. Earlier, azofurazan **7** was obtained by the oxidation of 3-amino-4-nitrofurazan **5** only with potassium permanganate.[10,11]

Scheme 3



Reagents and conditions: *i*. NaOCl, CH_2Cl_2—H_2O (1 : 1), 5—10 °C.

In conclusion, the studies conducted in this work resulted in the first synthesis of mono- and dichloroamines of the furazan series and in the first time oxidation of 3-amino-4-nitrofurazan **5** to 4,4′-dinitro-3,3′-azofurazan **7** by the chlorinating agents.

Experimental

IR spectra were recorded on a Specord M-80 spectrometer in KBr pellets. NMR spectra were recorded on Bruker WM-250 (^{1}H, 250 MHz) and Bruker AM-300 (^{13}C, 75.5 MHz) spectrometers, chemical shifts are given in δ scale relative to the internal standard Me_4Si. Mass spectra were recorded on a Varian MAT CH-6 instrument. Thin-layer chromatography was carried out on Silufol UV-254 plates with visualizing under a UV lamp. Melting points were determined on a Boetius heating stage. 4,4′-Diamino-3,3′-azofurazans **1**,[12] **2a**[7], 4-amino-3-nitrofurazan **5**,[13] and 4,4′-dinitro-3,3′-azofurazan **7**[10,11] were obtained according to the known procedures.

4,4′-Bis(dichloroamino)-3,3′-azofurazan (3). Chlorine was passed through a solution of NaOH (17.5 g, 0.42 mol) in water (135 mL) at 5—10 °C until pH 7, followed by the addition of 4,4′-diamino-3,3′-azofurazan **1** (0.5 g, 2.5 mmol) and CH_2Cl_2 (150 mL) with stirring, then the cooling bath was removed. After 30 min, the organic layer was separated, washed with water (2×10 mL), dried with $MgSO_4$ for 20 min, and the solvent was evaporated *in vacuo* to obtain compound **3** (0.76 g, 97%) as an orange powder, m.p. 85—86 °C, R_f 0.63 (C_6H_6—AcOEt, 5 : 1). ^{13}C NMR (acetone-d_6), δ: 155.08 ($CNCl_2$), 158.99 (CN_2). IR, ν/cm^{-1}: 1585, 1550, 1450, 1390, 1350, 1240, 1040, 930, 880, 820, 745. MS, *m*/*z* (I_{rel} (%)): 338 [M(3 Cl^{37} + Cl^{35})]$^+$, (12), 336 [M(2 Cl^{37} + 2 Cl^{35})]$^+$ (49), 334 [M(Cl^{37} + 3 Cl^{35})]$^+$ (100), 332 [M(4 Cl^{35})]$^+$ (76). Found (%): C, 14.82; N, 42.27; Cl, 33.06. $C_4N_8Cl_4O_2$. Calculated (%): C, 14.37; N, 42.51; Cl, 33.53.

Precautions should be made while determining elemental composition of compound 3, since this compound can explode on heating. Dichloroamines are known[14] to explode on rapid heating.

4,4´-Bis(chloroamino)-3,3´-azofurazan (4) was obtained similarly to azofurazan **3** from 4,4´-diamino-3,3´-azofurazan (**1**) (0.1 g, 0.5 mmol) and NaOCl, the reaction time 24 h. The organic layer was separated, dried with $MgSO_4$ for 40 h, the solvent was evaporated *in vacuo*. The residue was diluted with CH_2Cl_2 (3 mL), a precipitate formed was filtered off to obtain compound **5** (0.14 g, 52%) as a bright yellow powder, m.p. 167—169 °C, R_f 0.79 (C_6H_6—AcOEt, 5 : 1). ^{1}H NMR (acetone-d_6), δ: 8.77 (s). IR, ν/cm^{-1}: 3280 (NH), 3180 (NH), 1600, 1500, 1435, 1350, 1245, 1040, 940, 800. MS, m/z (I_{rel} (%)): 266 [M(Cl^{37} + Cl^{35})]$^+$ (65), 264 [M(2 Cl^{35})]$^+$ (100). Found (%): C, 18.43; H, 0.90; Cl, 27.04; N, 41.97. $C_4H_2Cl_2N_8O_2$. Calculated (%): C, 18.11; H, 0.75; Cl, 26.79; N, 42.26.

Orange crystals were formed in the NMR tube while recording ^{13}C NMR spectrum of compound **4**, subl.p. 175 °C. IR, ν/cm^{-1}: 3460, 3410, 3340, 2600, 2470, 2440, 1615, 1410, 1180, 1040, 965, 770.

Transformation of 4,4´-bis(dichloroamino)-3,3´-azofurazan (3) to 4,4´-diamino-3,3´-azofurazan (1). Calcined $MgSO_4$ (2 g) was added to a solution of tetrachloride **3** (0.67 g, 2 mmol) in CH_2Cl_2 (10 mL), and the reaction mixture was stirred for 3 days at room temperature until compound **3** disappeared (TLC monitoring, R_f 0.63 (C_6H_6—AcOEt, 5 : 1)). A precipitate was filtered off, washed with CH_2Cl_2 (3 mL), the solvent was evaporated to dryness to obtain diaminoazofurazan **1** (0.38 g, 97%), m.p. 324—326 °C (*cf.* Ref. 12: 325 °C). The spectroscopic characteristics of compound **1** corresponded to the literature data.[12]

Synthesis of 4,4´-dinitro-3,3´-azofurazan (7) by the reaction of 3-amino-4-nitrofurazan (5) with NaOCl in the CH_2Cl_2—H_2O mixture. Chlorine was passed through a solution of NaOH (4.4 g, 0.11 mol) in water (35 mL) at 5—10 °C to pH 7, followed by the addition of 3-amino-4-nitrofurazan **5** (0.16 g, 1.25 mmol) and CH_2Cl_2 (40 mL) with stirring, the cooling bath was removed. After 30 min, the organic layer was separated, washed with water (2×10 mL), dried with $MgSO_4$ for 20 min, the solvent was evaporated *in vacuo*. The residue was recrystallized from CH_2Cl_2—C_5H_{12} (1 : 1) to obtain compound **7** (77 mg, 62%) as an orange powder, m.p. 53—54 °C (*cf.* Ref. 13: 51—53 °C). The spectroscopic characteristics of compound **7** corresponded to the literature data.[13]

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