Russian Chemical Bulletin, International Edition, Vol. 54, No. 7, pp. 1715—1719, July, 2005

Reactions of 3-amino-4-methylfurazan with nitrating agents

A. B. Sheremetev★ and N. S. Aleksandrova

N. D. Zelinsky Institute of Organic Chemistry, Russian Academy of Sciences,
47 Leninsky prosp., 119991 Moscow, Russian Federation.
Fax: +7 (095) 135 5328. E-mail: sab@ioc.ac.ru

Depending on the type of nitrating agent and the reaction temperature, nitration of 3-amino-4-methylfurazan **1** gives either nitramine or the products of formal oxidation of the amino group, namely, nitroso-, nitro-, azo-, and azoxyfurazans. The methyl group of compound **1** is resistant against all the nitrating agents studied.

Key words: aminofurazans, nitramines, nitraminofurazans, nitrofurazans, nitration.

Nitraminofurazans are of interest as potential explosives and components of rocket propellants and gas generating mixtures. The chemistry of these compounds has been surveyed in reviews.[1—3]

The nitration of secondary aminofurazans with, for example, $HNO_3/(CF_3CO)_2O$,[4,5] HNO_3/Ac_2O,[5—10] or N_2O_5 (see Refs 5, 7) is known to yield nitramines. The type and the amount of by-products have not been analyzed. It was only reported that the use of traditional HNO_3/H_2SO_4 mixtures is accompanied by side nitrolysis of the N—CH bond, resulting in the formation of primary nitraminofurazans.[10]

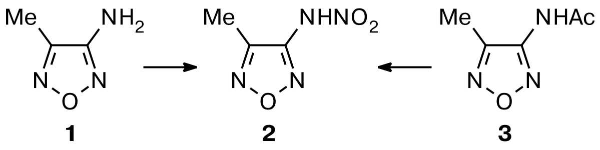
The information on nitration of primary aminofurazans is limited. Nitramines can be obtained by reactions with N_2O_5,[11] HNO_3 (see Refs 5, 12—15), or $NaNO_3/H_2SO_4$ (see Ref. 10), HNO_3/H_2SO_4 (see Refs 5, 13), and $HNO_3/AcOH$ (see Ref. 16) mixtures. Treatment of aminofurazans with excess N_2O_5 (see Refs 12, 17) or NO_2BF_4 (see Refs 17, 18) affords nitro derivatives of furazan; however, this process also goes through nitramine formation.

To continue the research into the reaction of furazan derivatives with nitrating reagents, we studied the nitration of 3-amino-4-methylfurazan **1**[19] as the simplest and the most readily available model compound.

The furazan ring exerts a strong electron-withdrawing effect on the groups it bears.[2] As a consequence, aminofurazans are very weak bases.[20] This fact allows one to carry out nitration for amines rather than for derivatives with protected amino groups (the technique normally used for nitrating other primary amines[21]).

We showed that the outcome of the reaction of compound **1** with 100% nitric acid depends on the content of nitrogen oxides in the acid. The acid containing no nitrogen oxides smoothly transforms compound **1** into nitramine **2** (Scheme 1). The reaction is carried out either in the acid or in its mixtures with organochlorine solvents. The change in the reaction temperature from –20 to 30 °C barely affects the product yield, which amounts to 65—80%. The reaction of compound **1** with nitrating mixtures such as HNO_3/H_2SO_4, $HNO_3/H_2SO_4/SO_3$, HNO_3/Ac_2O, and KNO_3/H_2SO_4 devoid of nitrogen oxides proceeds in a similar way to give nitramine **2** in 75—85% yield. The use of *N*-acetylated derivative **3** as the starting compound for nitration gives nitramine **2** in the same yield.

Scheme 1

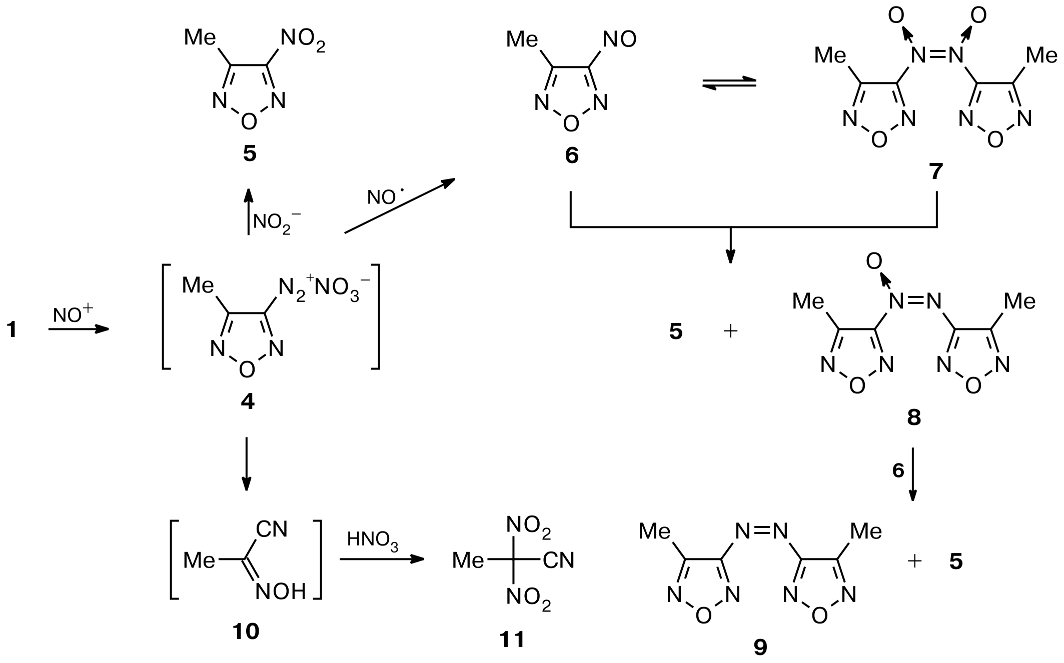


The reaction of amine **1** with concentrated HNO_3 containing even a small amount of nitrogen oxides (N_2O_3 and N_2O_4) is accompanied by the formation of substantial amounts of side products. Detailed analysis of the reaction mixtures (^1H and ^{14}N NMR, TLC, GLC, GC/MS; comparison with authentic samples) has shown that nitro-, nitroso-, azo-, and azoxyfurazans and α,α-dinitroacetonitrile are the main impurities. The by-products are apparently formed due to the diazotization and further transformations of the intermediate diazonium salt (Scheme 2). The possibility of preparing nitrofurazan **5** by diazotization of compound **2** has been reported.[22] Nitrogen oxides present in the reaction mixture serve as the source of nitrite ions required to perform this transformation.

Nitroso compound **6** might be formed with participation of the $NO^{\bullet}$ radical or through substitutive nitrosation with preliminary electron redistribution between diazonium salt **4** and species present in the reaction mixture.

Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 7, pp. 1665—1669, July, 2005.

Scheme 2



Nitroso compound **6** dimerizes to give diazene dioxide **7**.[23] Pure compound **6** [23] in a CH_2Cl_2 solution or without a solvent undergoes disproportionation typical of nitroso compounds,[24] resulting in the formation of compounds **5**, **8**, and **9**. The diazotization of compound **1**, like that of other aminofurazans,[2] is accompanied by opening of the furazan ring to give α-cyanoxime **10** (see Ref. 22, 25). According to the typical cyanoxime reactivity,[26] compound **10** is nitrated under the reaction conditions being converted into dinitro derivative **11** (see Ref. 27).

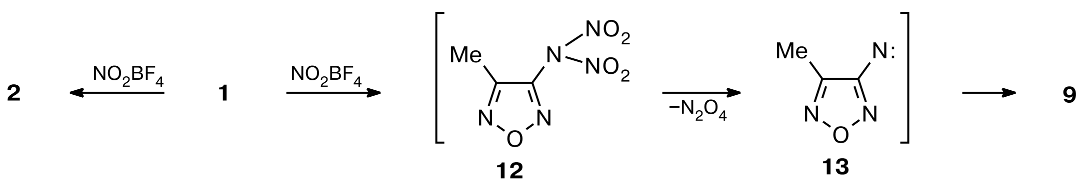
The number and the yield of by-products depend on the amount of nitrogen oxides and the reaction temperature. After the nitration of amine **1** with anhydrous nitric acid containing ~10% N_2O_4, no nitramine **2** was isolated. When the nitrogen oxide content was ~2%, the yield of nitramine **2** was 40—45%. The nitration carried out at −5—0 °C resulted in the formation of nitroso compound **6** and its dimer **7**.

Yet another reagent widely used[28] for nitration is N_2O_5. The reaction of N_2O_5 with primary aminofurazans may yield different products.[11,12,17] We studied the nitration of compound **1** with the HNO_3/N_2O_5 mixture and $HNO_3/(CF_3CO)_2O$ and HNO_3/P_2O_5 mixtures in which N_2O_5 is formed *in situ*. Unlike N_2O_4, the presence of up to ~5% N_2O_5 in a reaction mixture containing excess nitrating reagent increases the yield of nitramine **2** (to 96%). However, further increase in the concentration of N_2O_5 gives rise to side formation of nitro- (**5**) and azoxyfurazans (**8**). For mixtures in which more than 80% of nitric acid has been converted into N_2O_5 (on treatment with trifluoroacetic anhydride or P_2O_5), these are the major reaction products at a 10-fold molar excess of the nitrating mixture. When an equimolar amount of this mixture is used, the desired nitramine **2** can be obtained in a yield of 75—80%.

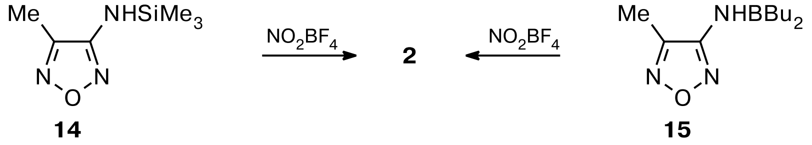
Nitronium salts are usually potent reagents for *N*-nitration of amines.[29] However, the yield of nitramine formed upon nitration of both amine **1** and its *N*-acetyl derivative with nitronium tetrafluoroborate in MeCN or CH_2Cl_2 at 0—5°C is not more than 65%. Azofurazan **9** is formed as the major by-product (up to 30% at elevated temperatures). Note that the formation of azo compounds has been detected previously[30] upon treatment of 5-amino-1,2,4-triazole with NO_2BF_4. Since no nitrosofurazan **6**, its dimer **7**, or azoxy derivative **8** has been found upon the reaction of amine **1** with NO_2BF_4, it is reasonable to assume that azo compound **9** is formed by a route differing from that shown in Scheme 2. Probably, *N,N*-dinitration[29] of the amino group takes place as a side process (Scheme 3), and labile compound **12** decomposes, similarly to *N,N*-dibromoamines, to generate nitrene **13**, which dimerizes into azo compound **9**. However, nitrene **13** could arise upon the oxidation of nitramine **2**, as takes place in the electrolysis of nitraminofurazans.[14]

As an attempt to improve the outcome of nitration with NO_2BF_4, we carried out preliminary silylation of the amino group in compound **1** by the procedure we developed previously.[31] The nitration of the silyl derivative **14**

Scheme 3



Scheme 4



in CH_2Cl_2 at −30 °C furnished nitramine **2** in 89—93% yield (Scheme 4).

Previously,[32,33] it was found that borylation of the amino group bonded to the furazan ring increases its reactivity. We were the first to demonstrate that the reaction of borylated amine with nitronium tetrafluoroborate is accompanied by cleavage of the N—B bond to give nitramine. For example, nitramine **2** was obtained in 85% yield on treatment of derivative **15** with NO_2BF_4 at −30 °C.

It is noteworthy that nitration of alkylaromatic compounds is often accompanied by oxidative transformations of the alkyl groups and substitution of a nitro group for their α-hydrogen atoms. The methyl group attached to the furazan ring is stable against nitrating agents; in none of the experiments, were products resulting from nitration or oxidation of this group detected. Only recently,[34] were the conditions found for involving the methyl group in the reaction.

Thus, it was shown that a number of reagents and procedures are suitable for *N*-nitration of the amino group attached to the furazan ring. The presence of nitrosating species in the reaction mixture is the key factor decreasing the yield of the target nitramine.

Experimental

Melting points were determined in a Gallenkamp hot stage, Sanyo. ^1H and ^{14}N NMR spectra for natural isotope abundances were recorded on a Bruker AM-300 spectrometer operating at 300.13 and 21.5 MHz, respectively, in acetone-d_6. The ^1H NMR chemical shifts (in the δ scale) were measured relative to the solvent as an internal standard, while the ^{14}N NMR chemical shifts were referred to external nitromethane. The reference NMR signals[35] used in the analysis of reaction mixtures are presented in Table 1.

Table 1. Reference signals in the ^1H and ^{14}N NMR spectra, δ

Compound	^1H NMR	^{14}N NMR
2	2.43	−41.0 ($NH\underline{N}O_2$)
5	2.71	−32.4 ($\underline{N}O_2$)
6	2.65	515.1 ($\underline{N}O$)
7	2.58	−68.2 ($\underline{N}\rightarrow O$)
8	2.56, 2.83	−66.5 ($\underline{N}\rightarrow O$)
9	2.63	—

Mass spectra were recorded on Finnigan MAT INCOS-50 and Varian MAT CH-111 instruments (EI, 70 eV).

The reactions were monitored and the product purity was checked by TLC on Silufol UV-254 plates. For analysis of compounds **5**, **6**, **9**, and **11**, a pentane/CH_2Cl_2 mixture (1 : 3 v/v) was used as the eluent, while for compounds **1**, **7**, **8**, a $MeCN/CCl_4$ mixture (1 : 4) was used. The spots corresponding to all of the starting compounds and final products luminesce in the UV range. The spots for nitroso-, nitro-, azo-, and azoxy compounds can also be visualized by spraying the plates with a 5% solution of diphenylamine in hexane; the spots become colored.

GLC analysis was carried out on a Biochom-1 chromatograph equipped with a quartz capillary column (0.2 mm×20 m, SE-54 phase) with a flame ionization detector and helium as the carrier gas.

The initial compound **1**[19] and the authentic samples of products **2**,[12] **5**,[35] **6**,[23] **7**,[23] **8**,[23] **9**,[37] and **11**[27] were prepared by known procedures. Characteristics of the products corresponded to those published previously.[35]

Nitration of 3-amino-4-methylfurazan (1). *A. Treatment with 100% HNO_3.* Amine **1** (1.98 g, 20 mmol) was added in small portions at −10 °C to a vigorously stirred mixture of colorless 100% nitric acid (ρ = 1.5 g cm^{-3}, 5 mL) and CH_2Cl_2 (5 mL). After 1 h, the reaction mixture was poured on ice, the resulting emulsion was extracted with ether (3×30 mL), and the extract was dried with $MgSO_4$ and concentrated. Recrystallization from CF_3CO_2H/CCl_4 gave 0.7 g (22%) of compound **2,** m.p. 88—89 °C. IR (KBr), ν/cm^{-1}: 3228, 3164, 3120, 3008, 2948, 1612, 1576, 1536, 1472, 1448, 1392, 1244, 1236,1224, 1040, 1000, 936, 900. MS, *m/z*: 144 [M$^+$], 97 [M$^+$– NO$_2$ – H], 67 [M$^+$ – NO$_2$ – H – NO]. Found (%): C, 24.96; H, 2.75; N, 38.91. $C_3H_4N_4O_3$ (144.09). Calculated (%): C, 25.01; H, 2.80; N, 38.88.

***B.** Treatment with 100% HNO_3 and N_2O_4 (2%).* Amine **1** (0.99 g, 10 mmol) was added in small portions at –5 °C to a vigorously stirred mixture of colorless 100% nitric acid (ρ = 1.5 g cm^{-3}, 5 mL) and N_2O_4 (0.15 g). After 1 h, the reaction mixture was allowed to warm up to ~20 °C and poured on ice. The product was extracted with ether (3×30 mL) and the extract was washed with cold water and dried with $MgSO_4$. The resulting solution was analyzed by TLC, GLC, and GC/MS (the products were identified by comparison with authentic samples). After evaporation of the solvent, the mixture was analyzed by NMR. The yields of nitramine **2** were 40—45 %.

***C.** Treatment with NO_2BF_4.* Compound **1** (0.99 g, 10 mmol) was added in small portions to a vigorously stirred suspension of NO_2BF_4 (1.5 g, 11.3 mol) in CH_2Cl_2 (20 mL) cooled to 0 °C. The reaction mixture was stirred for 1 h and the temperature was slowly raised to 5 °C. The products were analyzed as in procedure *B*. To isolate compound **2**, the reaction mixture was treated as in procedure *A* to give 0.9 g (63%) of compound **2** identical to an authentic sample.

Nitration of 4-methyl-3-trimethylsilylaminofurazan (14). A suspension of aminofurazan **1** (0.99 g, 10 mmol) and hexamethyldisilazane (2 g, 12.4 mol) in toluene (10 mL) was refluxed for 1 h under dry argon. The excess of the silylating reagent and the solvent were removed *in vacuo* from the resulting solution of compound **14**. The residue was dissolved in anhydrous CH_2Cl_2 (25 mL) and cooled to –30 °C, and NO_2BF_4 (1.5 g, 11.3 mol) was added. The temperature was gradually raised to 0 °C and the mixture was kept until the reaction was completed (TLC monitoring). Then the solvent and all volatile products were evaporated *in vacuo*. The residue was dissolved in ether (50 mL) and the solution was washed with 20% hydrochloric acid (2×20 mL) and dried with $MgSO_4$. After the removal of the solvent, the product was frozen out of CH_2Cl_2 to give 1.31 g (91%) of nitramine **2**.

Nitration of 3-dibutylborylamino-4-methylfurazan (15). A suspension of amine **1** (0.99 g, 10 mmol) and BBu_3 (1.8 g, 10.4 mol) in xylene (10 mL) was refluxed for 2 h under dry argon. The solvent was removed *in vacuo* from the resulting solution of compound **15**. The residue was dissolved in cold anhydrous CH_2Cl_2 (20 mL) and the solution was cooled to –30 °C and slowly displaced by argon into a different flask containing a suspension of NO_2BF_4 (1.5 g, 11.3 mol) in CH_2Cl_2 (20 mL) vigorously stirred at –30 °C. The reaction mixture was stirred for 2 h at –30 °C and the temperature was slowly raised to 0 °C. The mixture was stirred for 2 h at this temperature, a mixture of CH_2Cl_2 (5 mL) and methanol (5 mL) was added dropwise, the temperature was allowed to increase to ~20°C, the mixture was kept for 2 h, and the solvent and all volatile products were removed *in vacuo*. The residue was purified as described in the previous experiment to give 1.2 g (85 %) of nitramine **2**.

The work was partially financially supported by the Federal Target Program "Integration of Science and Higher Education of Russia for 2002—2006" (State Contract I0667).

References

1. A. B. Sheremetev, *Ros. Khim. Zhurn. (Zhurn. Ros. khim. o-va im. D. I. Mendeleeva)*, 1997, **41**, No. 2, 43 [*Mendeleev. Chem. J.*, 1997, **41**, No. 2, 62 (Engl. Transl.)].
2. A. B. Sheremetev, N. N. Makhova, and W. Friedrichsen, *Adv. Heterocycl. Chem.*, 2001, **78**, 65.
3. A. B. Sheremetev and I. L. Yudin, *Usp. Khim.*, 2003, **72**, 93 [*Russ. Chem. Rev.*, 2003, 72, 87 (Engl. Transl.)].
4. R. L. Willer and D. W. Moore, *J. Org. Chem.*, 1985, **50**, 5123.
5. A. B. Sheremetev, V. O. Kulagina, N. S. Aleksandrova, T. S. Novikova, and L. I. Khmelnitskii, *Proc. 3th (Beijing) International Symposium on Pyrotechnics and Explosives. November 6—9, 1995*, Beijing, China, 1995, 249.
6. Sun Qiuliang, Fu Xiayun, Jiang Maogui, Xu Daxin, and Du Yanqun, in *Proc. Intern. Symposium on Pyrotechnics and Explosives, October 12—15, 1987*, Beijing, China, 1987, 412.
7. R. L. Willer, R. S. Day, R. Gilardi, and C. George, *J. Heterocycl. Chem.*, 1992, **29**, 1835.
8. A. S. Ermakov, S. A. Serkov, V. A. Tartakovskii, T. S. Novikova, and L. I. Khmel´nitskii, *Khim. Geterotsikl. Soedinen.*, 1994, 1129 [*Chem. Heterocycl. Compd.*, 1994 (Engl. Transl.)].
9. A. S. Ermakov, S. A. Serkov, V. A. Tartakovskii, T. S. Novikova, and L. I. Khmel´nitskii, *Izv. Akad. Nauk. Ser. Khim.*, 1995, 719 [*Russ. Chem. Bull.*, 1995, **44**, 699 (Engl. Transl.)].
10. I. V. Tselinskii, S. F. Mel´nikova, and S. N. Vergizov, *Zh. Organ. Khim.*, 1995, **31**, 1234 [*Russ. J. Org. Chem.*, 1995, **31** (Engl. Transl.)].
11. R. L. Willer, R. S. Day, and D. J. Park, Pat. USA 5460669, 1995; *Chem. Abstrs*, 1996, **124**, 33168.
12. A. M. Churakov, S. E. Semenov, S. L. Ioffe, Yu. A. Strelenko, and V. A. Tartakovskii, *Mendeleev Commun.*, 1995, 102.
13. A. B. Sheremetev, I. L. Yudin, N. S. Aleksandrova, S. M. Aronova, and I. A. Kryazhevskikh, *Proc. 34th Int. Annual Conf. of ICT — Energetic Materials: Reactions of Propellants, Explosives and Pyrotechnics, 24—27 June, 2003*, Karlsruhe, FRG, 2003, 101/1—10.
14. V. A. Frolovskii and V. A. Petrosyan, *Izv. Akad. Nauk. Ser. Khim.*, 1999, 1935 [*Russ. Chem. Bull.*, 1999, **48**, 1911 (Engl. Transl.)].
15. S. D. Shaposhnikov, T. V. Romanova, N. P. Spiridonova, S. F. Melnikova, and I. V. Tselinsky, *Zh. Organ. Khim.,* 2004, **40**, 922 [*Russ. J. Org. Chem.*, 2004, **40**, 884 (Engl. Transl.)].
16. A. V. Sergievskii, T. V. Romanova, S. F. Melnikova, and I. V. Tselinsky, *Zh. Organ. Khim.,* 2005*,* **41***,* 270 [*Russ. J. Org. Chem.*, 2005, **41**, 261 (Engl. Transl.)].
17. A. M. Churakov, S. L. Ioffe, and V. A. Tartakovskii, *Mendeleev Commun.*, 1995, 227.
18. A. M. Churakov, S. L. Ioffe, Yu. A. Strelenko, and V. A. Tartakovskii, *Tetrahedron Lett.*, 1996, **37**, 102.
19. A. B. Sheremetev, Yu. L. Shamshina, and D. E. Dmitriev, *Izv. Akad. Nauk. Ser. Khim.*, 2005, 1007 [*Russ. Chem. Bull., Int. Ed.*, 2005, **54**, No. 4].
20. I. V. Tselinskii, S. F. Mel´nikova, and S. N. Vergizov, *Khim. Geterotsikl. Soedin.*, 1981, 321 [*Chem. Heterocycl. Compd.*, 1981 (Engl. Transl.)].

21. A. L. Fridman, V. P. Ivshin, and S. S. Novikov, *Usp. Khim.*, 1969, **38**, 1448 [*Russ. Chem. Rev.*, 1969, **38**, 640 (Engl. Transl.)].
22. O. A. Rakitin, O. A. Zalesova, A. S. Kulikov, N. N. Makhova, T. I. Godovikova, and L. I. Khmel´nitskii, *Izv. Akad. Nauk. Ser. Khim.*, 1993, 1949 [*Russ. Chem. Bull.*, 1993, **42**, 1865 (Engl. Transl.)].
23. A. B. Sheremetev, T. S. Novikova, T. M. Mel´nikova, and L. I. Khmel´nitskii, *Izv. Akad. Nauk SSSR. Ser. Khim.*, 1990, 1193 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1990, **39**, 1073 (Engl. Transl.)].
24. J. H. Boyer, in *The Chemistry of the Nitro and Nitroso Groups*, Intersci. Publ., Wiley and Sons, New York, 1969, p. 215—299.
25. A. B. Sheremetev, Yu. L. Shamshina, D. E. Dmitriev, D. V. Lyubetskii, and M. Yu. Antipin, *Heteroatom Chem.*, 2004, **15**, 199.
26. S. G. Zlotin, G. N. Varnaeva, and O. A. Luk´yanov, *Usp. Khim.*, 1989, **58**, 796 [*Russ. Chem. Rev.*, 1989, **58** (Engl. Transl.)].
27. L. W. Kissinger and H. E. Ungnade, *J. Org. Chem.*, 1960, **25**, 1471.
28. J. W. Fischer, in *Nitro Compounds: Recent Advances in Synthesis and Chemistry*, Eds H. Feuer and A. T. Nielsen, VCH, New York, 1990, p. 267—365.
29. Yu. V. Guk, M. A. Ilyushin, E. L. Golod, and B. V. Gidaspov, *Usp. Khim.*, 1983, **52**, 499 [*Russ. Chem. Rev.*, 1983, **52**, (Engl. Transl.)].
30. M. S. Pevzner, T. N. Kulibabina, N. A. Povarova, and L. V. Kilina, *Khimiya geterotsikl. soedinenii*, 1979, 1132 [*Chem. Heterocycl. Compd.*, 1979 (Engl. Transl.)].
31. E. T. Apasov, A. B. Sheremetev, B. A. Dzhetigenov, A. V. Kalinin, and V. A. Tartakovskii, *Izv. Akad. Nauk. Ser. Khim.*, 1992, 1916 [*Bull. Russ. Acad. Sci., Div. Chem. Sci.*, 1992, **41**, 1500 (Engl. Transl.)].
32. V. A. Dorokhov, E. A. Shagova, T. S. Novikova, A. B. Sheremetev, and L. I. Khmel´nitskii, *Izv. Akad. Nauk SSSR. Ser. Khim.*, 1988, 2363 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1988, **37**, 2128 (Engl. Transl.)].
33. V. A. Dorokhov, E. A. Shagova, A. B. Sheremetev, Yu. A. Strelenko, and T. S. Novikova, *Izv. Akad. Nauk SSSR. Ser. Khim.*, 1992, 174 [*Bull. Russ. Acad. Sci., Div. Chem. Sci.*, 1992, **41**, 140 (Engl. Transl.)].
34. A. B. Sheremetev, E. A. Ivanova, N. P. Spiridonova, S. F. Melnikova, I. V. Tselinsky, K. Yu. Suponitsky, M. Yu. Antipin, *J. Heterocycl. Chem.*, 2005, **42**, 1237.
35. D. E. Dmitriev, Yu. A. Strelenko, and A. B. Sheremetev, *Izv. Akad. Nauk. Ser. Khim.*, 2002, 277 [*Russ. Chem. Bull., Int. Ed.*, 2002, **51**, 290].
36. T. S. Novikova, T. M. Melnikova, O. V. Kharitonova, V. O. Kulagina, N. S. Aleksandrova, A. B. Sheremetev, T. S. Pivina, L. I. Khmelnitskii, and S. S. Novikov, *Mendeleev Commun.*, 1994, 138.
37. S. E. Semenov, A. M. Churakov, S. L. Ioffe, E. A. Vinogradova, S. G. Zlotin, and O. A. Luk´yanov, *Izv. Akad. Nauk.SSSR. Ser. Khim.*, 1991, 1940 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1991, **40**, 1727 (Engl. Transl.)].

Received March 14, 2005;
in revised form May 3, 2005