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The Synthesis of Some 3-Thietanyl-Substituted Thiocarbamides and the Study of Their Antioxidant Activity

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Abstract—3-Thietanyl-substituted thiocarbamides were synthesized via the reaction of 3-thietanyl-substituted isothiocyanate. The synthesized compounds were found to exhibit a high antioxidant activity in the inhibited oxidation of cumene.

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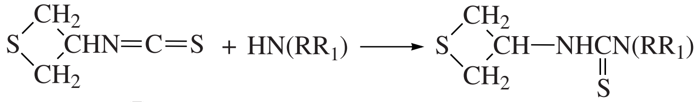
Earlier, we performed a systematic investigation into the synthesis and the antioxidant activity of various organic sulfur compounds [1–4].

In a continuation of the study of the synthesis of thiocarbamides and examination of their antioxidant properties [5–7], we prepared and studied various thietanyl-substituted thiocarbamides.

Their synthesis was conducted according to the following scheme:


(I)

The reaction of 1,2-epithio-3-chloropropane with ammonium thiocyanate was studied in an aqueous medium and 3-thietanylisothiocyanate was obtained as a result [8]. 3-Thietanyl-substituted thiocarbamides (**II**–**VI**), which are colorless crystals, were prepared via the addition reactions of 3-thietanylisothiocyanate with various aliphatic and aromatic amines:


(**I**)

(**II**–**VI**)

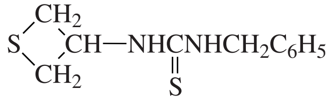
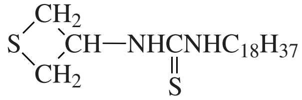
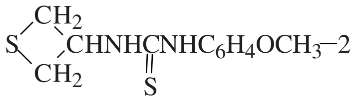
where R = H, $R_1 = C_6H_5CH_2-$ (**II**); R = H, $R_1 = C_{18}H_{37}-$(**III**);
R = H, $R_1 = CH_3OC_6H_4-$ (**IV**); R = H, R_1 = 2-$C_{10}H_7-$ (**V**);
$R = R_1 = (CH_2)_5N-$ (**VI**).

The structure of the compounds was proven by IR and ^{1}H NMR spectroscopy, and their purity was controlled by thin-layer chromatography and elemental analysis.

EXPERIMENTAL

1-*N*-Piperidino-3-(3'-thietanyl)thiocarbamide was prepared according to the following procedure: 8.5 g (0.001 mol) of piperidine was mixed with 13.1g (0.1mol) of 3-thietanylisothiocyanate (**I**); a strong self-heating of the reaction mixture was observed (to 50°C). After cooling the mixture to room temperature and its dilution with benzene (20 ml), the desired product was isolated in the crystalline form. The yield of **VI** was17 g (80%), bp 155–156°C, $R_f = 0.72$. Found, %; C 52.41, H 7.98, N 12.42, S 27.73. Calculated for $C_{10}H_{18}N_2S_2$, %: C 52.13, H 8.01, N 12.56, S 27.84. 4-phenyl-1,3-thiazole (**I**); Parent 2-amino-4-phenyl-1,3 was synthesized as described in [10].

Table 1. Yield, melting point, R_f value, and elemental analysis data for 3-thietanylthiocarbamides **II–VI**

Compound no.	Formula	Yield, %	T_{mp}, °C	Found, % Calculated, % C	H	N	S	Empirical formula	R_f
II		87	165	55.92 55.43	5.96 6.02	11.37 11.75	26.08 26.90	$C_{11}H_{14}N_2S_2$	0.76
III		91	125	65.71 65.94	11.23 11.62	6.78 6.99	16.17 6.99	$C_{22}H_{44}N_2S_2$	0.81
IV		75	190–191	51.71 51.91	5.18 5.33	10.82 11.01	25.48 25.21	$C_{14}H_{14}N_2S_2$	0.63
V		78	165–166	61.96 61.28	5.36 5.53	10.03 10.21	25.51 27.84	$C_{14}H_{14}N_2S_2$	0.43
VI		80	155–156	52.41 52.13	7.98 8.01	12.42 12.16	27.73 27.84	$C_{10}H_{18}N_2S_2$	0.72

Other 3-thietanyl-substituted thiocarbamides (**II–V**) were synthesized from 3-thietanylisothiocyanate **I** and various amines in a similar manner. Some properties of the products are given in Table 1.

The progress of the reaction was monitored by means of thin-layer chromatography (TLC) and IR spectroscopy. The purity of the synthesis products was controlled by the TLC technique as well [9] on Silufol UV 254 plates using a 5 : 1 (by volume) hexane–isopropyl alcohol solvent blend as an eluent.

The IR spectra were recorded on a Specord 75-IR spectrometer in a nujol mull, and the ^{1}H NMR spectra were measured on a Bruker (300 MHz) instrument. The chemical shifts (ppm) are given on the σ scale relative to HMS as an internal standard.

Cumene hydroperoxide (CHP) was purified according to the conventional method [10] followed by distillation, and chlorobenzene and cumene were purified according to the procedure based on the sulfonation of impurities with concentrated sulfuric acid [10, 11]. The CHP concentration was determined by iodometric titration of the periodically sampled reaction mixture [10].

The experiments on CHP decomposition were conducted in a chlorobenzene solution at 110°C in a glass bubble reactor under nitrogen with the concentrations of CHP and the compounds of interest being varied over the ranges 0.2–0.6 and $(3–5) \times 10^{-4}$ mol l^{-1}, respectively. The initiated oxidation of cumene was studied in a manometric unit [12]. The initiator was azobisisobutyronitrile (AIBN), which has an initiation rate constant of 1×10^{-5} l mol^{-1} s^{-1} at 60°C [13]. The initiator concentration was the same in all experiments, 2×10^{-2} mol l^{-1}, and the concentration of the test compounds was 5×10^{-5} mol l^{-1}. The IR spectra of synthesized 3-thietanyl substituted thiocarbamides **II–VI** displayed absorption bands at 670–680, 715–735, and 1415–1440 cm^{-1} characteristic of stretching vibrations of the four-membered thietane cycle. The stretching vibrations of the thiocarbamide moiety NHC(S) were detected at 1510–1525 cm^{-1}. Absorption bands in the region of 3320–3330 cm^{-1} correspond to NH bond stretching, and the absorption bands at 3380 and 3430 cm^{-1} revealed in a dilute (0.005 M) solution in CCl_4 are due to the free stretching vibration of the NH bond. Along with these bands, the spectrum of the dilute solution displayed absorption bands at 3040 cm^{-1} attributed to intramolecular hydrogen bonds NH…S [14].

The ^{1}H NMR spectra of 3-thietanylthiocarbamides **II–VI** exhibited signals from four protons of the two equivalent methylene groups of the thietane cycle at 2.55–3.55 ppm as a quintet with a 1 : 4 : 6 : 4 : 1 ratio. In the 4.15–4.65 ppm region, a signal of the single methine proton of the thietane cycle is displayed. The signals of the thiocarbamide NH protons appeared at 7.10–7.55 ppm.

RESULTS AND DISCUSSION

The antioxidant activity of the synthesized compounds in the elementary stages of the inhibition of cumene oxidation was studied in the reactions of these compounds with cumyl peroxide radicals and the cumyl peroxide itself. Cumene was used as a model hydrocarbon, since its oxidation mechanism is well-documented.

The ability of the compounds of interest to terminate oxidation chains in the reaction with cumene peroxide radicals was studied using the AIBN-initiated oxidation of cumene at 60°C as an example. As is seen in Fig. 1, the process in the case of the initiated oxidation of cumene is suppressed in the presence of compounds **I–VI**.

From the induction period (τ), the stoichiometric inhibition factor (*f*) defined as the number of oxidation chains terminated per inhibitor molecule and the products of its transformation was calculated: $f = \tau W_i/[\mathrm{InH}]_0$, where τ is the induction period (s), W_i is the initiation rate ($W_i = 2 \times 10^{-7}$ mol l^{-1}s^{-1} under the given experimental conditions) [15], and $[\mathrm{InH}]_0$ is the initial inhibitor concentration.

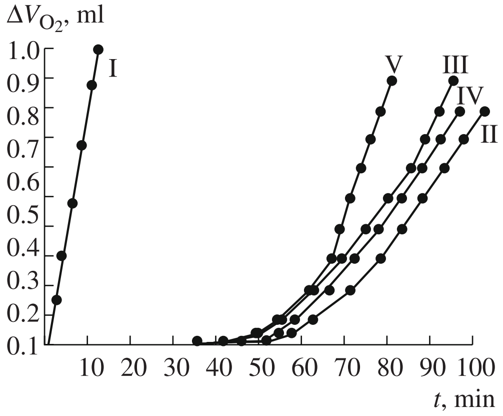


Fig. 1. Kinetic curves for the initiated oxidation of cumene in the presence of synthesized compounds **II–V** at 60°C. V_{O_2} is the oxygen volume (ml), *t* is the time (min), [InH] = 0 (**I**) $c_{(\mathrm{I})} = 3 \times 10^{-4}$ mol l^{-1}, and $c_{(\mathbf{II–V})} = 5 \times 10^{-5}$–5 mol l^{-1}.

The rate constant for the reaction of the inhibitors under study with cumene peroxide radicals (k_7) was calculated from the oxygen absorption kinetics [15, 16]. For this purpose, the oxygen uptake rate curves were transformed from the $\Delta(\mathrm{O_2})$-τ to the $\Delta(\mathrm{O_2})$-τ^{-1} coordinates; then, the slope of the straight line (tan α) expressed by

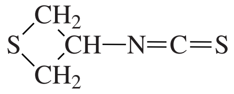
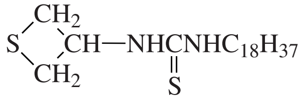
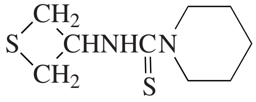
$$\tan\alpha = \frac{f k_7[\mathrm{InH}]_0}{k_2[\mathrm{RH}]W_i},$$

according to [15] gave k_7 as

$$k_7 = \frac{\tan\alpha k_2[\mathrm{RH}]W_i}{f[\mathrm{InH}]_0},$$

where $k_2 = 1.51$ l mol^{-1} s^{-1} is the propagation rate constant [13] and [RH] = 6.9 mol l^{-1}.

Table 2. Kinetic parameters for the reactions of 3-thietanylthiocarbamides **I–VI** with cumyl peroxide radicals and the catalytic decomposition of cumene hydroperoxide

Compound no.	Formula	$T = 60$°C, [AIBN] $= 2 \times 10^{-3}$ mol l^{-1}		$T = 110$°C		
		f	$k_7 \times 10^{-4}$ l mol^{-1} s^{-1}	*K* l mol^{-1} s^{-1}	ν	τ, min
I		0.96	2.23	32	82000	80
II		34.00	7.05	125	586000	250
III		2.08	3.27	22.05	58000	120
IV		2.20	3.19	30	86000	138
V		2.40	2.35	49	90000	120
VI		2.25	2.00	24	72000	95

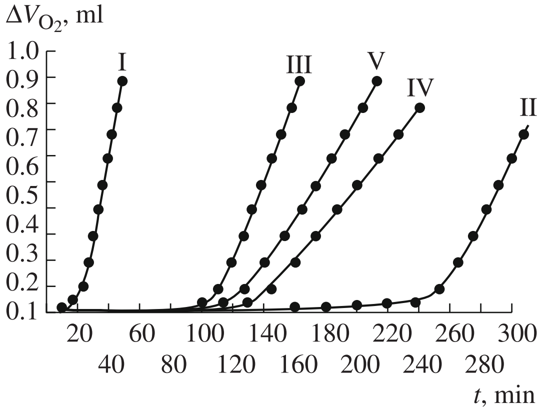


Fig. 2. Kinetic curves of the cumene autooxidation in the presence of the synthesized compounds: $T = 110°C$, V_{O_2} is the oxygen volume (ml), t is the time (min), and the other parameters are the same as specified in the legend to Fig. 1. [InH] (mol l^{-1}) (**I**) 0.

The data presented in Table 2 show that the value of the stoichiometric factor f for compounds **I–VI** ranges from 0.96 to 34. The inhibition rate constant k_7 varies from 2.00×10^{-4} to 7.05×10^{-4} l mol^{-1} s^{-1}.

The data in Table 2 also indicate that the reaction of 3-thietanylthiocarbamides **I–VI** with cumene peroxide radicals reveals a substantial effect of the nature of the substituent in the thiocarbamide group upon the reactivity toward these radicals. Investigations have shown that all compounds containing the thioamide moiety retard the initiated oxidation of cumene.

As is seen from the data presented in Table 2, thiocarbamide that contains the benzyl radical (**II**) multiply terminates the oxidation chain ($f = 34$) as compared to the case of naphthyl, phenyl, and piperidyl radicals, and displays a very high reactivity toward cumene peroxide radicals ($k_7 = 7.05 \times 10^{-4}$ l mol^{-1} s^{-1}). The study of cumene autooxidation (110°C) in the presence of compounds **II–V** ([InH] = 5×10^{-5} mol l^{-1}) has shown (Fig. 2) that these compounds inhibit the autooxidation process.

The results of the study show that all of the synthesized compounds actively decompose cumene hydroperoxide (Figs. 3a, 3b). The autocatalytic character of the rate curves suggest that CHP degradation is mediated by the products of the conversion of 3-thietanylthiocarbamides at the first step in the slow reaction with cumene hydroperoxide, rather than the reactant substituted thiocarbamides.

To determine the reaction rate order, we studied the dependence of the initial rate of the catalytic degradation reaction of cumene hydroperoxide on the concentrations of the reactants and found that the reaction was first order in both the inhibitor and CHP.

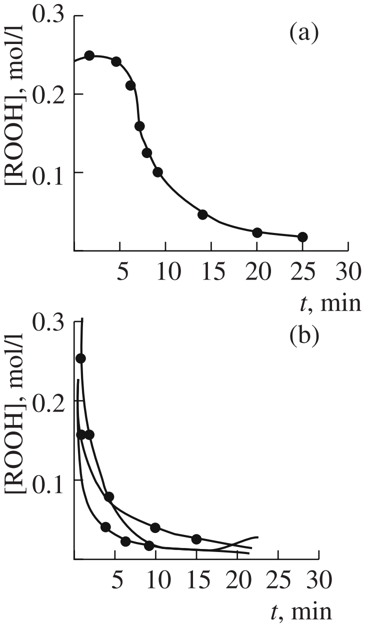


Fig. 3. Kinetic curves for the catalytic decomposition of CHP (a) in the presence of 3-thietanylisothiocyanate **I** at $c_{(\mathbf{I})} = 1 \times 10^{-4}$ mol l^{-1}, 110°C, and $[\mathrm{CHP}]_0 = 0.27$ mol l^{-1} and (b) by the action of compounds **I**, **IV**, and **V** at $c_{(\mathbf{II}, \mathbf{IV}, \mathbf{V})} = 5 \times 10^{-4}$ mol l^{-1} and an initial CHP concentration of 0.32 mol l^{-1}; t is the time in min.

To determine the catalytic factor ν of the reaction, CHP was taken in excess. The values of ν were calculated from the relationship:

$$\nu = \frac{[\mathrm{CHP}]_0 - [\mathrm{CHP}]_{\mathrm{exc}}}{[\mathrm{InH}]_0},$$

where $[\mathrm{CHP}]_0$ and $[\mathrm{CHP}]_{\mathrm{exc}}$ are the initial and final concentrations of cumene hydroperoxide, respectively, andν shows how many CHP molecules are decomposed by one inhibitor molecule. One molecule of test inhibitors **I–VI** decomposed a few thousand CHP molecules. The highest catalytic activity is displayed by compound **II**. One molecule of this compound decomposes 5.86×10^5 CHP molecules.

REFERENCES

1. M. A. Allakhverdiev, R. M. Babai, V. M. Farzaliev, et al., Neftekhimiya **41**, 153 (2001) [Pet. Chem. **41**, 135 (2001)].
2. M. A. Allakhverdiev and S. A. Shamkhalova, Zh. Prikl. Khim. **77**, 787 (2004).
3. I. A. Rzaeva, S. E. Sadigova, T. M. Vekilova, et al., Neftekhimiya **45**, 476 (2005) [Pet. Chem. **45**, 436 (2005)].
4. V. M. Farzaliev, M. A. Allakhverdiev, N. A. Akperov, and V. B. Liksha, Neftekhimiya **30**, 706 (1990).
5. A. I. Alikhanova, M. S. Salakhov, G. R. Mekhtieva, et al., *Azer. Khim. Zh.*, No. 2, 122 (2004).

6. V. M. Farzaliev, L. A. Dzhavadova, I. A. Rzaeva, et al., in *Proceedings of IV Baku International Conference on Petroleum Chemistry Dedicated to Mamedaliev, Baku, 2000*, p. 89.
7. A. M. Magerramov, L. A. Dazhavadova, I. A. Rzaeva, and S. G. Mamedova, Vestn. Bakinsk. Univ., Ser. Estestv. Nauki, No. 4, 5 (2002).
8. N. O. Nuretdinova and F. F. Guseva, Izv. Akad. Nauk SSSR, Ser. Khim., No. 3, 662 (1976).
9. A. A. Akhrem and A. I. Kuznetsova, *Thin-Layer Chromatography* (Nauka, Moscow, 1965) [in Russian].
10. V. K. Karnozhitskii, *Organic Peroxides* (Nauka, Moscow, 1961) [in Russian].
11. A. Weissberger, E. S. Proskauer, J. A. Riddick, and E. E. Toops, *Technique of Organic Chemistry, vol. VII. Organic Solvents* (Interscience, New York, 1955; Inostrannaya Literatura, Moscow, 1958).
12. N. M. Emanuel, E. T. Denisov, and Z. K. Maizus, *Chain Hydrocarbon Oxidation Reactions in the Liquid Phase* (Nauka, Moscow, 1965) [in Russian].
13. E. T. Denisov, *Rate Constants of Homolytic Liquid-Phase Reactions* (Nauka, Moscow, 1971) [in Russian].
14. R. Silverstein, G. Bassler, and T. Morrill, *Spectrometric Identification of Organic Compounds* (Wiley, New York, 1974; Mir, Moscow, 1977).
15. E. T. Denisov, V. V. Kharitonov, and V. V. Fedorova, *Method of Transformation of Rate Curves as a Means of Efficiency Assessment for Oxidation Inhibitors* (Chernogolovka, 1973) [in Russian].
16. N. M. Emanuel, G. P. Gladyshev, E. T. Denisov, et al., *Regulations for Testing Chemicals as Polymer Stabilizers* (Chernogolovka, 1976) [in Russian].