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REACTION OF FURAN COMPOUNDS WITH HYDROGEN SULFIDE AND ASPECTS OF ITS APPLICATION

UDC 547.727'732.07

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The conversion of α -methylfuran, di- and polyalkylfurans, and ethers, esters, ketones, and other derivatives of the furan series to the corresponding substituted thiophenes was realized under acid-catalysis conditions.

The conversion of compounds of the furan series upon reaction with hydrogen sulfide and hydrogen selenide under acid-catalysis conditions to the corresponding isoelectronic analogs, viz., 2,5-disubstituted thiophenes and selenophenes, has been previously reported [1-4]. Our investigation was undertaken in order to ascertain the peculiarities of this reaction in the case of mono-, di-, and polyalkyl-substituted furans, as well as ketones, alcohols, ethers, and esters of the furan series; we also studied the effect of the degree of substitution of the furan ring by alkyl groups and the position and character of the functional substituents of the side chain on the course of the reaction. The reaction of furan compounds II-XX with hydrogen sulfide was carried out in alcohol under the influence of concentrated hydrochloric acid or hydrogen chloride at 20-50°C.

It was established that, regardless of the length and degree of branching of the hydrocarbon chain or the number of substituents, 2,5-dialkyl- (II-VII), 2,3,5-trialkyl- (VIII, IX), and 2,3,4,5-tetraalkylfurans (X) are capable of reacting with hydrogen sulfide under conditions presented above to give the corresponding alkyl substituted thiophenes (XXII-XXX). In the case of the reaction of furans II-IX with hydrogen sulfide using 2-2.5 N hydrochloric acid, in addition to thiophenes XXII-XXIX, one observes the formation of the corresponding 1,4-diketones, which, under the reaction conditions, are also converted to thiophene

N. G. Chernyshevskii Saratov State University, Saratov 410026. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 11, pp. 1453-1456, November, 1986. Original article submitted May 7, 1985.



I, XXI R¹=H; II, VIII, X, XXII, XXVIII, XXX R¹=CH₃; III, IX, XXIII, XXIX R¹= = C_2H_5 ; IV, XXIV R¹= C_3H_7 ; V, XXV R¹= $n-C_4H_9$; VI. XXVI R¹=CH(CH₃)C₃H₇; VII, XVII R¹=C(CH₃)₂C₃H₇; XI, XXXI R¹=**2**-(hydroxycyclopentyl)methylXII, XXXII R¹=(**2**-hydrocyclohexyl)methyl XIII, XXXIII R¹=CH₂CH₂CH(OH)C₆H₅; XIV, XXXIV R¹=(**2**-oxocyclohexyl)methyl XVI, XXXVI R¹=(CH₂CH(OH)C₆H₅; XIV, XXXIV R¹=(**2**-oxocyclohexyl)methyl XV, XXVV R¹=(**2**-oxocyclohexyl)methyl XVI, XXVI R¹=CH₂CH₂CH₆CH₅; XVII, XXXVII R¹=(CH₂)₃OCH₂CH₂OH; XVIII, XXXVII R¹=(CH₂)₂COC₆H₅; XVII, XXXVII R¹=(CH₂)₂COOC₂H₅, XX, XL R¹=(CH₂)₃OCOCH₃; I--VII, XI--XXVII, XXX--XL R²=H, VIII, XXVIII R²=C₂H₅, IX, X, XXIX, XXX R²=CH₃; I--IX, XI--XXIX, XXXI--XL R³=H, X, XXX R³=CH₃

compounds, although at a lower rate. When the hydrochloric acid concentration is increased to 4.5 N, 1,4-diketones are absent in the reaction mixtures.

It has been previously shown that an increase in the electron density of the furan ring promotes a smoother reaction with hydrogen sulfide and hydrogen selenide [1-4]. However, the preparative yields of β -substituted thiophenes XXVIII-XXX amount to 37-44%, as compared with 47-60% in the case of 2,5-dialkylthiophenes XXII-XXVII. The reaction of α -methylfuran (I) with hydrogen sulfide was carried out at -10° to $+60^{\circ}$ C in the presence of perchloric, hydrochloric, and trifluoroacetic acids, as well as hydrogen chloride in various solvents (methanol, ethanol, acetic acid, ethylene glycol, etc.). We established the fundamental possibility of the conversion of α -methylfuran to 5-methylthiophene (XXI) at 50-60°C under the influence of dry hydrogen chloride in absolute ethanol, methanol, and ethylene glycol. The yield of XXI does not exceed 5%, since α -methylfuran is more susceptible to oligomerization than furan in acidic media [5].

We studied the reactions with hydrogen sulfide of furan compounds XI-XX, which contain functional groups in the side chain. We found that the more remote the functional groups from the furan ring, the more intense the reaction of the starting furans with hydrogen sulfide and the higher the yields of the desired products. Thus, furan ketones XIV-XVI, which contain a carbonyl group in the γ position relative to the heteroring, are converted to the corresponding ketones of the thiophene series XXXIV-XXXVI in up to 78% yields, whereas compounds that contain a carbonyl group in the α position relative to the heteroring do not react with hydrogen sulfide under the reaction conditions; this can be explained by a significant decrease in the electron density of the furan ring, as a result of which the resistance of the heteroring to protic acids increases.

Alcohols XI-XIII and ethers and esters XVII-XX of the furan series behave like ketones in reactions with hydrogen sulfide; XI, XII, XIV, and XV, which contain functional groups in alicyclic rings, are also successfully converted to the corresponding thiophenes XXXI, XXXII, XXXIV, and XXXV in up to 78% yields. The conversion of furan ethers and esters with functional groups attached to the $C_{(1)}$ and $C_{(2)}$ atoms of the side chain cannot be realized.

The compositions and structures of the synthesized thiophenes XXI-XL were confirmed by the results of elementary analysis and IR and PMR spectral data, as well as by comparison of the constants of the known XXI-XXIV, XXIX, and XXX with the literature values [6]. The IR spectra of XXII-XL contain absorption bands at 1520-1560, 1440-1450, 1360-1380, 1245-1260, and 800-805 cm⁻¹ (characteristic for the skeletal vibrations of the thiophene ring), 3075 cm⁻¹ (β -CH), and 1575-1585 cm⁻¹ (C=C) [7]. The PMR spectra of 2,5-di- (XXII) and polyalkylthiophenes (XXVIII, XXIX) are presented in Table 1.

Com-	Chemical shift, δ, ppm						
pound	α-CH3 (α'-R')	β'-R²	β-H, s				
XXII XXVIII	2,31 s 2.33 s		6,33 6,33				
XXIX	2,35 s (2.74g, 1.19 t)	2,49 q 2,04 s	6,39				

TABLE 1. PMR Spectra of Alkylthiophenes XXII, XXVIII, and XXIX

Com- pound•	bp, °C (mm)	n _D ²⁰	Found, %		Empirica1	Ca1c., %		Yield,	Litera-
			с	н	formula	с	н	9/0	ture
I II II VV VI VII VII VII XII XII XII XVI XV	$\begin{array}{c} 62-63\\ 93-94\\ 116-118\\ 112-144\\ 160-161\\ 67-68\\ (20)\\ 74-75\\ (20)\\ 142-144\\ 146-147\\ 129-131\\ (10)\\ 135-136\\ (7)\\ 149-151\\ (2)\\ 119-120\\ (8)\\ 140-142\\ 126-128\\ (3)\\ 136-137\\ (10)\\ 100-102\\ (10)\\$	1,4340 1,4308 1,4467 1,4489 1,4498 1,4510 1,4530 1,4520 1,4995 1,4552 1,4995 1,4552 1,4995 1,4575 1,4976 1,5438 1,4790 1,4747 1,4579			$\begin{array}{c}\\\\\\\\\\\\\\ C_{10}H_{16}O\\\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{12}H_{16}O_2\\ C_{10}H_{10}O_3\\ C_{$			40 45 63 76 62 47 51 44 51 44 70 70 82 62 68 67 20 28 69	$ \begin{array}{c} 8\\ 2\\ 10\\ 10\\ 10\\ 11\\ 12\\ \hline 13\\ 17\\ \hline 17\\ \hline 17\\ \hline 15\\ 16\\ \end{array} $

TABLE 2. Alkylfurans I-X and Functional Derivatives of Furan XI-XX

*The constants presented for I-V, VII, VIII, X, XI, XIV, XIX, and XX are in agreement with the literature data.

TABLE 3. Alkylthiophenes XXI-XXX and Functional Derivatives of Thiophene XXXI-XL

Com-	bp, *C (mm)	ⁿ D ²⁰	Found, %			Empirical	Calc., %			Yield,
pound •			с	н	s	formula	с	Н	s	
XXI XXII XXIII XXIV XXVI XXVII XXVII XXVII XXXII XXXII XXXII XXXII XXXII XXXII XXXVI XXXVII XXXVII XXXVII XXXVII XXXVII XXXVII XXXIX XXXXXXXII XXXIX	$\begin{array}{c} 111\\ 134-135\\ 68-70\ (30)\\ 73-75\ (15)\\ 87-88\ (15)\\ 96-97\ (15)\\ 93-94\ (15)\\ 80-81\ (34)\\ 81-82\ (34)\\ 81-82\ (34)\\ 130-131\ (2)\\ 169-170\ (4)\\ 155-157\ (1)\\ 119-121\ (1)\\ 169-170\ (4)\\ 150-153\ (1)\\ 140-142\ (3)\\ 125-126\ (1)\\ 110-113\ (3)\\ 105-106\ (3)\\ \end{array}$	$\begin{array}{c} 1,5190\\ 1,5138\\ 1,5060\\ 1,5022\\ 1,4951\\ 1,4935\\ 1,4935\\ 1,4930\\ 1,5090\\ 1,5054\\ 1,5190\\ 1,5359\\ 1,5430\\ 1,5708\\ 1,5708\\ 1,5719\\ 1,5719\\ 1,5770\\ 1,5070\\ 1,5072\\ 1,5042\\ 1,5315\end{array}$	$\begin{array}{c c} - & - \\ - & - \\ 70,0 \\ 71,8 \\ 72,4 \\ 68,2 \\ 67,2 \\ 69,4 \\ 72,4 \\ 68,1 \\ 69,4 \\ 72,4 \\ 68,1 \\ 69,4 \\ 72,8 \\ 60,4 \\ 58,4 \\ 58,4 \\ \end{array}$	9,1 9,4 9,7 8,8 8,2 7,6 6,8 7,3 6,7 8,5 8,5 7,1 6,3		$C_5H_6S\\C_6H_8S\\C_7H_{10}S\\C_9H_{12}S\\C_9H_{14}S\\C_9H_{14}S\\C_9H_{14}S\\C_9H_{14}S\\C_9H_{14}S\\C_9H_{14}S\\C_9H_{12}S\\C_8H_{12}S\\C_8H_{12}S\\C_9H_{12}S\\C_{11}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}H_{16}S\\C_{12}S\\C_{13}H_{16}S\\C_{12}S\\C_{14}H_{16}S\\C_{25}S\\C_{16}H_{16}S\\C_{25}S\\C_$	$\begin{array}{c} - \\ - \\ 70,1 \\ 71,4 \\ 72,5 \\ 68,6 \\ -7,3 \\ 69,2 \\ 72,4 \\ 68,0 \\ 69,2 \\ 73,0 \\ 69,2 \\ 73,0 \\ 60,6 \\ 58,7 \\ \end{array}$	$\begin{array}{c} - \\ - \\ 9,1 \\ 9,5 \\ 9,9 \\ - \\ 8,6 \\ 8,2 \\ 7,7 \\ 6,9 \\ 7,2 \\ 7,7 \\ 6,1 \\ 8,1 \\ 8,5 \\ 7,1 \\ 6,5 \end{array}$	$\begin{array}{c} - \\ - \\ 20.8 \\ 19.0 \\ - \\ 22.9 \\ 16.3 \\ 15.4 \\ 13.8 \\ 16.6 \\ 15.4 \\ 13.8 \\ 16.0 \\ 14.9 \\ 15.4 \\ 17.4 \end{array}$	$\begin{array}{c} 5\\ 60\\ 73\\ 49\\ 47\\ 53\\ 51\\ 37\\ 40\\ 44\\ 52\\ 78\\ 56\\ 49\\ 78\\ 56\\ 49\\ 78\\ 56\\ 60\\ 69\\ 69\\ \end{array}$

*The constants presented for XXI-XXIV and XXVIII are in agreement with the data in [6].

EXPERIMENTAL

The IR spectra of films of the compounds were recorded with a UR-20 spectrometer. The PMR spectra of solutions in CDC1, were obtained with a Varian-80 A spectrometer (80 MHz) with hexamethyldisiloxane (HMDS) as the internal standard. Analysis by gas-liquid chromatography was carried out with a Tsvet-101 chromatograph with a flame-ionization detector and a 1 m by 3 mm steel column packed with 15% Apiezon L on Chromaton N-AW; the carrier gas was helium, the flow rate was 2 liters/h, and the temperature was 160°C.

Starting furan compounds I-XX were obtained by the methods in [8-17].

The characteristics of the synthesized compounds I-XL are presented in Tables 2 and 3.

General Method for the Preparation of Thiopene Compounds XXII-XL. A thermostatted (at 35° C) reactor was charged with 30 ml of a 3.2N solution of dry hydrogen chloride in absolute ethanol, and the solution was saturated with hydrogen sulfide for 1.5 h. Then, without interrupting the flow of hydrogen sulfide, 0.06 mole of the corresponding furan was added to the reaction mixture. The course of the reaction was monitored by means of GLC. At the end of the reaction the mixture was neutralized with a saturated solution of sodium hydroxide until the mixture was slightly alkaline, after which it was extracted with ether. The ether extracts were washed thoroughly with water and dried with calcined magnesium sulfate. The ether was removed, and the residue was distilled in vacuo. Syntheses of the thiophenes were carried out similarly using hydrochloric acid in place of hydrogen chloride.

<u>2-Methylthiophene (XXI)</u>. This compound was obtained via the method described above at 50-60°C in a 3.5 N solution of hydrogen chloride in absolute ethanol, methanol, or ethylene glycol from 0.061 mole of α -methylfuran. The yield of 2-methylthiophene was 0.3 g (5%). The product had bp 111°C and $n_D^{2^\circ}$ 1.5190 (bp 112.5°C [6]).

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