Furan derivatives. CIII.
Nitration of methyl 3-(5-nitro-2-furyl)acrylate

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Nitration of methyl 3-(5-nitro-2-furyl)acrylate with fuming nitric acid afforded 5-nitro-2-furancarboxylic acid (*II*) as a main product (70%) and 5-nitro-2-furaldehyde (*III*) and methyl ester of 2-nitro-3-(5-nitro-2-furyl)acrylic acid *IV* as by-products. The nitration of methyl ester of *I* gave at −10°C the corresponding methyl ester of *IV* in a 29% yield, whereas the nitration with a solution of N_2O_4 in CCl_4 furnished methyl ester of *IV* even in a better yield. Both procedures led prevalently to the *Z* configuration of the ester of *IV*.

Нитрованием метилэфира 3-(5-нитро-2-фурил)акриловой кислоты дымящей азотной кислотой получился как основной продукт 5-нитро-2-фуранкарбоксильная кислота *(II)* (70%) и как побочные продукты 5-нитро-2-фуральдегид *(III)* и метилэфир 2-нитро-3-(5-нитро-2-фурил)-акриловой кислоты *IV*. Нитрованием метилэфира *I* при −10°C выходы соответствующего метилэфира *IV* увеличились на 29%. Еще более высокие выходы метилэфира *IV* получились, когда нитрование осуществилось раствором N_2O_4 в CCl_4. Производный эфир *IV* образуется в большинстве в *Z*-конфигурации.

As we have already shown, 3-(5-nitro-2-furyl)acrylic acid (*I*) undergoes under various reaction conditions of nitration prevalently a decarboxylation nitration [1]. According to preceding findings the reaction of nitrogen oxides with 3-(2--furyl)acrylic acid proceeds in two consecutive steps — nitration and decarboxylation [2], and therefore, we investigated the nitration of methyl ester of *I* under conditions where the decarboxylation nitration of free acid *I* takes place aiming to stop the reaction in the first step and isolate the nitration product, since the ester does not undergo a direct decarboxylation, and presuming the obtained products to be of the same structure as compounds prepared by condensation of 5-nitro-2-furaldehyde (*III*) with methyl nitroacetate [3].

Experimental

Melting points were determined on a Kofler micro hot-stage. Infrared spectra were recorded with a UR-20 (Zeiss, Jena) spectrophotometer in KBr discs at a standard concentration 2 mg of substance/1 g of KBr. The instrument was calibrated against a polystyrene foil. ^{1}H-n.m.r. spectra were taken with a Tesla BS 487 C apparatus at an operating frequency 80 MHz in deuterated acetone or chloroform tetramethylsilane being the internal reference substance. Mass spectra were measured with an AEI MS 902 S spectrophotometer. The nitration was carried out with methyl ester of *I* prepared according to [4].

Nitration of methyl ester of 3-(5-nitro-2-furyl)acrylic acid (I) with nitric acid

Method A

The ester of *I* (19.7 g; 0.1 mole) was cooled at 0°C, fuming HNO_3 (30 ml) was added and stirring was continued for 1 h. After this time the temperature was allowed to reach 20°C, the mixture was stirred for additional 1 h and then poured into ice containing water (100 ml). The product extracted twice with ether (10 ml each) was washed with 5% aqueous sodium carbonate solution, the dark-red aqueous layer was separated, the ethereal solution dried with $MgSO_4$ and the solvent distilled off. The product was identified by ^{1}H-n.m.r. spectroscopy and chromatography as consisting of *III*, methyl nitroacetate (*V*), and methyl ester of 2-nitro-3-(5-nitro-2-furyl)acrylic acid (*IV*). This mixture was extracted with boiling heptane (100 ml) from which methyl ester of *IV* (1.2 g; 4.95%, m.p. 77—79°C) crystallized at room temperature. The ester of *IV* was identified by spectral means (mass, infrared, and ^{1}H-n.m.r.). The aqueous layer was acidified with HCl and extracted with ether (300 ml) from which *II* was obtained, in a 70% yield (11 g). This substance was identified also on the basis of spectral evidence (mass, infrared, and ^{1}H-n.m.r.) and mixed melting point with the authentic specimen.

Method B

To the methyl ester of *I* (19.7 g; 0.1 mole) cooled at −10°C fuming HNO_3 (30 ml) was added under stirring; this being continued for 1 h. After this time the solution was cooled at −20°C, ether (100 ml) was added and stirring was continued for additional 10 min. The ethereal solution was then separated, ether distilled off and the residue extracted with hot heptane, from which methyl ester of *IV* (7 g; 29%) crystallized at room temperature in long needles; m.p. 77—79°C. Identification as above.

Nitration of methyl ester of I with oxides of nitrogen

Nitrogen(IV) oxide (27.6 g; 0.3 mole) in CCl_4 (250 ml) was dropwise added to a solution of methyl ester of *I* (19.7 g; 0.1 mole) in CCl_4 (100 ml) placed in a three-necked flask provided with a stirrer, dropping funnel fitted with a $CaCl_2$ tube under stirring at 0°C. After addition of the total amount, stirring was continued for 1 h at 0°C and at room temperature for another 4 h. The mixture was then evaporated under reduced pressure, extracted with heptane (200 ml) and allowed to crystallize. The methyl ester of *IV* (8.5 g; 35.1%) was obtained within 48 h of standing.

Action of fuming HNO_3 *on 5-nitro-2-furaldehyde (III)*

Fuming HNO_3 (6 ml) was added under efficient cooling and stirring to the solution of *III* (1 g) in CCl_4 (10 ml) at -10°C. After the intense evolution of nitrous gases discontinued, the reaction mixture was poured onto crushed ice, CCl_4 was separated, washed with 5% sodium carbonate solution and the product was isolated after cooling and acidifying. Yield 0.3 g of *II*.

Action of water on methyl ester of IV

A mixture of *Z* and *E* isomers of methyl ester of *IV* (1 g) was stirred in water (10 ml) at room temperature for 1 h, one part of this solution was separated, extracted with ether and the dried ethereal solution evaporated. The residue dissolved in deuterated chloroform was subjected to ^{1}H-n.m.r. measurement ($O_2NCH_2COOCH_3$: $\delta_{CH_2} = 5.17$; $\delta_{CH_3} = 3.82$; *III*: $\delta_{CHO} = 9.72$). The second part was treated with an excess of standard acid solution of 2,4-dinitrophenylhydrazine, the separated precipitate was filtered off with suction, dissolved in ethyl acetate and identified by t.l.c. on Silufol (developing system CCl_4—ethyl acetate 3:2) as a 2,4-dinitrophenylhydrazone of aldehyde *III*. The aqueous solution was extracted with ether and identified by t.l.c. as methyl esters of *IV* and *V*.

Discussion

Nitration of methyl ester of *I* with fuming HNO_3 at 0—20°C was accompanied with an intense evolution of nitrous gases. A considerable amount of acid products was extracted with ether after decomposition of the nitration mixture with water. This procedure was utilized for separation of the mixture, since acid components can be extracted from the ethereal layer into water with sodium carbonate solution.

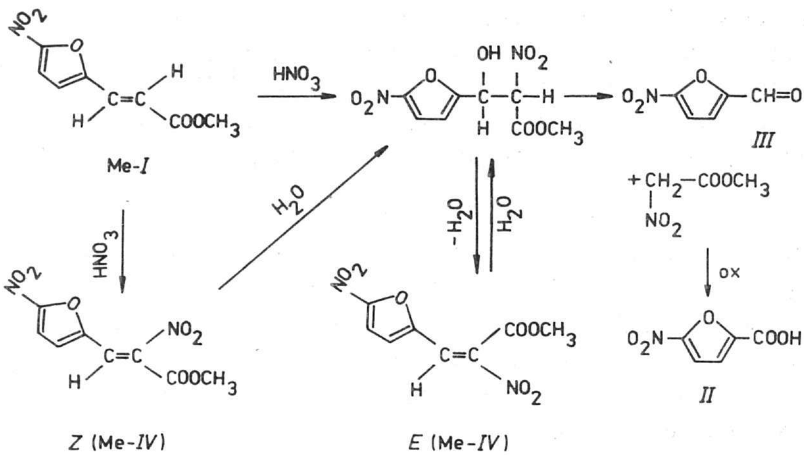
In addition to the methyl ester of *IV*, substances *III* and *V* were found in the neutral ethereal solution, whereas acid *II* was obtained in a 70% yield from the aqueous layer after extraction of the ethereal extract with sodium carbonate solution.

According to experience [1], the C=C bond in 3-(5-nitro-2-furyl)acrylic acid derivatives is stable towards oxidation reagents and therefore, the formation of *II* as a main reaction product has to proceed otherwise than by oxidation of the side-chain double bond. The most probable route for formation of *II* under the given conditions is considered the oxidation of *III* which has to originate, if decomposition of the primary addition product in the reaction mixture resulting from methyl ester of *I* and nitric acid or alternatively from methyl ester of *IV* and water, takes place.

This reaction course is supported by the appearance of aldehyde *III* in products of decomposition of the reaction mixture by water determined both by ^{1}H-n.m.r. spectrum and t.l.c.

The small amount of methyl ester of *IV* obtained in addition to the main product of reaction *II* indicates that two concurrent reactions of different rate took place under the given conditions, addition is the main, substitution the side reaction.

To evidence the suggested mechanism of the main reaction the individual steps presumed were analyzed. Addition of water to methyl ester of *IV* (Scheme 1)



Scheme 1

afforded a compound identical with that formed by addition of HNO_3 to methyl ester of *I*. Decomposition of the product in water to give *V* and *III* (which has been experimentally proved) confirms the second step of the scheme. Oxidation of *III* with HNO_3 to yield *II* proceeded vigorously, although it was performed under mild conditions; it can be brought under control only in solution and at temperatures not exceeding -20°C. This argument confirms the suggested mechanism of the main reaction.

This conclusion is in accordance with the hydration rate constant of water to the double bond of 2-nitrocrotonate [5], the order of magnitude of which was found to be 10^{-2} s^{-1}.

Aiming to enhance the yield of the substitution by-product, methyl ester of *I* was nitrated at -10°C; to avoid addition of water to the originating methyl ester of *IV*, the nitration mixture was deeply cooled and extracted with ether. This procedure led to a 29% yield of methyl ester of *IV*. To prevent proceeding of further reactions after addition of HNO_3 to the double bond, the reaction was carried out with nitrogen oxides in CCl_4; yield of the nitration product was thus raised to 35%.

Methyl ester of *IV* exists in *Z* and *E* configurations according to the preparation mode. During the decarboxylation nitration of 3-(5-nitro-2-furyl)acrylic acid the leaving and the approaching nitro groups are on the same side of the double bond, and consequently, the *E* isomer was formed [1]. This process is possible only under a presumption that the decarboxylation nitration proceeds by an addition-elimination mechanism and after addition of HNO_3 to the C=C double bond of the acrylic acid the molecule occupies a more favourable spatial arrangement during the elimination, enabling the generation of the *E* isomer.

A characteristic differentiation feature in the ^{1}H-n.m.r. spectra of esters of *IV* are differences in chemical shifts of protons associated with position 3 of acrylic acid: protons of *E* isomers resonate in a lower field than those of *Z* isomers. This chemical shift of ethylene protons is due to a greater magnetic anisotropy of the nitro group when compared with the carboxyl group. Chemical shifts of olefinic protons in *E* and *Z* isomers were calculated on the basis of additive increments for substituents in *cis* and *trans* positions towards the proton according to [6]

$$\delta_{CH=C} = 5.25 + Z_{gem} + Z_{cis} + Z_{trans}$$

The obtained values differ by 1 p.p.m. evidencing thus the nonplanarity of the molecule.

Both isomers could be distinguished also by stretching vibrations $\nu_s(NO_2)$ and $\nu_{as}(NO_2)$ of the methyl ester of *IV* (Table 1). Stretching vibrations of the nitro group of the *E* isomer, having the nitro group in a *trans* arrangement towards furan ring, appear at lower wavelength than in the *Z* isomer.

Condensation of *III* with *V* [3], where the latter compound could be oriented toward the aldehyde in both directions, furnished methyl ester of *IV* as a mixture of *Z* and *E* isomers in a 1:8 ratio.

The ^{1}H-n.m.r. spectrum of methyl ester of *IV*, obtained by nitration of methyl ester of *I* with HNO_3, proved the existence of *Z* and *E* isomers in a 9.2:1 ratio. It means that the nitration led to a substance of less favourable configuration, which

Table 1

Constants of *E* and *Z* isomers of *IV*

Isomer	$\delta_{CH=C}$ (p.p.m.)		OCH_3 (p.p.m.)	$\nu_s(NO_2)$ cm^{-1}	$\nu_{as}(NO_2)$ cm^{-1}	M.p. °C
	calculated	found				
E	8.75	7.77	4.01	1330	1540	102—103
Z	8.10	7.28	3.86	1375	1555	77—79

could exist in a nonplanar form only under a presumption that the furan ring and nitro group are located above each other [7]. Formation of the *Z* isomer as a prevailing form is of importance for determination of the reaction mechanism, since this isomer can be exclusively generated in a case, when hydrogen in position 2 of acrylic group undergoes displacement under maintaining the original molecular geometry; nevertheless, this was not observed during nitration of free *I*.

Similarly as in the former case, nitration of methyl ester of *I* with N_2O_4 leads to formation of *Z* and *E* isomers of methyl ester of *IV* in a 4:1 ratio indicating thus that also radical substitution favourizes maintaining the same molecular geometry.

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