

Novel Building Block, Furan-annelated 3-Sulpholene; Diels–Alder Reactions of 4,6-Dihydrothieno[3,4-*c*]furan *S,S*-Dioxide

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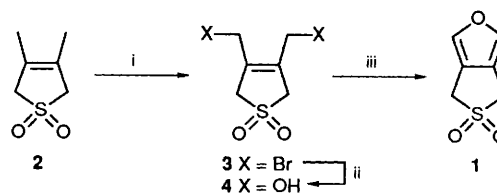
The preparation of the hitherto unknown 4,6-dihydrothieno[3,4-*c*]furan *S,S*-dioxide **1** and its intermolecular Diels–Alder reactions with typical dienophiles are described.

In the course of our studies on the chemistry of 2,5-dihydrothiophene *S,S*-dioxide (3-sulpholene),¹ we synthesized the previously unknown furan-annelated 3-sulpholene **1**, the precursor of the furan analogue of *o*-quinodimethane.² This compound **1** contains furan and 3-sulpholene moieties, both of which are readily functionalized, and so it would be expected that it could be used as a bis-diene which can sequentially react with two different kinds of dienophiles (tandem Diels–Alder reaction). Such a sequence is useful in the syntheses of variously substituted multicyclic molecules.

Compound **1** was synthesized as described in Scheme 1. The bromination of 3,4-dimethylsulpholene **2** with *N*-bromosuccinimide (NBS) gave the dibromide **3** (54%),³ which on hydrolysis with silver trifluoroacetate in water afforded the diol **4** (m.p. 93–95.5 °C; 93%); furan-forming reactions of **4** were attempted under various conditions, but without success.⁴ The desired furansulpholene **1** (m.p. 139–140 °C; 72%),[†] however, was obtained on treatment with pyridinium chlorochromate (PCC) in the presence of trifluoroacetic acid.

The Diels–Alder reaction of **1** with dimethyl acetylenedicar-

boxylate (DMAD; 3 equiv.) was carried out at 150 °C for 1 h (benzene; sealed tube), affording two types of cycloadducts: the monocycloadduct **5** bearing two methylene groups [(type A), 45%, cycloaddition to furan moiety and then desulphonylation] and the biscycloadduct **7** [(type B), 47%, cycloaddition to both furan and sulpholene, tandem cycloadduct] (Table 1, entry 1). Even at lower temperatures (120 °C; room temperature) the same cycloadducts were obtained (entries 2 and 3). Essentially the same type of reaction was observed with dimethyl fumarate as dienophile (entries 4 and 5). With other ethylenic dienophiles such as dimethyl maleate, cycloaddition proceeded at 150 °C, making it possible to isolate a new type of monocycloadduct **10b** [(type C), 10%, formal cycloaddition to sulpholene moiety, *i.e.* the retroreversion of **8b**] in addition to



Scheme 1 Reagents and conditions: i, NBS, CHCl₃, reflux, 17 h; ii, CF₃CO₂Ag, H₂O, room temp., 72 h; iii, PCC, CF₃CO₂H, CH₂Cl₂, room temp., 30 min

[†] ¹H NMR (CDCl₃; SiMe₄) δ 4.16 (4H, d, *J* 1.5 Hz) and 7.45 (2H, t, *J* 1.5 Hz); ¹³C NMR (CDCl₃; SiMe₄); δ 51.2 (t), 116.5 (s) and 137.4 (d); IR (CHCl₃); ν/cm⁻¹ 1305, 1115, 1015 and 880 cm⁻¹; *m/z* 158 (M⁺) and 94 (M⁺ - SO₂).

Table 1 Reactions of furansulpholene **1** with dienophiles

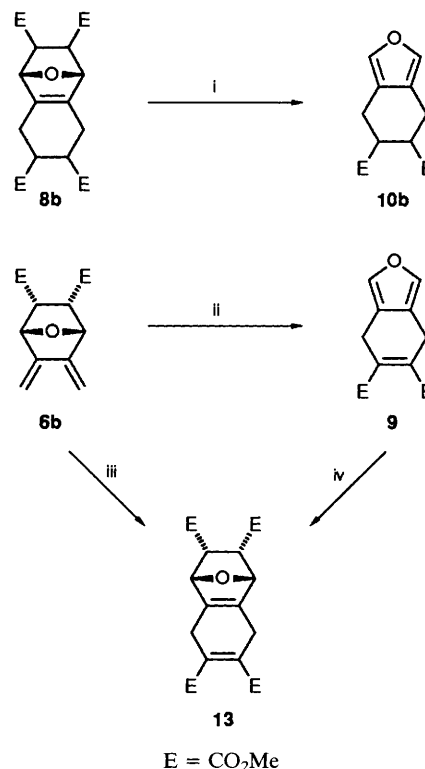
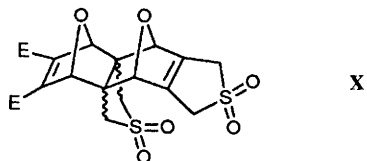
Entry	Dienophile (3 equiv.)	Reaction conditions ^a (sealed tube)	Products (yield, %) ^b				Total yield ^c (%)
			Type A	Type B	Type C	Type D	
1	DMAD	150 °C, 1 h	5 (45)	7 (47)			92
2	DMAD	120 °C, 1 h	5 (62)	7 (29)			91
3	DMAD	R.t., 168 h	5 (54)	7 (39)			93
4	Dimethyl fumarate	150 °C, 2 h	6a (61)	8a (26)			87
5	Dimethyl fumarate	120 °C, 4 h	6a (78)	8a (11)			89
6	Dimethyl maleate	150 °C, 3 h	6b (<i>endo</i> 53) (<i>exo</i> 10)		10b (10)		73
7	Dimethyl maleate	120 °C, 12 h	6b (<i>endo</i> 51) (<i>exo</i> 10)	8b (<i>endo</i> 11) (<i>exo</i> 18)			90
8	Fumaronitrile	150 °C, 3 h	6c (36)		10c (38)		74
9	<i>N</i> -Phenylmaleimide	150 °C, 3 h	6d (<i>exo</i> 46)		10d (26)		72
10	<i>N</i> -Phenylmaleimide	120 °C, 1 h		8d (<i>exo</i> 72)			72
11	<i>N</i> -Phenylmaleimide	150 °C, 4 h	6e (<i>exo</i> 58)		10e (4)		62
12	Maleic anhydride	R.t., 72 h				12f (<i>exo</i> 62)	62

^a Each reaction stopped on consumption of the starting material **1**. R.t. = room temperature. ^b Isolated yields. ^c The reaction conditions were not optimized.

the type A monocycloadduct **6b** (entries 6 and 7). With fumaronitrile, the formation of the type C adduct **10c** (38%) predominated over that of type A **6c** (entry 8). Furthermore, **1** added to maleic anhydride at room temperature for 72 h to yield a single product, the fourth type of cycloadduct (**12f**) [(type D), *exo*, 62%, cycloaddition to furan moiety] (entry 12). The structures of all the new compounds thus obtained were confirmed by ¹H and ¹³C NMR spectral data.

Thus, **1** reacts with various dienophiles to give four types of cycloadduct, A, B, C and D, depending on the dienophile and the reaction conditions, and even reacts with dimethyl maleate and dimethyl fumarate, whose adducts with furan have not been isolated under thermal conditions,⁵ to afford Diels-Alder adducts. The formation of type A compounds, **5** and **6**, is the result of spontaneous desulphonylation of initially formed type D adducts, **11** and **12**, respectively. Despite the success in the isolation of **12**, all attempts to detect **11** failed owing to rapid desulphonylation (*e.g.* entry 3), but the isolation of a 1:1 adduct **X**† of **11** with **1** suggested the

† M.p. 160–161 °C (decomp.); ¹H NMR (CD₃SOCD₃; SiMe₄) δ 3.60 (6H, s), 3.77 (4H, m), 4.10 (4H, m), 5.09 (2H, s) and 5.38 (2H, s); ¹³C NMR (CD₃SOCD₃; SiMe₄) δ 52.53 (q), 56.15 (t), 56.53 (t), 69.35 (s), 79.06 (d), 82.68 (d), 139.84 (s), 144.78 (s) and 170.56 (s); *m/z*: 330 (M⁺ - 2 × SO₂), 299 (330 - OCH₃) and 271 (330 - CO₂CH₃). This adduct has structure **X** (unpublished data).



Scheme 2 Reagent and conditions: i, benzene, 150 °C, 1 h; ii, DMAD, benzene, 150 °C, 3 h; iii, DMAD, 12 kbar, 28 °C, 48 h; iv, benzene, 150 °C, 1 h

formation of **11**. In this rapid desulphonylation, the extra strain (which is attributed to two 'endocyclic alkene-oxa-bridge' repulsions⁶) of the oxanorbornadiene moiety of **11** plays an important role. Furthermore, the formation of the type C adduct at 150 °C can be explained by a retro-Diels-Alder reaction where the 7-oxanorbornene skeleton of the type B adduct **8** releases the unit alkene to afford furan owing to the restoration of aromatic character and the reduction of steric strain.⁷ Compound *endo*-**8b**, when kept at 150 °C for 1 h, gave the type C adduct **10b** (36%) and *endo*-**6b** reacted with DMAD at the same temperature for 3 h to afford **9** (84%) which could not be isolated on treatment of **1** with DMAD (Scheme 2). These results suggested the formation of the 7-oxanorbornene system **13**§ by the process shown in Scheme 2. Indeed, **13** underwent retro Diels-Alder reaction to give **9** in quantitative yield.

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§ This compound was prepared from *endo*-**6b** and DMAD under 12 kbar pressure (CH₂Cl₂; 28 °C; 48 h; yield 98%) (unpublished data).

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