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Journal of Chromatography A, 847 (1999) 351–358

JOURNAL OF CHROMATOGRAPHY A

Determination of the products of the reaction of *N*-alkyl-2-benzothiazolesulfenamide by high-performance liquid chromatography with acetone

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Abstract

A slow reaction was observed between *N*-alkyl-2-benzothiazolesulfenamide derivatives and acetone at ambient temperature. The formed products identified by NMR technique are 1,1-bis-(2′-benzothiazolethio)-2-alkylaminoprop-1-ene, 1-(2′-benzothiazolethio)-2-morpholinoprop-1-ene and 2′-(benzothiazolylthio)propan-2-one. A packed octadecyl-bonded silica column has been employed for the separation of the main reaction products by HPLC. The precision of the gradient method used was below 2.3%.

Keywords: 1,1-Bis-(2′-benzothiazolethio)-2-alkylaminoprop-1-ene; 1-(2′-Benzothiazolethio)-2-morpholinoprop-1-ene; 2′-(Benzothiazolylthio)propan-2-one; Alkylbenzothiazolesulfenamide; Acetone

1. Introduction

Derivatives of *N*-alkyl-2-benzothiazolesulfenamide are commercially used as accelerators for vulcanization in the rubber industry. They are soluble in many polar organic solvents and easily react with anhydrides of acetic, maleic or phthalic acid with the formation of alkyl bis(2-benzothiazolylsulfen)amide [1]. Carr et al. [2] have observed that *N*-cyclohexyl-2-benzothiazolesulfenamide reacts also with acetone, however, the products were not identified. Recently Chapman [3] has described that the reaction of *N*-cyclohexyl-2-benzothiazolesulfenamide with acetone leads to the formation of two main products, 2′-(benzothiazolylthio)propan-2-one and 1,1-bis(2′-benzothiazolylthio)-2-cyclohexylaminoprop-1-ene.

In this paper, the main reaction products formed by the reaction of *N*-isopropyl-, *tert.*-butyl-, *tert.*-amyl-, *tert.*-octyl- and morpholyl-2-benzothiazolesulfenamide with acetone are described. The compounds were identified by NMR technique and determined using reversed-phase high-performance liquid chromatography.

2. Experimental

2.1. Materials

Methanol, acetonitrile and tetrahydrofuran were HPLC grade (Merck). Osmometric purified water was made by a W. Werner system (Germany). Other chemicals were analytical reagent grade.

N-tert.-Butyl-2-benzothiazolesulfenamide (TBBS) (Monsanto), *N*-cyclohexyl-2-benzothiazolesulfenamide (CHBS) (Istrochem, SK) were commercial products. *N*-Isopropyl-2-benzothiazolesulfenamide

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0021-9673/99/$ – see front matter
PII: S0021-9673(98)01024-3

(IPBS), *N-tert.*-amyl-2-benzothiazolesulfenamide (TABS), *N-tert.*-octyl-2-benzothiazole-sulfenamide (TOBS) and *N*-morpholyl-2-benzothiazolesulfenamide (morBS) were prepared by the method described in Ref. [3]. All *N*-alkyl-2-benzothiazolesulfenamides were recrystallized from an ethanol–water solution. The derivatives of 1,1-bis-(2′-benzothiazolethio)-2-alkylaminoprop-1-ene (alkylAD), 1-(2′-benzothiazolethio)-2-morpholinoprop-1-ene (morAD) and 2′-(benzothiazolylthio)propan-2-one (MBTac) (Fig. 1) were prepared according to Ref. [2] and recrystallized from acetone.

2.2. NMR spectroscopy

Measurements were performed at ambient temperature on a Varian VXR-300 spectrometer with an operating frequency 300 MHz for protons and 75.429 MHz for carbons. Standard ^{1}H, ^{13}C, ^{13}C-APT (attached proton test) spectra and additional selective INEPT (intensive nuclei enhancement by polarisation transfer) experiments [4] were measured. Spectral width and the number of data points were set so that the digital resolution in 1D proton spectra was 0.3 Hz per point and in carbon spectra 1 Hz per point. The samples were dissolved in $C^{2}HCl_3$ (ca. 50 mg cm^{-1}). The number of scans in carbon spectra was from 500 up to 2000.

2.3. High-performance liquid chromatography

The chromatograph consisted of a Shimadzu LC10AD high-pressure binary solvent delivery system, using a Rheodyne injector provided with 20-μl sample loop, a Shimadzu SPD-M10Vp photodiode-array detector equipped with the Class 10 software for control of the system, data acquisition and integration. A 250×4.0 mm I.D., LiChrospher 100 RP-18 e, 5-μm Merck column was used. Analysis were carried out at ambient temperature.

3. Results and discussion

The stability of the acetone solution of *N*-isopropyl-, *tert.*-butyl-, *tert.*-amyl-, *tert.*-octyl-, cyclohexyl- and morpholyl-derivatives of 2-benzothiazolesulfenamides at ambient temperature is low and reaction with acetone proceeds. The products of the reaction are derivatives of alkylAD, morAD, and MBTac (Fig. 1). The formed compounds were identified by NMR and mass spectroscopy and determined using a reversed-phase HPLC method.

3.1. NMR spectroscopy

Signals in carbon spectra and their characteristic chemical shifts show that the studied samples contain two mercaptobenzothiazole (MBT) fragments, one amine fragment, one carbon belonging to CH_3 group (~16 ppm) and two quartenary carbons (~76–77 ppm; ~167 ppm). These fragments are assembled into the structure of alkylAD, as shown in Fig. 1. The suggested structure confirms the relatively low chemical shift of the sp2-hybridised quartenary carbon C_8, as a consequent effect of three free electron pairs in the β-position. The position of C_8, C_9 and C_{10} carbons was unambiguously confirmed by the $^{1}H-^{13}C$ long-range bond correlation between CH_3 protons and C_8 and C_9 carbons, as well as, by long range correlation between amino NH-R proton and C_{10} and C_9 carbons determined by selective INEPT experiments. The spatial proximity between the amino and methyl protons was also proven by a 1D NOE (nuclear Overhauser effect) difference experiment [5].

Reaction of *N*-morpholine-2-benzothiazolesulfenamide with acetone produces morAD, as shown in Fig. 1. Arrangement of the bonds was confirmed using selective INEPT experiments and protonated carbon C_8 is evident from APT and DEPT (distortionless enhancement by polarisation transfer) spectra.

Identification of MBTac was simple. This consists only of a CH_2COCH_3 fragment and one mercaptobenzothiazole unit. Experiments in deuterated acetone confirmed that the CH_2COCH_3 fragment comes from acetone.

Assignment of resonances belonging to an amine fragment was made by comparison with the spectral lines of this fragment in similar substances, e.g. in free amine and *N*-alkyl-2-benzothiazolesulfenamide. It is useful because the chemical shift of C_{11} (carbon directly bonded to nitrogen) is influenced by two negative γ-effects of the nuclei in the γ-position with

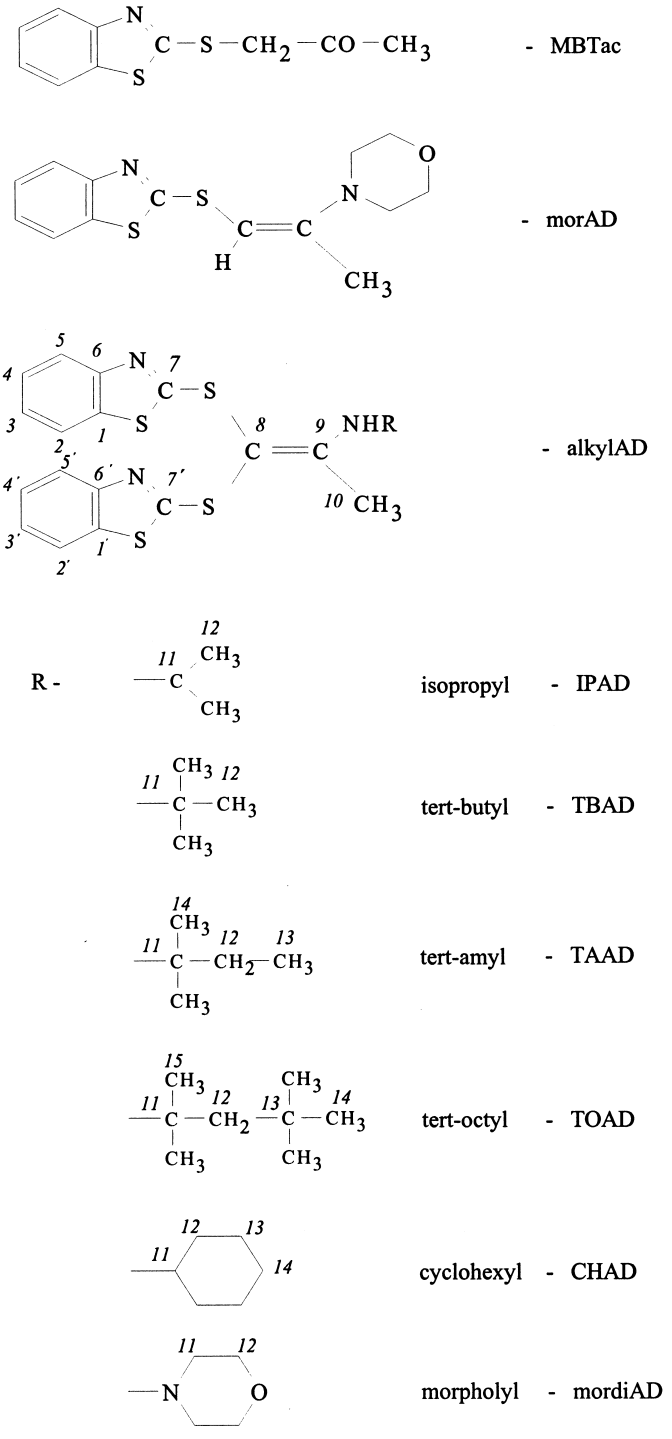

Fig. 1. Derivatives of 1,1-bis-(2′-benzothiazolethio)-2-alkylaminoprop-1-ene, 1-(2′-benzothiazolethio)-2-morpholinoprop-1-ene and 2′-(benzothiazolylthio)propan-2-one.

respect to C_{11}. This explains the smaller chemical shift of this carbon in alkylAD structure in comparison with the structure of *N*-alkyl-2-benzothiazolesulfenamide (only one γ-effect).

The starting point of the assignment of the resonances belonging to 2-mecaptobenzothiazole units was the resonances of carbons, $C_{1,1'}$ and $C_{6,6'}$ which can be unambiguously differentiated. The effect of the directly bonded nitrogen to the carbons $C_{1,1'}$ have higher chemical shifts (~155 ppm) then the carbons $C_{6,6'}$ bonded to sulphur (~135 ppm). Subsequently, via ^{1}H-^{13}C long-range through bond correlations (selective INEPT), resonances of the protons in the meta position to these carbons, $H_{3,3'}$ or $H_{4,4'}$, respectively were determined. H,H-COSY (correlated spectroscopy) experiments helped to assign all remaining aromatic ring protons and finally one-bond H,C-COSY experiments transferred the assignment information from protons to directly bonded carbons. We have found that the order of chemical shifts of protonated carbons of 2-mecaptobenzothiazole ($\delta(C_3)>\delta(C_4)>\delta(C_2)>\delta(C_5)$) does not depend on the structure of its derivatives. The remaining carbon resonances at ~167 ppm were carbons $C_{7,7'}$. Data are shown in Table 1.

3.2. HPLC analysis

An octadecyl-bonded endcapped silica material in a conventional 25 cm×4 mm I.D. column was used for the separation.

All of the alkyl derivatives of 2-benzothiazolesulfenamide have two absorption maxima at ca. 230 and 272 nm. The latter wavelength was chosen for the detection of the compounds.

Derivatives of alkylAD are partially soluble in acetone. Addition of dichloromethane to the acetone solution increases solubility. A mixture of acetone and dichloromethane in a volumetric ratio of 3:5 was a suitable solvent for all derivatives of alkylAD and it was used for analysis.

Acetonitrile, tetrahydrofuran and methanol as the organic modifiers in the mobile phase were compared for the selectivity control at isocratic condition. The capacity factors of the studied derivatives were measured at a flow-rate 1 $cm^3\,min^{-1}$, as is summarised in Table 2. The dead time was determined by water as a non-retained compound. At the chosen conditions with the tetrahydrofuran–water mixture, separation of these compounds was not achieved. With acetonitrile severe broad peak distortion occurred. This prompted the use of methanol in favour of acetonitrile. However, using a methanol–water mobile phase, two or three critical couples of derivatives were caused. One of them is TABS and morAD, the other is TOBS and IPAD. At a higher content of organic modifier in the mobile phase CHBS and TBAD or CHBS and TAAD can also appear as critical couples.

Table 1
^{13}C NMR chemical shifts (δ/ppm) of the compounds formed

C_i	IPAD	TBAD	TAAD	TOAD	CHAD	mordiAD	morAD
1,1′	155.0, 155.3	155.3, 155.6	155.2, 155.6	155.3, 155.6	155.1, 155.4	154.9, 154.6	155.1
2,2′	120.9, 121.0	121.0, 121.1	120.9, 121.0	120.8, 120.8	121.3, 121.4	120.9, 121.0	120.7
3,3′	126.0, 126.0	126.0, 126.0	126.0, 126.0	125.8, 125.8	126.5, 126.5	126.1, 126.1	125.9
4,4′	123.7, 124.0	123.6, 123.9	123.7, 124.0	123.6, 123.9	124.3, 124.5	123.9, 124.1	123.5
5,5′	121.7, 121.7	121.7, 121.8	121.6, 121.7	121.5, 121.6	121.5, 121.6	121.7, 121.8	121.5
6,6′	135.5, 135.0	135.5, 135.4	135.4, 135.5	135.3, 135.3	135.3, 135.4	135.3, 135.1	135.2
7,7′	172.1, 176.0	171.9, 175.9	171.9, 176.0	171.9, 175.8	173.4, 177.6	173.3, 171.8	175.4
8	76.1	78.5	78.0	77.4	76.1	84.8	159.0
9	166.3	167.6	167.6	167.1	166.9	168.3	84.0
10	16.3	17.4	17.2	17.5	16.4	21.1	16.2
11	24.1	53.8	56.4	57.5	53.9	51.0	47.6
12	46.7	31.1	35.4	54.5	24.9	67.2	66.5
13	–	–	8.4	31.7	34.4	–	–
14	–	–	28.8	31.5	25.3	–	–
15	–	–	–	31.4	–	–	–

Table 2
Capacity factors of the studied compounds in acetone–dichloromethane (3:5, v/v) solution at various compositions of the mobile phase at a flow-rate 1.0 $cm^3 min^{-1}$ and λ=272 nm

Mobile phases				
Water	20	20	20	15
MeOH	0	0	80	85
MeCN	0	80	0	0
THF	80	0	0	0
IPBS	NA	3.3	3.7	2.3
TBBS	NA	3.9	4.4	2.5
TABS	NA	5.2	6.2	3.2
TOBS	NA	6.6	8.6	4.2
CHBS	NA	11.2	15.2	6.2
IPAD	NA	8.1	8.8	4.3
TBAD	NA	11.5	12.8	5.8
TAAD	NA	15.1	16.8	7.2
TOAD	NA	16.6	20.4	8.3
CHAD	NA	29.8	>23	13.3
morBS	NA	2.5	2.9	1.6
morAD	NA	4.0	6.3	3.2
MBTac	NA	1.7	1.9	1.1

NA: not achieved.

To improve the selectivity and cut the analysis time, gradient elution was investigated. For adequate resolution of all alkylBS and alkylAD, derivatives in a standard solution was better to start the elution with methanol–water (6:4). Though, it is connected with a belated elution but it gains on the separation. Small changes in the gradient conditions cause dropping of the resolution of the critical couples, as shown in Table 3. A good separation of alkylBS and alkylAD standards is shown in Fig. 2. Separation of TABS from morAD was not achieved with sufficient resolution at these conditions. Up till now this phenomena has not been studied deeper because the first dominating product formed from *N*-morpholyl-2-benzothiazolesulfenamide in acetone is MBTac. This can call attention to the decomposition of the *N*-morpholyl-derivative of 2-benzothiazolesulfenamide.

The stability of alkylBS derivatives in a 0.1 m*M* standard mixture was studied. The derivatives stored at ambient temperature in darkness as well as in

Table 3
Resolution of some critical couples of various gradient elutions

Gradient		Resolution of		
Type	Condition	IPAD–TOBS	CHBS–TBAD	CHBS–TAAD
A	0–6 min conc. B 75% later isocratic	0	1.1	>1.5
B	0–12 min conc. B 67% 12–15 min conc. B 72% 15–18 min conc. B 100%	0.9	1.5	0
C	0–15 min conc. B 70% 15–17 min conc. B 72% 17–19 min conc. B 100%	1.2	0.95.	>1.5
D	0–15 min conc. B 70% 15–18 min conc. B 72% 18–19 min conc. B 100%	0.95	1.2	>1.5
E	0–15 min conc. B 70% 15–17.5 min conc. B 72% 17.5–19 min conc. B 100%	1.2 1.2	1.1 1.1	>1.5

Conditions: Flow-rate 1.0 $cm^3 min^{-1}$, λ=272 nm, compounds dissolved in acetone–dichloromethane (3:5, v/v). Mobile phase A: MeOH–water (6:4), mobile phase B: MeOH.

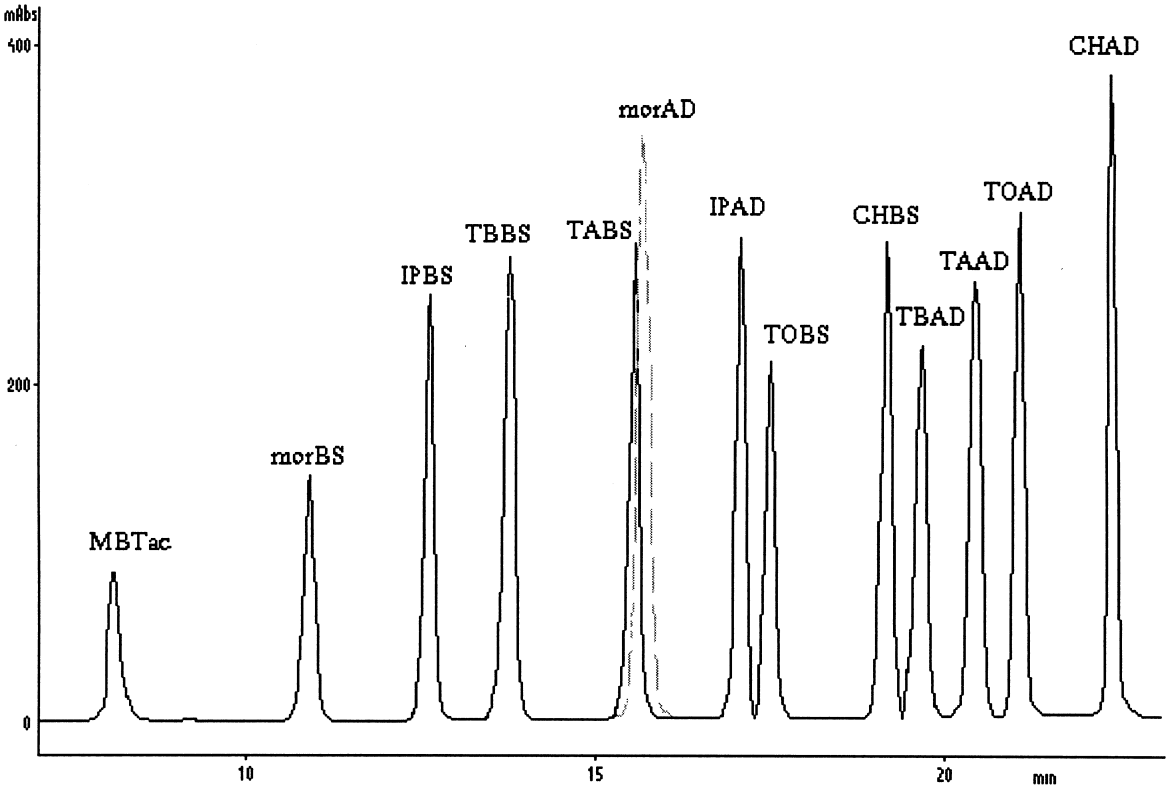

Fig. 2. Chromatogram of alkylBS, alkylAD and MBTac. Conditions: see gradient elution type E in Table 3.

daylight for a period of 8 days were analyzed at the gradient elution type E in Table 3. All derivatives of alkylBS showed a slow formation of alkylAD, as seen in Figs. 3 and 4. Significantly low stability of *N*-morpholyl-2-benzothiazolesulfenamide solution in acetone was observed (Fig. 4). Almost 25% of this derivative is decomposed to MBTac.

The detection limit using methanol–water at a flow-rate of 1 $cm^3\,min^{-1}$ and at $\lambda_{max}=272$ nm is $1.7\cdot10^{-4}$. The determined limits of quantification for isopropylAD, *tert.*-butylAD, *tert.*-amylAD, *tert.*-octylAD, cyclohexylAD, morAD and MBTac are 134, 124, 138, 153,161, 126 and 148 ng cm^{-3}, respectively.

Information concerning the reproducibility of the method was obtained using freshly prepared solutions of derivatives which were in contact with acetone no longer then 4 h at ambient temperature. The results are presented as relative standard deviations for peak areas per concentration in the sample containing ca. 10 $\mu g\,cm^{-3}$ of each components (Table 4). The R.S.D. of seven replicate injections for the studied derivatives was within 2.2%.

4. Conclusions

Derivatives of *N*-alkyl-2-benzothiazolesulfenamide undergo a slow decomposition in acetone solution already at ambient temperature. Products of the reaction identified by NMR spectroscopy are 1,1-bis-(2′-benzothiazolethio)-2-alkylaminoprop-1-ene, 1-(2′-benzothiazolethio)-2-morpholinoprop-1-ene and 2′-(benzothiazolylthio)propan-2-one. A conventional octadecyl-bonded silica-packed column and careful adjustment of mobile phase selectivity with methanol in a gradient elution were used for separation of these compounds by a HPLC method. Results presented here could warn environmental

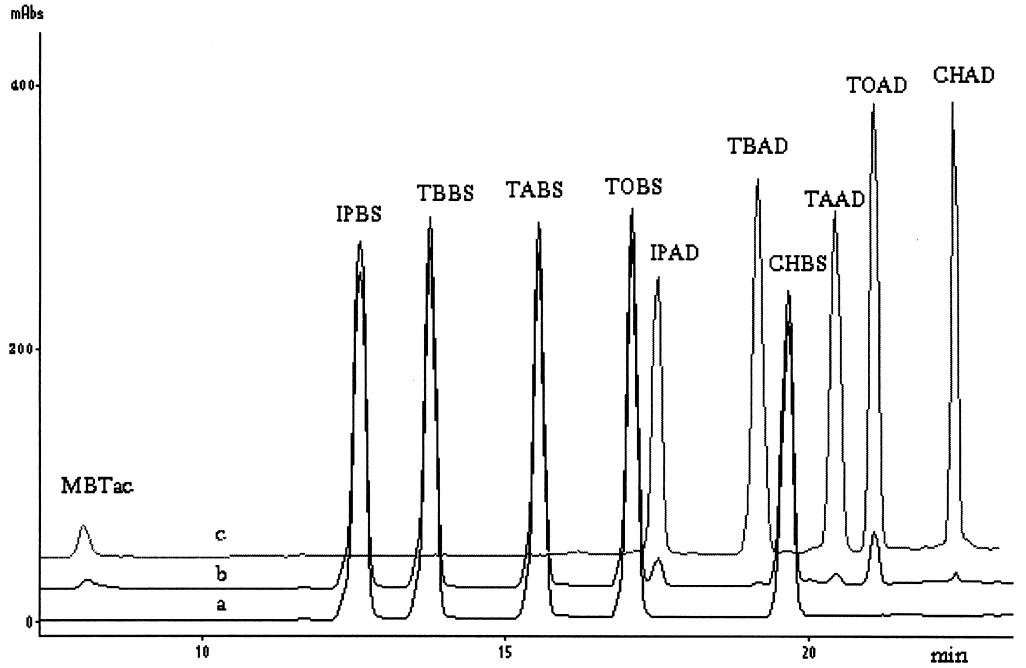

Fig. 3. Chromatograms of alkylBS and alkylAD. Conditions: as in Fig. 2, (a) a fresh solution of alkylBS, (b) the 8 days stored solution of alkylBS, (c) solution of alkylAD.

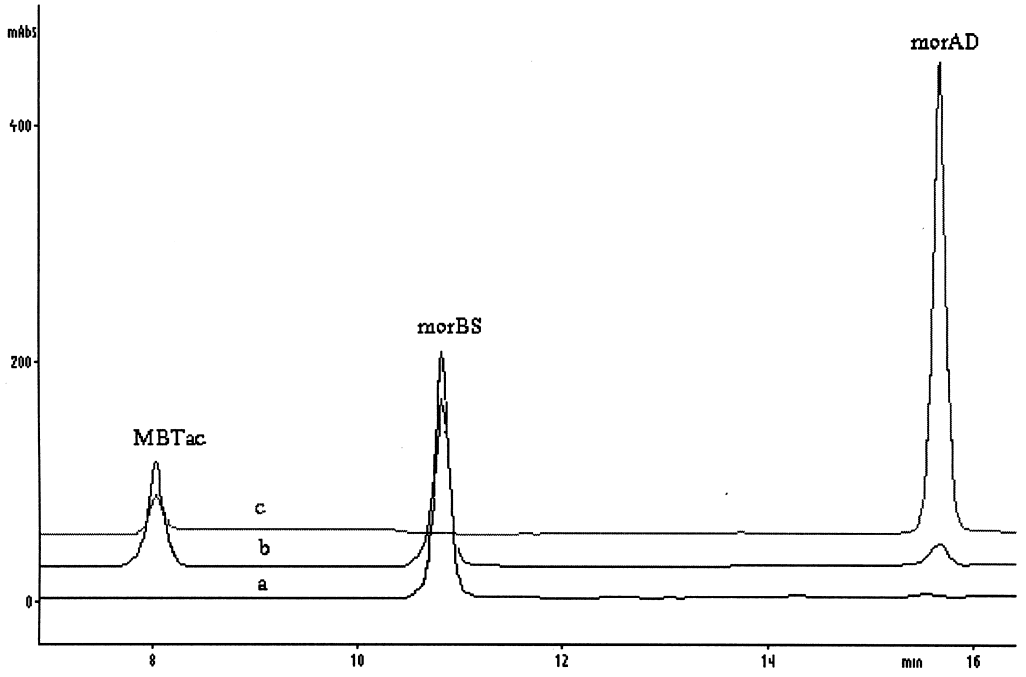

Fig. 4. Chromatograms of morBS and morAD. Conditions: as in Fig. 2, (a) a fresh solution of morBS, (b) the 8 days stored solution of morBS, (c) solution of morAD.

Table 4
Reproducibility of the method

Derivatives	R.S.D. (%)
MBTac	2.1
morBS	2.2
IPBS	1.9
TBBS	1.8
TABS	1.7
TOBS	2.0
CHBS	1.9
IPAD	2.1
TBAD	1.8
TAAD	1.6
TOAD	1.7
CHAD	1.1

Conditions: as in Fig. 2, the solution contents ca. 10 μg cm^{-3} and of each component.

analysts of using acetone as a solvent or extractive agent for the determination of *N*-alkyl-2-benzothiazolesulfenamides.

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