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Structures and GC retention times of persistent compounds of technical toxaphene (CTTs)

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1. Introduction

The chlorination of camphene yields a complex mixture of chlorinated compounds which has been applied as pesticide with one of the world's highest production rates¹). Wagner-Meerwein rearrangements during the synthesis lead to several hundreds of chlorinated bornanes, chlorinated camphenes and further unspecified chlorinated hydrocarbons, here abbreviated as compounds of technical toxaphene (CTTs). In biota a much lower number of CTTs remains unmetabolized²⁾³. In former times, a proper quantitation of residues of toxaphene was often difficult for lack of single standards. This dilemma has been overcome by synthesis and structural elucidation of single CTTs⁴⁾⁵. The commerically available "Parlar 22 components standard" consists of 17 chlorinated bornanes and 5 chlorinated camphenes⁴. Relative retention times of its compounds were available on DB-5⁶. Additionally, we have isolated a further recalcitrant heptachlorobornane in marine organisms⁷⁾ and observed 5 CTTs with so far unknown structure in blubber of different seal species⁸. These CTTs, together with the "Parlar 22 components standard", were analyzed on a very non-polar CP-Sil 2 column.

Up to now, the knowledge on the structure of further compounds in technical toxaphene and in biota is limited. Our presentation is a first approach to compare the substructures of known CTTs in order to recognize structural elements of CTTs leading to short GC retention times, low response factors in GC/ECNI-MS, and persistence in biota.

2. Experimental

GC/ECNI-MS was performed on an HP 5989B MS Engine connected to an HP 5890 II plus gas chromatograph (Hewlett-Packard). Separations were carried out on the non-polar CP-Sil 2 column (Chrompack, Middelburg, The Netherlands). The column parameter were: 50 m length, 0.25 mm internal diameter, and 0.25 µm film thickness. GC oven program: 80°C, 1 min, 15°C/min to 160°C, 1 min, 2°C/min to 255°C, 15°C/min, 290°C (21.67 min). Run time: 80 min. The "Parlar 22 Components Standard" was obtained from Dr. Ehrenstorfer, Augsburg, Germany.

3. Results and Discussion

3.1 General considerations referring structures of CTTs

Theoretical calculations showed that most of the polychlorinated bornanes are chiral⁹⁾. Due to the steric conditions of the bornane skeleton (ring system), both enantiomers must be assigned to different chemical names⁹⁾. A symmetry plane through carbons C1, C4 and C7 is existing and the mirror image of a chlorobornane is obtained by exchange of the substituents at C2, C3 and C9 with those at C6, C5 and C8, respectively (see Table 1)⁹⁾. E. g. the mirror image of 2-endo, 3-exo, 5-endo, 6-exo, 8, 8, 10, 10-octachlorobornane is 2-exo, 3-endo, 5-exo, 6-endo, 9, 9, 10, 10-octachlorobornane. When structures of CTTs have to be compared it is important to keep the structures of both enantiomers in mind. Instead of the long chemical names, code names according to Andrews and Vetter are used which allow to distinguish between the two enantiomeric forms¹⁰).

chemical structure enantiomer a	chemical strucutre enantiomer b	RT on CP-Sil 2	common names in literature	systematic code [10]
2-exo, 3-endo, 5-exo, 9,9,10,10	3-exo, 5-endo, 6-exo,8,8,10,10	49.20	TOX7	B7-1453
2-endo,3-exo,5-endo,6-exo,8,8,10,10	2-exo,3-endo,5-exo,6-endo, 9,9,10,10	53.14	Parlar #26; T2; TOX8	B8-1413
2, 2, 5-endo, 6-exo, 8,9,10	2-exo, 3-endo, 6,6, 8,9,10	55.38	Parlar #32; Toxicant B	B7-515
2,2,5,5,9,9,10,10	3,3,6,6,8,8,10,10	57.41	Parlar #38	B8-789
2,2,3-exo,5-endo,6-exo,8,9,10	2-exo,3-endo,6,6,8,9,10	57.90	Parlar #39	B8-531
2-endo,3-exo,5-endo,6-exo,8,9,10,10	2-exo,3-endo,5-exo,6-endo,8,9,10,10	57,94	Parlar #40	B8-1414
2-exo,3-endo,5-exo,8,9,9,10,10	3-exo,5-endo,6-exo,8,8,9,10,10	58.19	Parlar #41	B8-1945
2,2,5-endo,6-exo,8,8,9,10	2-exo,3-endo,6,6, 8,9,9,10	58.31	}Parlar #42	B8-806
2,2,5-endo,6-exo, 8,9,9,10	2-exo,3-endo,6,6,8,8,9,10			B8-8 09
2-ex0,5,5, 8,9,9,10,10	3,3,6-exo,8,8,9,10,10	58.89	Parlar #44	B8-2229
2-endo,3-exo,5-endo,6-exo,8,8,9,10,10	2-exo,3-endo,5-exo,6-endo, 8,9,9,10,10	59.69	Parlar #50; T12; TOX9	B9-1679
2,2,5,5,8,9,9,10,10-	3,3,6,6,8,8,9,10,10-	63,58	Parlar #62	B9-1025
2-exo,3-endo,5-exo,6-exo,8,8,9,10,10	2-exo,3-exo,5-endo,6-exo,8,9,9,10,10	63.99	Parlar #63	B9-2206

TABLE 1: Chlorosubstituents, retention times, common names in literature, and systematic code [10] of important chlorinated bornanes

The following short description of this code system is presented with the example of 2-endo,3-exo,5endo,6-exo,8,8,10,10-octachlorobornane (B8-1413). The code starts with a letter for the hydrocarbon backbone (B for bornane) followed by a number which reflects the number of chloro substituents (8 for an octachlorinated CTT); after a hyphen a 1-4 digit number is following which systematically counts the respective isomers due to their exact chloro substituents. In the case of chiral CTTs one code number is valid for both enantiomers. Furthermore, enantiomers can be distinguished by a small letter as suffix (B8-1413a or B8-1413b). On request the code system with structures and codes of all chlorinated bornanes is available as a Windows program from the authors or on Internet by anonymous ftp from hpb1.hwc.ca in /pub/tox.

The importance of considering the structure of both enantiomers of a CTT is explained in the following example: elimination of the 2-endo chloro atom from B8-1413 (Parlar #26) leads to B7-1453 (TOX7). However, one must look at B8-1413a and B7-1453b (or B8-1413b and B7-1453a) to recognize the structural relationship of the compounds while B8-1413a and B7-1453a (or B8-1413b and B7-1453b) look completely different on the first view (see Table 1). Consequently, when structures shall be compared the enantiomer that shows the best relationship to another CTT has to be used in order to recognize common structural elements. Table 1 presents chemical names of both enantiomers and retention times on CP-Sil 2 of important hepta-, octa-, and nonachlorobornanes in the "Parlar 22 components standard" (Dr. Ehrenstorfer, Augsburg, Germany)⁶⁾ and our isolate TOX7 (B7-1453)⁷⁾. Note also that structures of both enantiomers in Table 1 apply the IUPAC bornane skeleton numbering which means that the bridge carbon C9 is located above the carbon pairs C2 and C3¹¹).

3.2 Elution order of CTTs on GC phases related to the substitution patterns of CTTs

The bornanc skeleton can be divided in three parts a) the six-membered ring (C1-C6), b) the methyl groups of the bridge (C8 and C9), and c) the methyl group at the bridgehead (C10). Two parts were fixed while the influence of the substituents at the third part on the retention times was studied. From heptachlorobornanes on, all CTTs (except for B7-499 (Parlar #21)) had either two or three chloro substituents at the bridge carbons C8 and C9. Furthermore, both carbon pairs C2/C3 and C5/C6 carried one to three chloro substituents; unsubstituted or persubstituted carbon pairs C2/C3 and C5/C6 were not observed⁴⁾⁵.

CTTs with the same structure except for the distribution of the substituents at C8 and C9:

• CTTs with 2 chloro substituents at C8 (or C9) had much lower retention times than CTTs with one chlorine at both C8 and C9.

(8,8,9) or (8,9,9) substitutions at C8 and C9 had only little influence on the retention times of CTTs. Considering this observation allowed also to compare CTTs with inverse substitution at C8 and C9 like B9-2206 (Parlar #63) and B9-1679 (Parlar #50): the difference (except for C8/C9 exchange) is 2-endo (B9-1679a) versus 2-exo (B9-2206b) which, however, has considerable influence on the retention time.
All in all, CTT isomers with two or three substituents at C8 and C9 showed an impressive trend: 8,8-substituted isomers eluted in front of 8,9-substituted isomers and 8,8,9- (or 8,9,9-) substituted isomers.
Octa- and nonachlorobornanes with only one chloro substituent at the bridge carbons C8 and C9 were not available for this study. However, B7-499 (Parlar #21) which has only one substituent at the bridge carbons C8 and C9, eluted at comparably short retention time though it has a 2,2,5,5-substitution. Therefore, it is most likely that CTTs with only one substituent at C8 or C9 generally elute early.

CTTs which different substitution in the six-membered ring (C1-C6)

• Exclusively alternating endo-exo-endo-exo substitution at the six-membered ring yields particularly low retention times.

• 2-endo,3-exo,5-endo,6-exo-substituted CTTs had much lower RT as 2,2,5,5-substituent CTTs. The difference in the retention times was very high.

• Nonachlorobornanes: Regarding identical substitution at the bridge carbons (C8 and C9), the retention time increased in the following order: 2-endo,3-exo,5-endo,6-exo (B9-1679a; Parlar #50) < 2,2,5-endo,6-exo (B9-1046a; Parlar #56) < 2-exo,5-endo,6,6 (B9-536b; Parlar #59) < 3,3,6,6 (B9-1025b; Parlar #62) < 2-exo,3-endo,5-exo (B9-2206a; Parlar #63).

CTTs which differed only with one chloro substituent

B8-1414 (Parlar #40) changes into B8-1945 (Parlar #41) when the 2-endo chloro atom is moved to C8. Both CTTs show very similar retention times. As already mentioned, 8,8,9 substitutions and 8,9 substitutions had identical ranges in retention times. Further examples were observed¹².

3.3 Structure and persistence of CTTs.

In different seal species from the Antarctic 11 persistent CTTs were detected and 6 of them were of known structure⁸). These highly abundant CTTs are B8-1413 (Parlar #26), B9-1679 (Parlar #50), B7-1453 (TOX7), B8-2229 (Parlar #44), B8-1945 (Parlar #41), and B8-1414 (Parlar #40)⁸). A further abundant CTT in fish samples is B9-1025 (Parlar #62)¹³⁾¹⁴). It is remarkable that these 7 persistent CTTs have six common substituents: all 7 persistent CTTs are substituted at 3-exo, 6-exo, 8, 8, 10,10 position (or 2-exo, 5-exo,9,9,10,10 for the other enantiomer). The 3-exo, 6-exo, 8, 8, 10,10-hexachlorobornane with the code name B6-1131, seems to be a key compound for persistent toxaphenes⁷).

4. References

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