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STRIPPING ANALYSIS AND CHROMATOGRAPHIC SNIFFING FOR THE SOURCE IDENTIFICATION OF ODOROUS COMPOUNDS IN DRINKING WATER

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SUMMARY

Chemical and sensory methods have been combined into an improved technique for the source identification of odorous compounds in drinking water. A simple device for gas chromatographic sniffing, in which the capillary column is lead to the odour observer via heated copper tubing, has been developed. This system is highly sensitive and highly accurate for the determination of retention times. A stripping technique that permits high stripping temperatures without technical problems has also been developed, and it has been shown to increase significantly the number of odorous compounds detected by column sniffing. The design of the stripping system gives a very low blank level that results in almost no compounds detected on column sniffing of extracts from odour-free water.

Odour profiles from a river basin with discharges from agriculture, industry and municipalities are presented. Special attention has been given to the effects of pulp mill discharges, and it is shown that they are mainly of local importance with regard to odorous compounds.

INTRODUCTION

Off-flavours in drinking water are usually due to incomplete elimination of odorous organic compounds present in the raw water source[1–4]; some of these are of natural origin and can be produced by algae, actinomycetes and other microorganisms[5–10], others are of industrial origin or by-products of water treatment processes[3,11–13]. Still others are so far unidentified and have only been detected by the so-called column-sniffing technique, where the human nose is used as detector in a gas chromatograph[3,14].

For a reliable source identification of off-flavours in drinking water, it is in most cases necessary to combine chemical and sensory methods[15,16]. The strategy recommended and elaborated in this work is based on the following steps:

(1) Efficient enrichment of odorous compounds from the water sample.

(2) Gas chromatographic (GC) separation followed by sensory and instrumental detection of individual odorous compounds.

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(3) Determination of the geographical origin of each odorous compound.

(4) Estimation of the contribution of each individual compound to the total off-flavour of the sample.

(5) Chemical identification of odorous compounds.

In various fields of aroma research the column-sniffing technique has turned out to be a powerful tool in combined sensory and chemical methods[17]. The technique has also been used in the analysis of drinking water[3], but without such apparent success. The concentration step preceding the column sniffing is one of the weak points[16]. The extremely low concentrations of the compounds of interest, sometimes below the nanogram per litre level, and the complex composition of many water samples, make the correlation of odour perceptions from the column sniffing with the GC peaks uncertain. Moreover, drinking water typically contains several odorous compounds that combine into a single odour perception. This makes it difficult to know if a particular explanation of an off-flavour phenomenon is a complete or only a partial one. In fact, there have been very few studies in which the cause of off-flavours in drinking water has been determined with certainty.

The extremely demanding technical requirements in chemical and sensory analysis of drinking water make this field interesting from a methodological point of view. We have considerably improved the recovery of odorous compounds in the concentration step and have also investigated and optimized the precision and sensitivity of the column-sniffing technique. Our improved techniques have been successfully used in a case study of off-flavour compounds in a waterworks downstream from a pulp mill. However, there still remain some weak points in the procedures for identifying sources of off-flavours in drinking water. These points are discussed in the final section.

AN OPTIMIZED AND SIMPLE DEVICE FOR COLUMN SNIFFING

In order to minimize the risk of condensation problems and optimize the sensitivity and precision of the column sniffing, a very simple sniffing device has been constructed. Instead of an effluent splitter being used, aliquots of the sample are injected twice. The first time the flexible fused-silica column is lead into a "sniffing cup" through heated copper tubing (Fig. 1), and the perceived odours are recorded. The second time the column is connected to a flame ionization detector and an ordinary chromatogram is obtained. Since the nose of the odour observer can be located very close to the column end, and the column outside the chromatograph is heated by the copper tubing, several advantages are obtained (*cf.* Sandra *et al.*[18]). Contamination and condensation problems are avoided. Dead volumes, where remixing can occur, are minimized. Furthermore, the absence of transfer tubing between the column end and the nose makes the use of an auxiliary gas unnecessary and thus increases the sensitivity.

When this sniff device is used, the duration of one odorous peak is short, usually less than 5 sec, which makes it possible to distinguish between odorous compounds with a retention time difference as low as 6 sec. The high resolution obtained by our technique is of great value when analysing such complex samples as drinking and raw water extracts, but requires continuous sniffing during the whole chromatographic run. We use two odour observers during each run, with each observer's

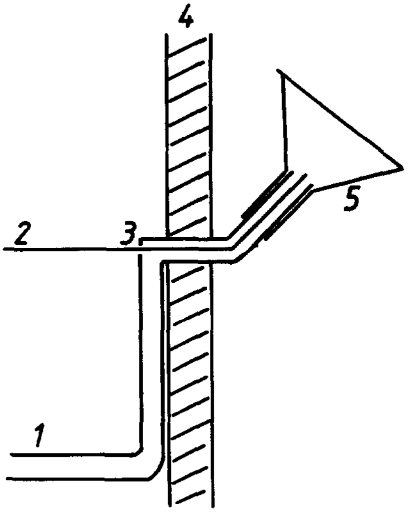

Fig. 1. A simple device for chromatographic sniffing. The fused-silica column is lead through the oven wall inside a copper tube to the sniffing funnel. The distance from the hole in the copper tubing (point 3) to the column end in the sniffing funnel is 15 cm. The length of the copper tubing in the GC oven is 50 cm. 1 = copper tubing; 2 = capillary column; 3 = hole in the copper tubing; 4 = GC oven wall; 5 = sniffing funnel.

sniffing period lasting for 6–8 min. The precision and accuracy of the retention time determinations with flame ionization detection (FID) and sensory detection, respectively, have been evaluated by repeated injections of synthetic mixtures of odorous compounds. The GC parameters are shown in Table I. Carbon disulphide was used as solvent and the injected amount of each compound varied between 0.005 and 2 ng. The C_6, C_8, C_{10} and C_{12} 1-chloroalkanes were used as standards, and retention indices were calculated according to

$$I = \frac{t_{R(\text{substances})} - t_{R(Z)}}{t_{R(Z+1)} - t_{R(Z)}} + Z$$

where $t_{R(Z)}$ and $t_{R(Z+1)}$ are the retention times for the standards that bracket the substance of interest, and $Z = 1, 2$ or 3.

The estimated standard deviation of retention times determined by odour detection varied between 0.010 and 0.029 min (see Table II). The difference in mean

TABLE I

GAS CHROMATOGRAPHIC PARAMETERS

Gas chromatograph	Hewlett-Packard 5880A
Column	50 m × 0.3 mm, OV-101, fused silica
Carrier gas and flow-rate	Helium, 40 cm/sec
Injector temperature	250°C
Injected volume	1.5 µl, splitless injection
Temperature programme	30°C (5 min), 5°/min, 220°C (10 min)
Detector	Flame ionization detector, attenuation 2^0

TABLE II

PRECISION AND ACCURACY OF INSTRUMENTAL AND SENSORY DETERMINATION OF RETENTION TIME

Compound	*FID**			*Odour detection***			*Difference between mean retention times $\bar{t}_{OD} - \bar{t}_{FID}$ (min)*
	Mean retention index	*S.D. of retention index*	*S.D. of retention time (min)*	*Mean retention index*	*S.D. of retention index*	*S.D. of retention time (min)*	
Dimethyl trisulphide	1.488	0.0007	0.005	1.482	0.0025	0.019	−0.052
2-Isopropyl-3-methoxypyrazine	2.155	0.0006	0.004	2.147	0.0021	0.014	−0.056
2-Methylisoborneol	2.588	0.0009	0.006	2.586	0.0028	0.019	−0.012
2,6-Dichloroanisole	2.617	0.0003	0.002	2.620	0.0020	0.013	+0.021
2,3,6-Trichloroanisole	3.448	0.0008	0.005	3.460	0.0017	0.010	+0.071
Geosmin***	3.658	0.0007	0.004	3.670	0.0041	0.024	+0.069
2-Methoxynaphthalene	3.813	0.0008	0.005	3.836	0.0050	0.029	+0.128

* Based on five determinations.
** Based on three to seven determinations.
*** *trans*-1,10-Dimethyl-*trans*-9-decalol.

retention times between odour detection and FID was found to vary between −0.056 and +0.128 min, depending on volatility. Because of the high sensitivity of the column-sniffing technique, the odour is usually detected before the peak maximum is reached. This explains the negative differences in retention times for the most volatile compounds. The least volatile compounds are retarded (in our study up to 8 sec) in the last, somewhat cooler, part of the capillary column. With a more sophisticated device, however, where the column temperature is synchronized with the oven temperature all the way to the sniffing funnel, we have shown that this retardation can be reduced. When we compared the two methods with raw water extracts we found no essential differences. Hence most of this study was undertaken using the simple device.

The small differences in retention indices between odour detection and FID, together with the low standard deviations, indicate that our sniffing device can be used to determine the retention times of odorous compounds with high accuracy. It is therefore possible to correlate detection of an odour with a particular peak in the

TABLE III

SENSITIVITY OF COLUMN SNIFFING

Odour intensities: 1 = weak; 2 = medium; 3 = strong; – = not detected.

Compound	*Injected amount (ng)*						
	0.75	*0.2*	*0.075*	*0.02*	*0.005*	*0.0003*	*0*
2-Isopropyl-3-methoxypyrazine	3	3	2	1	1	1	–
2-Methylisoborneol	3	3	2	1	1	–	–
Geosmin	3	2	2	2	–	–	–

chromatogram, provided that the sensitivity of the flame ionization detector is high enough.

The possibility of achieving simultaneous instrumental and odour detection by using a two-column system, following Veijanen *et al.*[14], was also considered. A fused-silica column (SP2100, 50 m × 0.2 mm) was cut into two columns of equal length. Both were connected to the injector of the gas chromatograph by using one soft graphite ferrule. The columns were compared by injecting a standard solution consisting of 36 compounds, with both columns connected to the flame ionization detector. Even after repeated adjustments of the lengths, the two columns performed differently. For some compounds the retention times on both columns were identical but for other compounds the difference in retention times was up to 0.10 min, probably owing to inhomogeneous coating of the stationary phase in the original 50-m column. It was concluded that the same column must be used for both instrumental and odour detection in order to take full advantage of the high precision obtainable with our sniffing devices.

COLUMN SNIFFING SENSITIVITY AND ODOUR INTENSITY

In order to study the sensitivity of column sniffing, different dilutions of a synthetic mixture of odorous compounds were analysed. The results from one trained observer are reported in Table III. These results indicate that certain odorous substances can be detected in very low amounts, *e.g.* 0.3 pg of 2-isopropyl-3-methoxypyrazine gave a weak but distinct odour perception. The detection limit of the flame ionization detector is *ca.* 0.1 ng for each compound in Table III. The sensory detection limit for the first three compounds is significantly lower than the FID detection limit. In the case of 2-isopropyl-3-methoxypyrazine, the difference is *ca.* three orders of magnitude.

The precision of odour intensity assessments with column sniffing has also been studied. Three trained observers analysed different concentrations of the same synthetic mixture on different occasions and were asked to assess the odour perceptions on a three-grade scale. The results from one specific concentration are summarized in Table IV. A similar random variation was also obtained for the other concentrations. From general olfactometric research it is known that, even under ideal circumstances, a trained odour observer can identify only about three levels of odour intensity[19]. The somewhat poorer results in our case can easily be explained by the short time available for each assessment at column sniffing.

Compound	*Injected amount (ng)*			
	4	*1*	*0.4*	*0.1*
Acetophenone	1	—	—	—
Naphthalene	1	—	—	—
2,6-Dichloroanisole	2	2	1	—
2,3,6-Trichloroanisole	2	1	—	—
2-Methoxynaphthalene	3	2	1	—

TABLE IV

PRECISION OF ODOUR INTENSITY ASSESSMENTS

Odour intensities: 1 = weak; 2 = medium; 3 = strong; – = not detected.

Compound	*Perceived odour intensity*			*Injected amount (ng)*
	Person A	*Person B*	*Person C*	
Dimethyl trisulphide	2, 1, 2, 2	2, 2, 1	1, 1	0.5
2-Isopropyl-3-methoxypyrazine	3, 2, 3, 3	2, 2, 2	2, 2	0.2
2-Methylisoborneol	3, 2, 3, 3	–, –, 1	1, 1	0.2
2,6-Dichloroanisole	2, 2, 2, 1	1, 2, 1	2, 2	1
2, 3, 6-Trichloroanisole	2, –, 1, 1	3, 1, 2	2, 1	1
Geosmin	2, 2, 2, 2	–, 2, 2	2, 2	0.2
2-Methoxynaphthalene	2, 1, 2, 2	–, 1, 1	–, 2	1

In Table IV the variation between different observers is not significantly greater than the variation for one observer on different occasions. However, odour assessments of a great number of drinking water extracts have revealed some systematic differences between the members of our test panel. Each of them is considerably less sensitive to one or two specific drinking water contaminants.

EVALUATION OF THE STRIPPING TECHNIQUE BY COLUMN SNIFFING

The closed-loop stripping technique developed by Grob and Zurcher[20] is widely used for the analysis of volatile organic compounds in water. Borén *et al.* have shown that the recovery of many organic compounds can be substantially improved by replacing the standard recirculating stripping system with an open system, which permits higher stripping temperature[21]. Furthermore, Sävenhed *et al.* demonstrated that stripping extracts from surface waters received a higher odour intensity and the corresponding stripped water samples a lower odour intensity when the stripping temperature and the stripping time were increased[16]. In this work the stripping technique was evaluated by column sniffing.

In a first attempt to evaluate the effect of the stripping parameters, the following experiment was performed. A surface water sample was stripped at 30°C for 2 h. After extraction of the carbon filter, the process was continued with a new filter at 60°C for 5 h. The results of the column sniffing showed that stripping under standard conditions (30°C, 2 h) gives a very incomplete enrichment of odorous compounds. All odorous compounds detected in the first extract could also be detected in the second extract. Furthermore, the change in stripping conditions implied that the number of odorous compounds detected increased by 110% to 160%, depending on the odour observer.

In order to distinguish between effects due to temperature and those due to stripping time, additional experiments were performed. A surface water sample was stripped at 10°C for 8 h. After extraction of the carbon filter, the process was continued at 60°C for 6 h. The stripping temperature was found to affect the number of odorous compounds detected, as well as the yield of these compounds. More precisely, the column sniffing showed that the second extract contained 16 odorous

TABLE V

EFFECT OF STRIPPING TEMPERATURE ON THE YIELD OF SOME ODOROUS COMPOUNDS

A raw water sample (1 l) from Norrköping waterworks was stripped with purified nitrogen gas (1 l/min). Dichloromethane was used as extracting solvent.

Compound	*GC–FID peak area*	
	Stripping at 10°C for 8 h	*Continued stripping at 60°C for 6 h*
Dimethyl trisulphide	23	13
Unidentified compound*	14	14
2-Methylisoborneol	2	15
Geosmin	<2	7

* This compound has a retention index of 1.940 and has a strong musty odour.

compounds that were not among the 27 compounds detected in the first extract. The increase of the yield of some strong-smelling compounds is shown in Table V.

The effect of the stripping time was evaluated in a similar way. A surface water sample was stripped at 60°C for 2 h, and then at the same temperature for a further 5 h. In this experiment the number of odorous compounds detected increased only slightly. It is noteworthy, however, that most of the odorous compounds detected in the first extract were also detected in the second extract. This means that, even at 60°C, the yield of odorous compounds can be increased by increasing the stripping time.

The results reported here concerning the effects of the stripping time and temperature on the yield of odorous compounds have been verified in other similar experiments. The results are reasonable from a theoretical point of view and are also in accordance with previous studies[16,22].

We have described above how certain odorous compounds can be detected with extremely high sensitivity by column sniffing. Consequently, it is very important that the stripping system is free from contamination by odorous substances from previously analysed water samples. In order to check the blank level of the whole analytical system, a blank water sample of sufficient purity is needed. Milli-Q® water processed through a Norganic™ trace organic removal cartridge made of activated carbon (Millipore), so-called Norganic water, was found to be suitable. Stripping of a Norganic water sample at 60°C for 2 h typically gives only two or three weak odour registrations on column sniffing of the dichloromethane extract. The use of Norganic water as blank water has thus demonstrated the very low blank level of the open stripping system as evaluated by chromatographic sniffing. It should be noted that the stripping system used in this study has been regularly used for more than 2 years.

MOTALA RIVER —A CASE STUDY

The Motala River, which runs from Lake Vättern to the Baltic, is one of the most important sources of drinking water in Sweden. At the same time it serves as receiving water for many sewage plants and industries, including a pulp mill with chlorobleaching. Leakage from agricultural areas and a high content of humic material in some affluents are two other important factors for the water quality of Motala River. A case study concerning organics in general in this river basin has been reported previously[21]. The present case study was focused on source identification of odorous compounds in the river water and off-flavour problems at the Norrköping waterworks near the river estuary.

In a first attempt to elucidate the origin of the off-flavour problems at the Norrköping waterworks, raw and drinking water samples were analysed by the methods described above. A typical pair of raw and drinking water chromatograms is shown in Fig. 2, in which the strongest-smelling compounds are marked by arrows. By comparing the perceived odours from the two water samples it can immediately be seen that the water treatment processes (coagulation, rapid and slow sand filtration, chlorination) give only a partial reduction in odorous compounds, In fact, the column-sniffing technique provides an even stronger link between the drinking water off-flavour and the raw water contaminants. All odorous compounds detected in the drinking water extract are also present in the raw water extract. This result has been confirmed by repeated sampling and analysis. Monitoring of the water quality at the Norrköping waterworks for more than a year has also revealed a very stable pattern of odorous compounds in the raw water as well as the drinking water. In contrast to most other reports on off-flavours in drinking water (*e.g.* McGuire *et al.*[1] and Yagi *et al.*[4]), the seasonal variation has not been very pronounced.

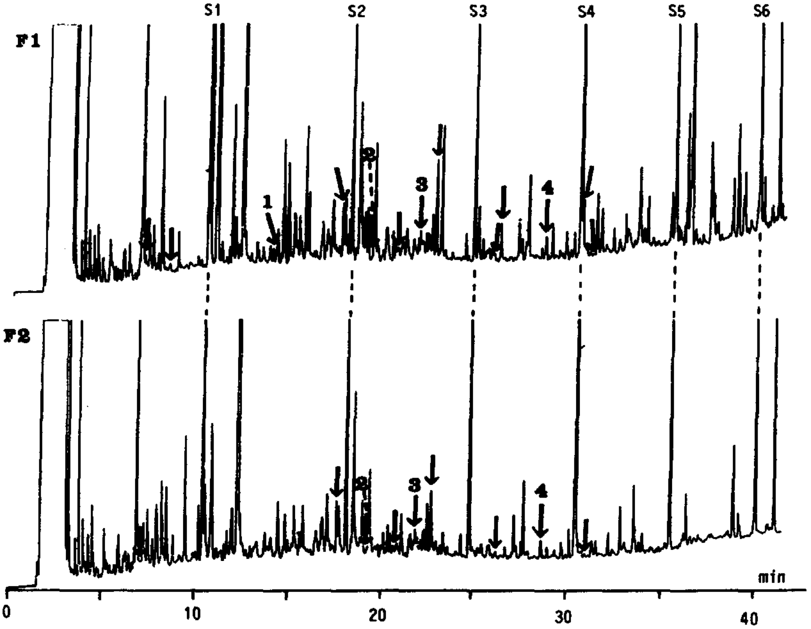

Fig. 2. Chromatograms of samples from the Norrköping waterworks: F1 = raw water; F2 = drinking water. The strongest-smelling compounds are marked by arrows, 1 = Dimethyl trisulphide; 2 = 2-isopropyl-3-methoxypyrazine; 3 = 2-methylisoborneol; 4 = geosmin. S1–S6 are internal standards (C_6, C_8, C_{10}, C_{12}, C_{14} and C_{16} 1-chloroalkanes) added to the water samples at a concentration of 0.05 μg/l before analysis. The samples were purged at 60°C for 2 h using the open stripping system. GC conditions as listed in Table I.

When comparing the perceived odours with the response of the flame ionization detector in Fig. 2 it is striking that all the perceived odours correspond to very small or even non-existent peaks, thus indicating that the compounds of interest have a very low threshold odour concentration. Among the most characteristic off-flavour compounds detected by the column-sniffing technique only one (dimethyl trisulphide) was present in high enough concentration to be identified by GC–mass spectrometry (MS). Three other compounds (geosmin, 2-methylisoborneol and 2-isopropyl-3-methoxypyrazine) could be identified by performing column sniffing on extracts with known odorous compounds and comparing odour quality and retention indices of the odour perceptions to corresponding data from the water extracts. The remaining off-flavour compounds, one of them with retention index 1.940 and a strong musty odour, are still unidentified.

The last part of the case study focused on the identification of sources of off-flavour compounds in the Motala River. A threshold odour number (TON) profile of the river is shown in Fig. 3. The river water is strongly affected by plant discharges immediately downstream from the pulp mill. Apart from this, however, the TON values alone did not support any conclusions about the contribution of industrial discharges to the river water off-flavour. A combination of stripping enrichment and the column-sniffing technique provided the answer. Fig. 4 summarizes the presence and odour intensity of the thirteen most characteristic off-flavour compounds at eight selected locations in the river basin. Except for the sampling point immediately downstream from the pulp mill, there is a striking similarity among the odour profiles. A

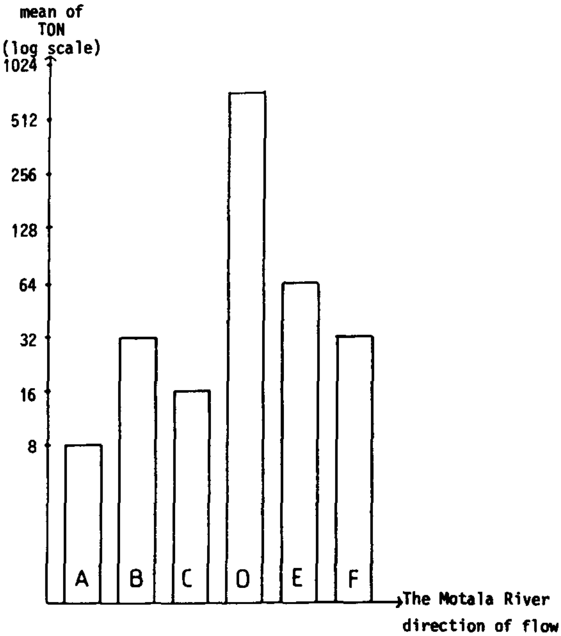

Fig. 3. A profile of the threshold odour number (TON) from six positions along the Motala River. A = Motala waterworks, raw water; B = Berggården waterworks (Linköping), raw water; C = Skärblacka waterworks, raw water; D = the Motala River immediately downstream from the pulp mill; E = Lake Glan; F = Norrköping waterworks, raw water. The TON at point D has shown great variation.

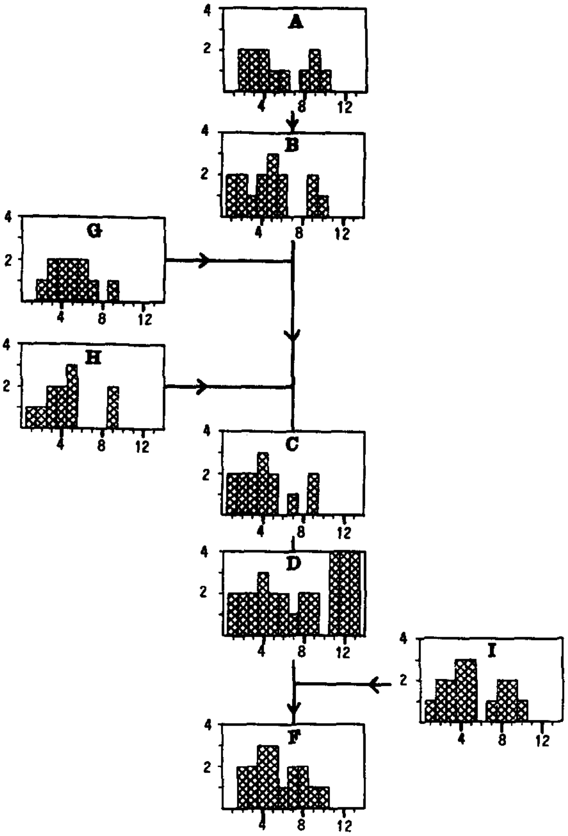

Fig. 4. Odour profiles consisting of odour intensities of the thirteen most characteristic off-flavour compounds at eight locations in the Motala river basin. Odour intensities: 1 = weak; 2 = medium; 3 = strong; 4 = very strong. The identities of compounds 1–4 are given in Fig. 2. Sampling sites: A = Motala waterworks, raw water; B = Berggården waterworks (Linköping), raw water; C = Skärblacka waterworks, raw water; D = the Motala River immediately downstream from the pulp mill; F = Norrköping waterworks, raw water; G = Mjölby waterworks, raw water ("Svartån"); H = Råberga waterworks, raw water ("Stångån"), I = "Finspångsån". All samples were taken during October 1983.

fairly small number of odorous compounds is responsible for the off-flavour of the water in all parts of the river basin. This strongly suggests that these compounds are all linked to microbiological activity in the water and that specific industrial discharges are of only local importance.

The case study has also shown that the discharge from the pulp mill cannot have more than a marginal effect on the off-flavour of the drinking water from the Norrköping waterworks. All important odorous compounds detected at the raw water intake have also been detected upstream from the pulp mill. Furthermore, none of the characteristic off-flavour compounds of the pulp mill discharge has been detected at Norrköping. Obviously these compounds evaporate, settle or decompose between the pulp mill and the Norrköping waterworks. Between these sites the river passes through a lake with a residence time of *ca.* 1 month.

DISCUSSION

In its general form, an off-flavour is a combined taste and odour phenomenon. In this paper we have emphasized odour assessments for the following reasons:

(1) What people ordinarily call "taste" is to a great extent an odour perception[23]. With regard to drinking water, the salt or bitter taste from some inorganic constituents seems to be the only exception to this general rule.

(2) For most organic compounds so far examined, the threshold odour concentration in water is lower than the threshold taste concentration, provided that the odour assessment is performed at sufficiently high temperature (60°C compared with 40°C for the taste assessment)[24].

(3) Source identification of off-flavours in drinking water usually involves sensory assessment of contaminated raw water and waste water samples, which might pose a health risk when tasted.

(4) The column-sniffing technique provides an elegant method of relating perceived odours for a water sample to perceived odours for individual compounds in the water.

The overall performance of the methods described in this paper has been very satisfactory. The remaining discussion elaborates the five steps listed in the introduction. Some suggestions for further research are also given.

Since odorous compounds in water have a certain volatility, one would expect that stripping and head-space techniques would be appropriate concentration techniques. Our studies have clearly demonstrated that many off-flavour compounds in raw water and drinking water are remarkably difficult to volatilize (*cf.* Lalezary *et al.*[25]). This makes the choice of concentration technique critical. The open stripping system described in this paper and by Borén *et al.*[21] has been shown to give a much higher recovery of odorous compounds than the standard closed-loop stripping technique, mainly because the open system allows a higher stripping temperature. However, even after prolonged stripping at high temperature (8 h, 60°C), some off-flavour compounds usually remain in the water. Consequently, there is a need for further improvements of the concentration step.

The column-sniffing technique has sometimes been criticized because it ignores all interactions among the perceived odours from different compounds. In our opinion this is not a serious drawback in the search for suspected off-flavour compounds in water. According to the most widely accepted model for the odour intensity of a mixture, the so-called "vector model", the resulting intensity cannot exceed the sum of the odour intensities of the individual compounds[26]. This, in turn, implies that a certain compound cannot contribute substantially, to the odour intensity of a mixture unless it has a noticeable odour intensity by itself. Since the column-sniffing technique has been shown to give detection levels well below the corresponding threshold odour concentrations in water, it seems reasonable to assume that all odorous compounds of interest will be detected if they are properly concentrated and chromatographed. Our studies strongly suggest that the latter requirements are fulfilled by the proposed stripping and column-sniffing techniques. With a negligible number of exceptions, there has been very good agreement between the odour quality of the water sample and the odour qualities of the strongest-smelling peaks at column sniffing. Furthermore, some preliminary studies at our laboratory have shown that the original odour quality can be reconstructed by trapping the column effluent into an odour-free water sample.

In order to establish the origin (microbiological metabolites, waste water discharges, water treatment by-products, etc.) of a certain drinking water off-flavour, we need information on two points: (i) the origin of individual off-flavour compounds; and (ii) the contribution of individual off-flavour compounds to the total off-flavour of the water.

The case study has shown that the combined stripping and column-sniffing technique is a powerful tool for obtaining information on the first point. Owing to the high sensitivity of the method and the high precision of the retention time determinations, it is not difficult to determine if a certain off-flavour compound in treated water is also present in the raw water and at various locations upstream from the waterworks. With the same technique we can also determine if off-flavour compounds from a specific point source can reach the raw water intake and survive the water treatment process.

Obtaining information on the second point is never simple and often very difficult (*cf.* Berglund *et al.*[27]). The rough estimates of odour intensity given by column sniffing might be sufficient in cases where all major off-flavour compounds have the same origin (*cf.* the case study). For some well-known off-flavour compounds we can also compare the recorded concentration with the threshold odour concentration. It is not difficult, however, to imagine situations where we need more accurate and general methods to determine the contribution of a single compound to the total off-flavour of the water. In such cases a final source identification of the off-flavour must be based on methods for trapping the column effluent, or fractions of the effluent, into odour-free water, thereby reconstructing the original off-flavour.

The low concentrations of the odour-causing compounds usually makes MS analysis of drinking water extracts inefficient. The column-sniffing technique can help to overcome this problem by proving that the odour quality and retention time of a certain perceived odour from the drinking water extract are identical with the same data from another extract that is more suitable for GC–MS analysis. In the case study we successfully compared column-sniffing data for water extracts with corresponding data for synthetic samples of known odorous compounds. Since many of the so-far-unidentified off-flavour compounds in drinking water obviously are of microbiological origin, a similar comparison of drinking water extracts with extracts from cultures of micro-organisms seems to be the most promising way to extend the list of identified odorous compounds in drinking water.

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REFERENCES

1 M. J. McGuire, S. W. Krasner, C. J. Hwang and G. Izaguirre, *Water Sci. Technol.*, 15, No. 6/7 (1983) 267.
2 A. J. Montiel, *Water Sci. Technol.*, 15, No. 6/7 (1983) 279.

3 G. J. Piet, B. C. J. Zoeteman, C. F. H. Morra, A. H. Nettenbreijer and F. E. de Grunt, in K. Aurand (Editor), *Organische Verunreinigungen in der Umwelt*, Erich Schmidt Verlag, Berlin, 1978, p. 195.
4 M. Yagi, M. Kajino, U. Matsuo, K. Ashitani, T. Kita and T. Nakamura, *Water Sci. Technol.*, 15, No. 6/7 (1983) 311.
5 N. N. Gerber, *Water Sci. Technol.*, 15, No. 6/7 (1983) 115.
6 F. Juttner, *Water Sci. Technol.*, 15, No. 6/7 (1983) 247.
7 P.-E. Persson, *Water Sci. Technol.*, 15, No. 6/7 (1983) 1.
8 G. J. Piet, B. C. J. Zoeteman and A. J. A. Kraayeveld, *Water Treat. Exam.*, 21 (1972) 281.
9 A. A. Rosen, C. I. Mashni and R. S. Safferman, *Water Treat. Exam.*, 19 (1970) 106.
10 G. P. Slater and V. C. Blok, *Water Sci. Technol.*, 15, No. 6/7 (1983) 181.
11 R. H. Burtschell, A. A. Rosen, F. M. Middleton and M. B. Ettinger, *J. Amer. Water Works Assoc.*, 51 (1959) 205.
12 P. Koppe and J. Traud, *Gwf-Wasser/Abwasser*, 10 (1973) 345.
13 A. A. Rosen, R. T. Skeel and M. B. Ettinger, *J. Water Pollut. Control Fed.*, 35 (1963) 777.
14 A. Veijanen, M. Lahtipera, R. Paukku, H. Kaariainen and J. Paasivirta, *Water Sci. Technol.*, 15, No. 6/7 (1983) 161.
15 J. M. H. Bemelmans and H. J. A. den Braber, *Water Sci. Technol.*, 15, No. 6/7 (1983) 105.
16 R. Sävenhed, H. Borén, A. Grimvall and A. Tjeder, *Water Sci. Technol.*, 15, No. 6/7 (1983) 139.
17 L. J. van Gemert, in H. Maarse and R. Belz (Editors), *Isolation, Separation and Identification of Volatile Compounds in Aroma Research*, Akademie-Verlag, Berlin, 1981, ch. 5, p. 243.
18 P. Sandra, T. Saeed, G. Redant, M. Godefroot, M. Verstappe and M. Verzele, *J. High Resolut. Chromatogr. Chromatogr. Commun.*, 3 (1980) 107.
19 B. Berglund and T. Lindvall, in I. Andersen and D. Proctor (Editors), *The Nose: Upper Airway Physiology and the Atmospheric Environment*, Elsevier, Amsterdam, 1982, ch. 11, p. 289.
20 K. Grob and F. Zurcher, *J. Chromatogr.*, 117 (1976) 285.
21 H. Borén, A. Grimvall and R. Sävenhed, *J. Chromatogr.*, 252 (1982) 139.
22 A. Grimvall, R. Sävenhed and H. Borén, *Water Sci. Technol.*, 15, No. 6/7 (1983) 169.
23 T. Engen, *The Perception of Odors*, Academic Press, New York, 1982, p. 145.
24 H. C. Alexander, W. M. McCarty, E. A. Bartlett and A. N. Syverud, *J. Amer. Water Works Assoc.*, 74 (1982) 595.
25 S. Lalezary, M. Pirbazari, H. J. McGuire and S. W. Krasner, *J. Amer. Water Works Assoc.*, 76, No. 3 (1984) 83.
26 B. Berglund, U. Berglund, T. Lindvall and L. Svensson, *J. Exp. Psychol.*, 100 (1973) 29.
27 B. Berglund, U. Berglund, T. Lindvall and H. Nicander-Bredberg, *Environ. Int.*, 8 (1982) 327.