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Determination of Benzene and Toluene In Exhaled Cigarette Smoke*

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SUMMARY

This study describes the results regarding the evaluation of retention efficiency by humans of benzene and toluene from cigarette smoke. The evaluated cigarette was a common commercial cigarette with 10.6 mg 'tar' [U.S. Federal Trade Commission (FTC) 'tar' is defined as the weight of total particulate matter minus nicotine and water]. The test was performed on ten subjects. The exhaled smoke was collected using a vacuum assisted technique that avoids strain in exhaling the smoke. The study showed that benzene was retained at levels of 89% to 98%, and toluene was retained at similar levels, between 87% and 99%. The lower limits of retention for both benzene and toluene are unexpectedly low compared to the retention of bi-and tricyclic aromatic hydrocarbons, which have retentions from cigarette smoke above 95%. This is probably caused by the fact that monocyclic aromatic hydrocarbons are present practically only in the vapor phase of cigarette smoke and at considerably higher levels than bi- and tri-cyclic aromatic hydrocarbons which are present almost completely in the particulate phase of cigarette smoke. [Beitr. Tabakforsch. Int. 23 (2008) 107–114]

ZUSAMMENFASSUNG

In dieser Arbeit werden die Ergebnisse einer Untersuchung über die Retentionseffizienz von Benzol und Toluol aus Zigarettenrauch beim Rauchen präsentiert. Bei der untersuchten Zigarette handelte es sich um eine handelsübliche Zigarette mit 10,6 mg Kondensat [Kondensat ist gemäß den Abrauchbedingungen der U.S. Federal Trade Commission (FTC) das Gewicht der nikotinfrein, Gesamtpartikelmasse unter Abzug von Wasser]. Die Untersuchung wurde mit 10 Testpersonen durchgeführt. Der exhalierte Rauch wurde in einem Vakuum-unterstützen Verfahren gesammelt, um einen Widerstand beim Exhalieren zu vermeiden. Die Untersuchung zeigte, dass Benzol zu 89 bis 98% retiniert wurde und Toluol in vergleichbarer Menge zwischen 87 und 99%. Die unteren Grenzwerte für die Retention von Benzol und Toluol sind im Vergleich zur Retention von bi- und trizyklischen aromatischen Kohlenwasserstoffen, welche Retentionswerte aus dem Zigarettenrauch von über 95% besitzen, unerwartet niedrig. Dies liegt höchstwahrscheinlich daran, dass monozyklische aromatische Kohlenwasserstoffe lediglich in der Gasphase des Zigarettenrauchs vorkommen und in wesentlich höheren Konzentrationen enthalten sind als bi- und trizyklische aromatische Kohlenwasserstoffe, welche fast ausschließlich in der Partikelphase des Zigarettenrauchs vorkommen. [Beitr. Tabakforsch. Int. 23 (2008) 107–114]

RESUME

Les résultats d'une étude sur l'évaluation de l'efficacité de la rétention du benzène et du toluène dans la fumée de cigarette chez le fumeur sont présentés. La cigarette évaluée est une cigarette commerciale de 10,6 mg de goudron [selon l'US Federal Trade Commission (FTC), le goudron est défini comme le poids de la matière particulaire totale exempte de nicotine et d'eau]. Dans cette étude, dix fumeurs ont fumé les cigarettes évaluées. La fumée exhalée a été échantillonnée à l'aide d'une technique sous vide pour éviter une trop grande résistance durant l'exhalation de la fumée. L'étude montre que le benzène est retenu de 89% à 98% et le toluène est retenu à un niveau comparable, entre 87% et 99%. Les limites de rétention pour le benzène et le toluène sont plus faibles que celles attendues, comparées avec la rétention des hydrocarbures aromatiques bicycliques et tricycliques ayant des taux de rétention supérieurs à 95%. Ceci est probablement due au fait que les hydrocarbures

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Table 1. Review of some previous studies on human retention from cigarette smoke of compounds other than nicotine

Author(s)	Reference	Analytes
Lehman (1909)	1	Ammonia, pyridine
Laskowski (1951)	16	Pyridine, ammonia, a few classes of compounds (free bases, aldehydes + ketones, free carbolic acids, etc.)
Haagen-Smith et al. (1959)	17	NO_x
Dahlman *et al.* (1968) (two studies)	13,14	Acetaldehyde, acetone, acetonitrile, isoprene, toluene, CO
Egle (1970)	18	Acetaldehyde
Backhurst and Martin (1973)	as reported in 15	Vapor phase constituents including benzene and toluene
Ingebrethsen (1989)	19	Phenol, triacetin, neophytadiene, glycerin
Armitage et al. (2004) (two studies)	4, 6	Solanesol (and nicotine)
Baker, Dixon (2006)	15	Review, also including some BAT internal reports
Feng *et al.* (2006)	20	TSNAs, acetaldehyde, isoprene, ethylene

aromatiques monocycliques sont seulement présents dans la phase gazeuse de la fumée de cigarette et ceci pour des teneurs considérablement plus élevées que les hydrocarbures aromatiques bicycliques et tricycliques nettement plus présents dans la phase particulaire de la fumée de cigarette. [Beitr. Tabakforsch. Int. 23 (2008) 107–114]

INTRODUCTION

The analysis of chemical composition of exhaled cigarette smoke and its comparison with the composition of the inhaled smoke received attention for almost 100 years (1). However, most studies on smoke retention were focused on nicotine and total particular matter (TPM) (1–15). A summary of some older studies on the retention of other mainstream cigarette smoke components is given in Table 1. More recently, several new studies were performed on chemical composition of exhaled cigarette smoke (20–24). One of these studies (21) evaluated the overall comparison between delivered and exhaled smoke for the levels of 160 compounds that can be directly analyzed in a gas chromatographic (GC) profile. Other studies evaluated the retention by humans of specific groups of smoke constituents such as tobacco specific nitrosamines, isoprene, and ethylene (20), carbonyl compounds (20, 22), polycyclic aromatic hydrocarbons (23), and phenols (24). This present study describes the findings regarding the retention by humans from cigarette smoke of benzene and toluene.

EXPERIMENTAL

The experiments for the evaluation of benzene and toluene retention by human smokers were performed using a common commercial cigarette with 10.6 mg 'tar' ('tar' is the weight of total particulate matter minus the weight of water and nicotine) as measured following U.S. Federal Trade Commission (FTC) recommendations. Other descriptors of the cigarette are cigarette length 83 mm, filter length 27 mm, filter ventilation 32%, blend type American, nicotine 0.92 mg/cig and CO 10.7 mg/cig. The number of smokers used in the present study was ten. For the measurement of the retention it was necessary to know both the level of benzene and toluene in the exhaled smoke as well as that from the delivered smoke. The benzene and toluene in the exhaled smoke were directly measured. The levels in the delivered smoke were obtained using dependence charts between the levels in smoke as a function of the nicotine level in the cigarette butt. These dependence charts were obtained by analyzing smoke generated with a smoking machine working under different regimes and simultaneously measuring the nicotine level in the cigarette butts. The whole procedure required several steps which included a) collection of samples from a smoking machine using a variety of smoking conditions, b) collection of exhaled smoke, c) measurement of benzene and toluene obtained from the smoking machine, or from the exhaled smoke, d) analysis of nicotine in the cigarette butts from the smoking machine, and from human smokers, and e) calculation of the results. Each of these steps is further discussed in detail.

Collection of samples from smoking machine

The particulate phase of cigarette smoke from five cigarettes was collected on one 92 mm Cambridge pad. The pad holder was connected to a charcoal trap for the collection of components from the vapor phase of cigarette smoke, and further to the pump of the smoking machine. The trap was an ORBO™-32 Small trap (Supelco, Bellefonte, PA 16823-0048 USA) that contains the charcoal in two sections indicated as A and B. Section A of the tube contains 100 mg absorbent charcoal and is designed to retain the analytes. Section B of the tube contains an additional 50 mg absorbent charcoal and is used as backup in case of breakthrough of the analyte. Smoking was done initially in conditions similar to those recommended by the FTC (25) but using a Borgwaldt rotary machine RM20/CSR (Borgwaldt, Hamburg, Germany). The puff volume taken under these conditions was 35 mL, with a duration of 2 s and each puff taken at 60 s interval. Then the cigarettes were smoked in more intensive conditions (26) including 60 mL puff volume, with a puff duration of 2 s each puff taken at 60 s interval (indicated as 60/60 conditions), 45 mL puff volume, with a puff duration of 2 s and each puff taken at 30 s interval (indicated as 45/30 conditions), and 60 mL puff volume, with a puff duration of 2 s and each puff taken at 30 s interval (indicated as 60/30 conditions). The cigarette butts from the cigarettes were also collected for the analysis of nicotine content.

Exhaled smoke collection

The smoke collection of exhaled smoke from the human subjects was done by a vacuum assisted procedure. This pro-

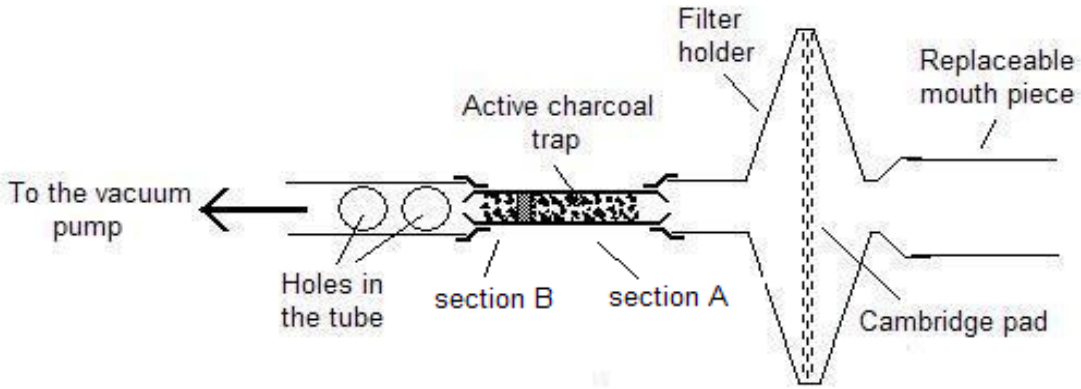

Figure 1. Schematic drawing of the device used for the collection of exhaled cigarette smoke

cedure has been used in order to avoid the excessive strain that would be necessary to otherwise overcome the flow resistance of the Cambridge pad. The device is schematically shown in Figure 1. The device consisted of a 92 mm Cambridge holder and pad having at one opening a replaceable mouth piece (Atlantic Medical Solutions, Charlotte, NC 28217, USA), and at the other opening being connected to the absorbent charcoal trap (ORBO™-32 Small trap). The Cambridge pad retains the particulate phase smoke component, while the trap was added for the collection of vapor phase smoke components. The trap was of the same type as that used for collection of vapor phase components from a smoking machine. A diaphragm vacuum pump which can aspirate up to 2.2 m^3/h (Vacuubrand GmBH, Wertheim, Germany) was attached to the trap. The flows through the trap were measured and were about 250 mL/sec during collection. The tube connecting the trap to the pump has two large holes to the exterior, which can be covered with the fingers. When no smoke is exhaled, the holes in the tube to the vacuum pump are kept open such that air from the surrounding is aspirated by the pump without passing the filter and the trap. During smoke exhaling, the smoker blows the smoke through the replaceable mouth piece. At the same time the holes in the tube are covered, such that the exhaled smoke is aspirated through the Cambridge pad and the charcoal trap. This allows the exhaled smoke to be collected without additional strain on the smoker. The device shown in Figure 1 has been used by ten human subjects selected to smoke their preferred brand. Each subject smoked three cigarettes within one hour, and the exhaled smoke was collected. The smoking was performed in an environment familiar to the smoker (office) with as little as possible change from typical conditions. No measurements were made on inhalation volume or breath-hold duration. The cigarettes were previously conditioned under FTC recommendations (25). The cigarette butts from the smokers were collected for nicotine analysis. In addition to exhaled smoke, the breath without smoking was collected from one smoker as a background check. The measurement was done by collecting the exhaled air from 24 breaths (mimicking the number of puffs from three cigarettes) after one hour of smoking the last cigarette.

Chromatographic analysis of benzene and toluene in smoke

The analysis of benzene and toluene was performed only in the vapor phase of cigarette smoke using a GC/FID (flame ionization detection) procedure. The absorbent charcoal from section A of the ORBO tube was transferred into a 4 mL vial to which 1 mL CS_2 was added (Aldich/Sigma, Saint Louis, MO 63178-9916, USA). The CS_2 also contained 100 µg/mL of 2-chloropentane used as a chromatographic standard. The charcoal was kept in the capped vials containing CS_2 for one hour at room temperature with occasional stirring. After the extraction, part of the CS_2 solution was removed with a pipette, transferred into a GC vial, and analyzed. The proof that the benzene and toluene were completely retained by the section A of the charcoal tube was obtained by analyzing the section B of the ORBO tube for several samples that collected vapor phase smoke from machine or from human smoked cigarettes. The same procedure of extraction as for section A of the ORBO tube was used for section B samples. The GC analysis was performed on a 6890 GC instrument (Agilent, Wilmington, DE 19808, USA), with a FID detector. The parameters for the instrument setup are given in Table 2.

A typical chromatogram obtained under the conditions from Table 2 for a 1R5F Kentucky reference cigarette is shown in Figure 2. The CS_2 extract of section B of the charcoal trap was also analyzed by the same GC procedure. No peaks for benzene or toluene were detected either for machine smoked cigarette, or for human smokers. This indicated that the two compounds are retained efficiently from the vapor phase of cigarette smoke on the section A of the absorbent tubes. The flow through the charcoal trap using machine smoking was within the recommended limits by the trap manufacturer. The flow of gases through the trap during exhaled smoke collection was higher than the recommended maximum flow. For this reason, the section B of the trap was analyzed for all human smokers. No benzene or toluene was detected in these analyses indicating that the retention was complete in section A of the charcoal trap.

The quantitation of benzene and toluene was obtained using six standards, each run twice. Curves representing quantity

Table 2. Gas chromatography (GC) operating parameters [a]

Parameter	Description	Parameter	Description
GC column	DB-1	Inlet mode	Split
Column dimensions	30 m, 0.32 mm i.d.	Injection volume	2.0 µL
Film thickness	2.0 µm	Split ratio	5:1
Initial oven temperature	40 ˚C	Split flow	6.1 mL/min
Initial time	3.0 min	Carrier gas	Helium
Oven ramp rate	25 ˚C/min	Flow mode	Constant flow
Oven final first ramp	110 ˚C	Flow rate	1.2 mL/min
Final time first ramp	0 min	Nominal initial pressure	6.3 psi
Oven ramp rate	15 ˚C/min	GC outlet	Atmosphere (FID)
Oven final temperature	280 ˚C	FID temperature	280 ˚C
Final time	0 min	FID H_2 flow	30 mL/min
Total run time	17.13 min	FID air flow	400 mL/min
Inlet temperature	280 ˚C	FID makeup gas flow	28.8 mL/min

* Abbreviation: FID = Flame ionization detection.

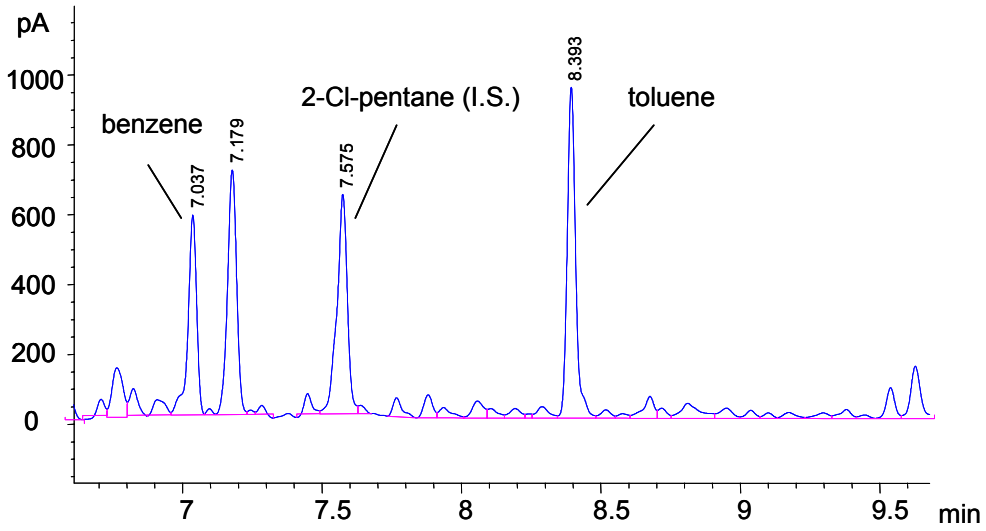

Figure 2. Typical GC chromatogram showing benzene, toluene and the internal standard peaks for a 1R5F Kentucky reference cigarette

vs. peak areas were generated for the two compounds. The calibration curves were linear and the R^2 values for the dependence were above 0.998 for both analytes. The normalization of the peak areas by the area of the internal standard was not used since its use did not improve the relative standard deviation (RSD%) of the results. The area of the internal standard was used only to verify the reproducibility of the chromatographic analysis.

Analysis of toluene in particulate and vapor phase of cigarette smoke

One particular aspect of the measurement of toluene for the evaluation of retention by smokers is that toluene was measured only in vapor phase of the cigarette smoke. Differently from benzene that is present mainly in the vapor phase of mainstream smoke, toluene is also present in the particulate phase. In order to prove that toluene is present mainly in the vapor phase of cigarette smoke, its partition between particulate phase and vapor phase was separately evaluated for eleven different cigarettes (each analyzed three times). This analysis started by collecting both particulate phase and vapor phase of cigarette smoke. The smoking was done using a Borgwaldt RM20 CSR smoking machine, working in conditions similar to FTC. Smoke from 20 cigarettes was collected in each run. The collection of particulate phase smoke was performed using an electrostatic precipitator (SL30 from Spellman High Voltage Electronic Corp., Hauppauge, NY 11788, USA) that was weighed before and after the smoking to measure the amount of total particulate matter (TPM). The exit of the electrostatic precipitator was connected to four traps in series, each containing glass beads and 5 mL acetone for the collection of vapor phase smoke. The first trap was cooled in ice water, and the other three traps were cooled with dry ice/isopropanol mixture. The acetone in the traps contained 1,1,1,3,3,3-hexafluoroisopropanol as an internal standard. The total particulate matter from the electrostatic precipitator was also dissolved in acetone containing the same internal standard. The final concentration of the internal standard in the acetone solutions was 200 nL/mL (323 µg/mL). The extracts were analyzed by GC/MS (GC/MSD 6890/5973, Agilent Wilmington, DE 19808, USA). The GC/MS conditions are given in Table 3.

Table 3. Gas chromatography/mass spectrometry (GC/MS) parameters for the evaluation of the distribution of toluene between particulate phase and vapor phase [a]

Parameter	Description
GC column	DB-Waxetr
Column dimensions	30 m long, 0.32 mm i.d.
Film thickness	0.50 µm
Carrier gas	Helium
Flow mode	Constant flow
Flow rate	1.5 mL/min
Initial oven temperature	37 ˚C
Initial time	2.0 minutes
Oven ramp rate	2.5 ˚C/mm
Oven final temperature	230 ˚C
Final time	25.8 min
Inlet mode	Splitless
Inlet temperature	250 ˚C
Injection volume	1 µL
MSD transfer line heater	250 ˚C
Ion source temperature	230 ˚C
Quadrupole temperature	150 ˚C
MSD EM offset	350 V
MSD solvent delay	5.0 min
MSD acquisition mode	TIC
Mass range	33 amu – 550 amu

[a] Abbreviations: MSD = Mass spectrometry detection; TIC = total ion chromatogram.

Analysis of nicotine in the cigarette butts

Previously reported results showed that the nicotine in the cigarette butt (1 cm from the mouth end) has a linear dependence on the amount of nicotine collected on the Cambridge pad (27, 28). In this study, dependence equations between the level of benzene and toluene in smoke and the nicotine level in the cigarette butts were obtained. For the analysis of nicotine in the cigarette butt, the smoked butts were collected and cut at lengths of 1 cm. The 1 cm mouth end portions were put together from each smoker, or from the smoking machine, and were extracted with 20 mL methanol containing an internal standard (dodecanol). The level of nicotine was measured using a standard GC procedure (29).

RESULTS AND DISCUSSION

Discussion on benzene and toluene analysis

Benzene is present in mainstream cigarette smoke mainly in vapor phase (30). Toluene is also present mainly in vapor phase of mainstream cigarette smoke but low levels are also present in particulate phase. In the first part of the study the distribution of toluene between particulate and vapor phase of cigarette smoke was evaluated. The ratios of the normalized peak areas (by the internal standard) obtained from particulate phase vs. vapor phase (PP/VP%) are given in Table 4. The same table also provides the measured 'tar' values for each run. As seen from Table 4, the toluene is present between 94% to 97% in the vapor phase portion of the cigarette smoke. Therefore, the measurement of the retention of toluene only from the vapor phase provides a good estimation of the retention by the smoker of this compound.

The analysis of benzene and toluene by the GC/FID analytical procedure was done initially for 2R4F and 1R5F Kentucky reference cigarettes machine smoked in FTC type conditions. This was performed for the verification of the procedure accuracy. The average values and RSD% for benzene and toluene in vapor phase from five replicates, and some values reported in literature are given in Table 5 for 2R4F Kentucky reference cigarette and in Table 6 for 1R5F Kentucky reference cigarettes. As seen from Table 5 and Table 6, the agreement with other data for the benzene and toluene are very good, except for toluene in 1R5F cigarette where the number reported in literature is relatively higher. The RSD% from the present work can be considered very good.

Generation of the dependence charts between the level of benzene and toluene for machine smoked cigarettes and cigarette butt nicotine

The analysis of benzene and toluene was performed initially for machine smoked cigarettes using different puffing conditions. At the same time with this analysis, nicotine was analyzed in the cigarette butts. Dependence charts between the level of benzene and toluene in vapor phase smoke as a function of the nicotine level in the cigarette butts were

Table 4. The distribution of toluene between particulate phase (PP) and vapor phase (VP) expressed as PP/VP% and the 'tar' levels (mg/cig) for eleven different cigarettes

Cigarette	'Tar' mg/cig	PP/VP%	Cigarette	'Tar' mg/cig	PP/VP%	Cigarette	'Tar' mg/cig	PP/VP%
Cig 1	9.09	3.11	Cig 5	10.13	3.66	Cig 9	8.92	2.79
	8.85	3.10		10.07	3.71		8.92	2.82
	8.39	3.03		10.25	4.22		8.97	2.72
Cig 2	10.73	5.64	Cig 6	9.40	3.17	Cig 10	9.91	3.24
	9.29	4.88		9.52	4.05		9.90	3.03
	10.30	4.72		8.90	4.20		9.56	3.35
Cig 3	9.81	3.84	Cig 7	10.45	3.21	Cig 11	10.09	3.09
	9.78	3.44		10.28	2.98		10.31	3.67
	9.78	3.22		10.36	3.13		10.32	3.78
Cig 4	10.63	5.77	Cig 8	11.01	3.41			
	10.53	4.97		10.46	4.57			
	10.60	5.90		10.43	4.00			

Table 5. Mainstream yields of benzene and toluene for 2R4F cigarette from this work and reported in the literature

Compound	This work average	This work RSD% [a]	Ref (31) average	Ref (31) RSD%
Benzene µg/cig	41.4	2.47	43.4	3.0
Toluene µg/cig	62.1	3.22	64.9	4.0
'Tar' mg/cig	11.20			

[a] RSD% = Relative Standard Deviation %.

Table 6. Mainstream yields of benzene and toluene for 1R5F cigarette from this work and reported in the literature

Compound	This work average	This work RSD%	Ref (32) average	Ref (32) RSD%
Benzene µg/cig	11.2	5.51	13	–
Toluene µg/cig	14.6	4.02	18	–
'Tar' mg/cig	2.24			

Table 7. Measured and calculated values in µg/cig for benzene and toluene from machine smoked cigarettes

	Smoking condition			
Compound	FTC	60/60	45/30	60/30
Benzene measured (µg/cig)	45.13	68.70	84.36	98.08
Benzene calculated (µg/cig)	47.80	63.94	86.94	97.60
Toluene measured (µg/cig)	64.29	106.30	139.84	151.46
Toluene calculated (µg/cig)	70.35	98.06	137.58	155.90
Butt nicotine (mg/cig)	0.19	0.26	0.36	0.40

Table 8. The levels in µg/cig of benzene and toluene in the exhaled smoke and the level of nicotine in the cigarette butt (mg/cig) for each of the human subjects

Compound	Exhaled 1	Exhaled 2	Exhaled 3	Exhaled 4	Exhaled 5	Exhaled 6	Exhaled 7	Exhaled 8	Exhaled 9	Exhaled 10
Benzene (µg/cig)	4.57	4.03	5.37	3.17	1.79	1.27	2.18	3.46	1.44	1.44
Toluene (µg/cig)	5.78	7.61	8.01	3.76	1.74	1.29	2.59	5.39	1.53	1.67
Butt nicotine (in mg/cig)	0.20	0.18	0.18	0.24	0.27	0.20	0.26	0.12	0.20	0.32

obtained. The levels of benzene and toluene for the cigarettes smoked in FTC, 60/60, 45/30, and 60/30 conditions, showed a linear dependence as a function of the corresponding level of nicotine in the smoked butts. The equations of the correlation lines were:

$$\text{Benzene}\,(\mu g/cig) = 228.34 \cdot \text{Butt nic.}\,(mg/cig) + 5.4215 \quad [1]$$

$$\text{Toluene}\,(\mu g/cig) = 392.27 \cdot \text{Butt nic.}\,(mg/cig) - 2.4585 \quad [2]$$

Using these equations and the levels of nicotine in the cigarette butts, the levels of benzene and toluene in smoke can be calculated. The verification obtained by comparing the calculated results with the measured values given in Table 7 for machine smoked cigarettes, showed very good agreement proving the validity of the approach.

Analysis of benzene and toluene in the exhaled smoke and the calculation of delivered levels

Before the analysis of benzene and toluene in the exhaled smoke, an evaluation of the background level in the breath of a smoker when no cigarette was smoked within one hour has been measured. It was found that only very low traces of these compounds were detected in exhaled breath. However, the measured levels were equivalent to values between 0.05 and 0.1 µg/cig, and were considerably lower than typical errors affecting the results. In addition to that, the peaks with retention time corresponding to benzene and toluene were not positively identified as these compounds (since the detection was done using FID only). It was concluded that any benzene or toluene from the breath without smoking had no effect on the results regarding the retention of these compounds.

The level of benzene and toluene in the exhaled smoke was analyzed for ten smokers and the results are reported in µg/cig in Table 8. The table also indicates the amount of nicotine in mg/cig measured in the collected cigarette butts from each smoker. Using the nicotine levels from the cigarette butts for each smoker, and Eqns. [1] and [2] the delivered levels of benzene and toluene were calculated. The results are given in Table 9.

Calculation of the retention % of benzene and toluene by human smokers

From the results for the exhaled smoke given in Table 8 and those calculated for the delivered smoke given in Table 9 the retention of benzene and toluene can be calculated for each smoker, using the expression:

$$\text{Retention}\% = 100 - \frac{(\text{exhaled level})}{(\text{delivered level})} \cdot 100 \quad [3]$$

Table 9. Calculated levels in µg/cig of benzene and toluene in the delivered smoke for each of the human subjects

Compound	Delivered 1	Delivered 2	Delivered 3	Delivered 4	Delivered 5	Delivered 6	Delivered 7	Delivered 8	Delivered 9	Delivered 10
Benzene (µg/cig)	50.86	46.07	46.75	59.99	67.53	51.23	65.25	31.91	49.95	77.81
Toluene (µg/cig)	75.60	67.37	68.54	91.29	104.24	76.39	100.32	43.04	74.03	121.89

Table 10. Retention % of benzene and toluene in the delivered smoke for each of the human subjects

No.	Compound	Ret. % 1	Ret. % 2	Ret. % 3	Ret. % 4	Ret. % 5	Ret. % 6	Ret. % 7	Ret. % 8	Ret. % 9	Ret. % 10	Average	RSD%
1	Benzene	91.01	91.25	88.51	94.72	97.35	97.52	96.66	89.16	97.12	98.15	*94.14*	3.77
2	Toluene	92.35	88.70	88.31	95.88	98.33	98.31	97.42	87.48	97.93	98.63	*94.34*	4.64

The retention values are given in Table 10 for each smoker. As seen from Table 10, the retentions of both benzene and toluene are in the range of 87% to 99%. The values for toluene retention are in excellent agreement with the data reported in a recent review of cigarette smoke retention (15), which references an internal BAT report (33) showing toluene retention between 87 ± 8% to 92 ± 4%. The same internal report indicates that the benzene retention is around 75 ± 7%, values that are surprisingly far from toluene retention. Higher values of retention for benzene were found in this study (89% to 98%), which better concur with the retention values found for toluene. The lower limits of retention for benzene and toluene are still unexpectedly low compared to the retention of bi-and tricyclic aromatic hydrocarbons, which have retentions from cigarette smoke above 95%. This is probably caused by the fact that monocyclic aromatic hydrocarbons are present practically only in the vapor phase of cigarette smoke and at considerably higher levels than bi- and tricyclic aromatic hydrocarbons which are found only in particulate phase.

CONCLUSIONS

This study provides information of the retention of benzene and toluene from mainstream cigarette smoke. The evaluated cigarette was a common commercially available product with 10.6 mg 'tar', and the test was performed on ten subjects, each smoking three cigarettes. The benzene was retained at levels of 89% to 98%, toluene being retained at similar levels, between 87% and 99%. The only other result reported in the literature (15) for benzene and toluene comes from an internal BAT study performed in 1973. The agreement with this study is excellent for toluene, but benzene is shown to be retained at higher levels than previously reported.

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