Beiträge zur Tabakforschung · Band 7 · Heft 5 · September 1974 DOI: 10.2478/cttr-2013-0342

Cigarette Peak Coal Temperature Measurements*

by Andrew T. Lendvay and Tibor S. Laszlo

Philip Morris USA, Research Center, Richmond, Virginia, USA

INTRODUCTION

A large body of experimental evidence supports the dependence of cigarette smoke composition on temperature. Phenol formation, during the pyrolysis of wood lignin, increased fourfold between 400° C and 600° C but decreased more than tenfold between 600° C and 900° C (1). In a study of the pyrolysis of tobacco leaf constituents (2), it was found that yields of benzene and biphenyl increase "dramatically" when the temperature increases from 420° C to 820° C. As the temperature approaches 820° C, the yield of fused-ring aromatics (indene, acenaphthene, etc.) also increases. A patented process (3) claims to reduce the polycyclic hydrocarbons in smoke by increasing the combustion temperature. The temperature increase can be achieved, it is claimed, by the addition of alkaline earth performates to the tobacco. Another patent (4) proposes the reduction of temperature from 880° C to 720° C by the addition of borates, phosphates and silicates in order to reduce the aromatic hydrocarbon content of the smoke.

Significant to this problem is work that was performed on the pyrolysis of organic compounds. *Lam* (5) obtained 3,4-benzpyrene and other aromatic compounds from aliphatic hydrocarbons heated at 700°—800° C; at 600° C, no such compounds were formed. The same author reported quantitative correlations between pyrolysis temperature and the generation of certain compounds (6). Heating 500 mg of tobacco paraffins at 850° C produced 1 mg 3,4-benzpyrene, and at a higher temperature (970° C) only 0.37 mg.

To these data, related to cigarette smoke, can be added the large volume of available information pertaining to the effect of temperature on the products of thermal cracking of petroleum fractions.

THE MEASUREMENT METHOD

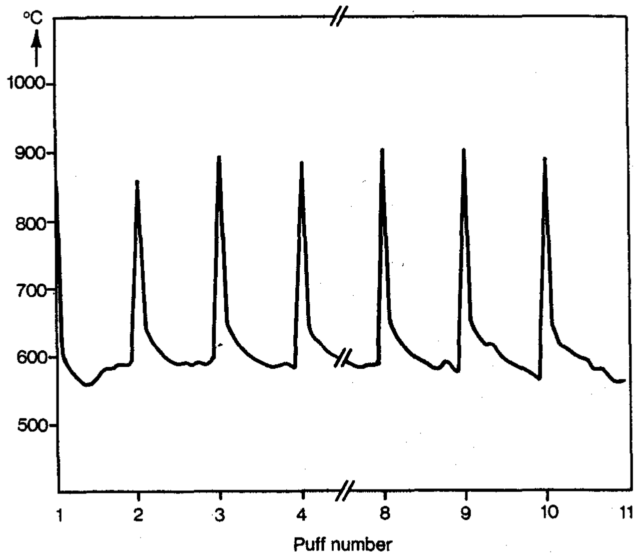
For this investigation of cigarette peak coal temperatures, a recently developed scanning infrared technique was used (7). This technique is based on the theoretically derived assumption that the cigarette coal has an emittance close to unity. Tests were carried out to support this assumption.

A burning cigarette was extinguished with nitrogen vapors after the fourth puff and was placed into a controlled temperature chamber. The radiation emitted by the coal was measured at several temperatures from 50° C to 125° C and compared with the radiation emitted by an artificial blackbody at the same temperature. The average emittance of the cigarette coal in the 2.0—5.4 μ spectral band was found to be 0.98.

The infrared method is applicable only to the measurement of surface temperatures. Due to the dynamics of the smoking mechanism, the highest temperature during the puff occurs on the periphery of the incandescent coal. As the combustion of the paper usually precedes the burning of the tobacco beneath the paper, part of the incandescent coal becomes visible to the heat detecting instrument during the puff. The visible part of the glowing coal is the hottest spot during the puffing; thus it is possible to measure the peak temperatures. Figure 1 shows the average peak temperatures of a reference cigarette during the two-second puffing period as well as the temperature readings taken every five seconds between puffs.

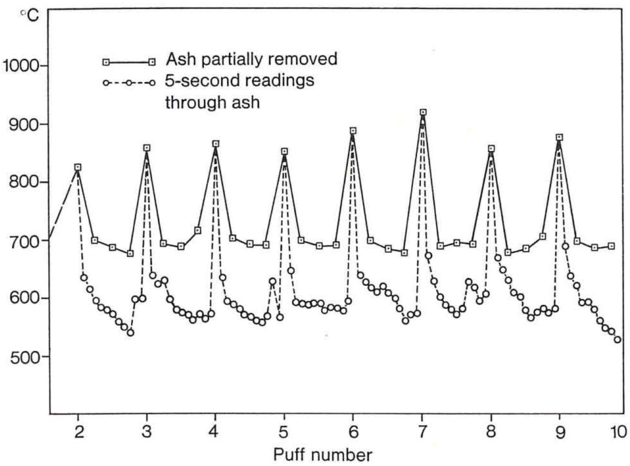
It can be observed that the recorded temperature values fall steeply after the puff is completed. With the exception of occasional flare-ups, as shown toward the end of the intervals, the surface temperature, as measured by the instrument, drops to the 600° C level. Although the temperature of the ash covered surface on the smoldering cigarette is not higher than is shown here, the incandescent part must have higher tempera-

Figure 1. Peak temperatures of cigarette coal.



* Presented, in part, at the CORESTA/26th TCRC Joint Conference held in Williamsburg, Virginia, USA, in October 1972.

Figure 2. Temperature profile — ash partially removed before reading between puffs.



ture regions. Figure 2 shows the result of temperature measurements when a very small part of the ash is removed during the smoldering period.

These results show that the surface temperature of the incandescent coal below the ash layer averages about 700° C vs. the 600° C average of the ash layer surface temperature.

By using the isotherm method on the screen of the oscilloscope of the AGA instrument during smoking experiments, it was observed that the hottest region of the incandescent coal moves from the periphery to the center of the coal during the smoldering period. Figure 3 demonstrates how the temperature peaks at the periphery during the puff and how the accumulating heat concentrates in the central part of the incandescent cone between puffs.

Most probably this heat accumulation, visible on the screen, is due to the fact that the center part is the most insulated portion of the coal. Based on the limitations mentioned before, the coal temperature is measured only during the puffing period when the hottest region appears on the periphery.

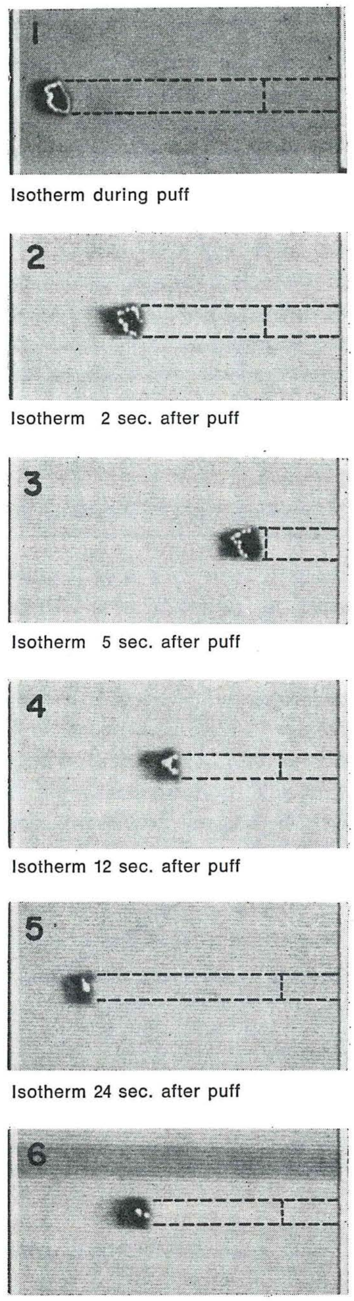
CORRELATION BETWEEN SMOKING CONDITIONS AND TEMPERATURE

If a burning cigarette is considered as a smoke generator, it is obvious that the composition of the smoke and the temperature of combustion are related. All recent pertinent data in the literature were obtained under standard smoking conditions, i.e., a 35 ml puff of two-second duration once every minute. However, it has to be realized that the standard smoking conditions apply to machine smoking only. Every individual may smoke somewhat differently according to his smoking habit and personality. (8a, b, c) The volume, duration and frequency of the puffs can vary considerably. These parameters were investigated one at a time.

A. Change of Volume vs. Temperature

The cigarettes were smoked on a one port smoking machine with a constant two-second puff duration per minute. The volumes per puff were changed from a 23 ml low to a 42 ml high. Figure 4 demonstrates how the combustion temperature rises when the volume increases. From the data, it is evident that with a changing puff volume and constant duration the temperature change results from the change in air/smoke velocity.

Figure 3. Infrared image of cigarette coal.



B. Change of Puff Duration vs. Temperature

The cigarettes were smoked on a one port smoking machine at a constant 35 ml volume per minute. The duration of the puff was changed to one, two and three seconds.

The temperature values observed due to the changed puff duration are presented in Figure 5. Here again, it is

Figure 4. Change of volume vs. temperature.

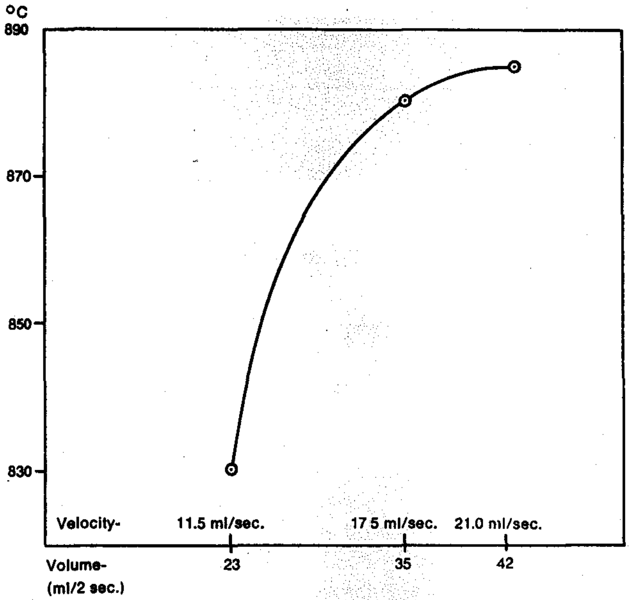
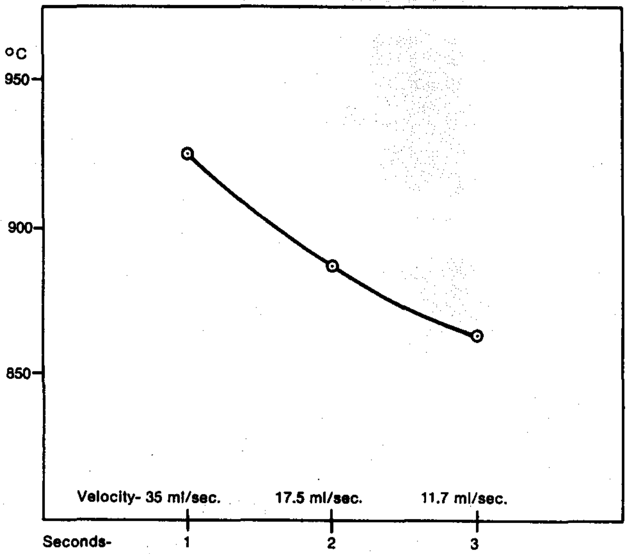


Figure 5. Change of puff duration vs. temperature.



obvious that the coal temperature correlates with velocity.

Comparing the actual temperature values in Figures 4 and 5 it is noticeable that besides the velocity of air, the duration of the puff is an additional influencing factor in the temperature development.

The air velocity in a 23 ml two-second puff (11.5 ml/sec.) is almost identical with the air velocity of the 35 ml three-second puff (11.7 ml/sec.). Yet the temperature averages are quite different (831° C vs. 863° C). These data suggest that the temperature constantly rises for the duration of the puff. Thus, the longer the puff the higher the temperature, other variables being equal.

C. Change in Volume vs. Smoke Delivery

Cigarettes were smoked similarly to those described in Section A. Twenty, thirty-five, and forty-five ml were drawn during the two-second puff. Analytical data are presented in Table 1. The table shows that higher puff volumes reduce the puff count. Due to the different smoke volumes per puff and different puff counts, the "per cigarette" values were converted to "per 100 ml smoke" values as seen in the lower portion of Table 1. TPM and H_2O increase with increased puff velocity (increasing coal temperature also). Nicotine shows a decrease.

Table 1. Change in volume vs. smoke delivery.

Puff volume	TPM	Nicotine	H_2O	Puff count
		(mg/cigt.)		
20 ml/2 sec.	14.9	0.85	1.5	10.1
35 ml/2 sec.	24.9	1.23	3.3	9.3
45 ml/2 sec.	31.0	1.40	6.8	8.9
		(mg/100 ml smoke)		
20 ml/2 sec.	7.38	0.421	0.74	
35 ml/2 sec.	7.64	0.378	1.01	
45 ml/2 sec.	7.75	0.350	1.70	

D. Change of Puff Duration vs. Smoke Delivery

Cigarettes were smoked and analyzed when 35 ml volume puffs were carried out in one, two, three and four seconds. Table 2 shows the analytical results per cigarette. The "per 100 ml smoke" values are shown at the bottom of Table 2. There are no trends observable in TPM, nicotine, or H_2O.

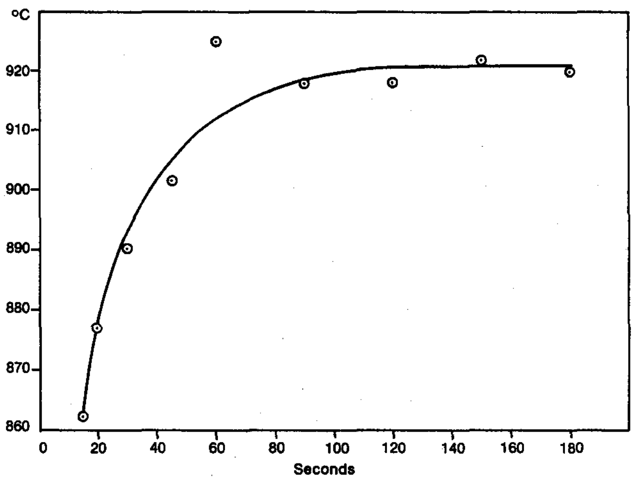
Table 2. Change of puff duration vs. smoke delivery.

Puff duration	TPM	Nicotine	H_2O	Puff count
		(mg/cigt.)		
35 ml/4 sec.	23.5	1.25	3.2	8.8
35 ml/3 sec.	23.4	1.22	3.1	10.2
35 ml/2 sec.	24.9	1.23	3.3	9.3
35 ml/1 sec.	22.7	N. A.	N. A.	9.5
		(mg/100 ml smoke)		
35 ml/4 sec.	7.63	0.41	1.04	
35 ml/3 sec.	6.55	0.34	0.87	
35 ml/2 sec.	7.65	0.38	1.01	
35 ml/1 sec.	6.83	N. A.	N. A.	

E. Change of Puff Frequency vs. Temperature

A definite trend could be observed when a series of reference cigarettes were smoked with different puff intervals. The frequency of puffs was changed gradually from four puffs per minute to one puff every three minutes. Figure 6 demonstrates how the average combustion temperature changed in correlation with the changed intervals. It can be seen that the average temperature increased with increasing intervals and leveled off at the sixty second interval. Pertinent facts which can be learned from this study are:

Figure 6. Change of intervals vs. temperature.

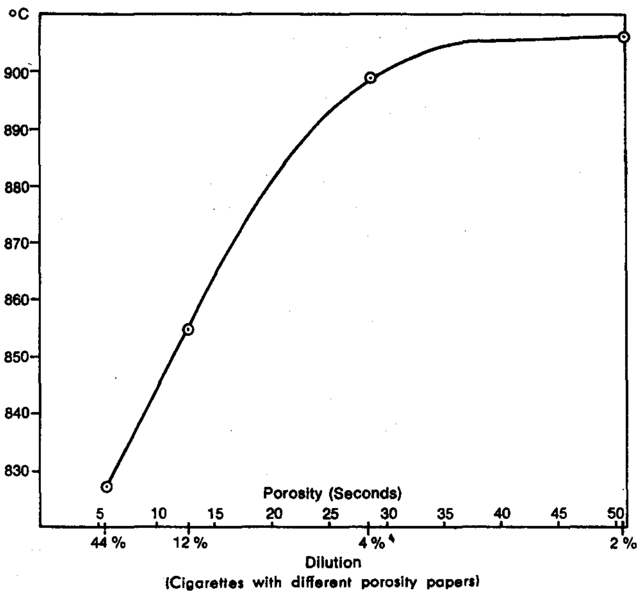


1. Within the limits of these tests, puff velocity and duration affect the combustion temperature.
   a. Increased velocity results in increased peak temperature.
   b. The peak temperature continuously rises during the puff.
2. The different puffing conditions result in differing temperatures and total smoke deliveries.
3. The different puffing conditions result in differing smoke compositions (per equal volume of smoke).

THE INFLUENCE OF STRUCTURAL PARAMETRIC CHANGES ON COMBUSTION TEMPERATURE

After establishing correlations between changes in smoking conditions and temperature or smoke composition respectively, the next step in the investigation was to look into the possible changes in the structure of the cigarette. One of the important parameters in the physical structure of a cigarette is the porosity of the wrapping paper. It was known that the porosity of the cigarette paper has an influence on the puff count, and on the composition of the smoke.

Figure 7. Paper porosity vs. temperature.



In these experiments, the purpose was to determine whether a change in paper porosity has influence on the combustion temperature and if so, in what direction. Otherwise identical reference cigarettes were prepared using different porosity wrapping paper. Figure 7 shows the influence of wrapping paper porosity on cigarette coal temperature. The conclusion from this experiment was that the higher degree of dilution through the porosity of cigarette paper lowers the combustion temperature.
The suggested mechanism is that with higher rate of dilution less air is drawn through the incandescent zone; therefore, the combustion temperature reaches a lower value. In order to check out this assumption, the next experiment was carried out with exactly adjusted dilutions on cigarettes.

CIGARETTES WITH PREPARED DILUTION

Otherwise identical cigarettes were prepared with 10 %, 20 %, 30 % and 40 % dilution in their filter. The cigarettes were smoked, the smoke was analyzed and the coal temperature was recorded. The results are shown in Table 3. As the table shows, every dilution level changed other parameters as well. The resistance to draw dropped with increased dilution rate. Puff count increased with increased dilution. The temperature was lower as dilution increased, similarly to the results with different porosity paper cigarettes. The delivery figures show the expected trend in reduction.

Table 3. Dilution on the filter.

Dilution rate	RTD	TPM mg/cigt.	Nicotine mg/cigt.	Temp.	Puff count
Control (no dil.)	4.4″	25.2	1.52	862° C	9.5
10 %	4.1″	23.0	1.43	852° C	9.7
20 %	4.0″	20.0	1.37	828° C	9.6
30 %	3.6″	18.7	1.32	831° C	10.1
40 %	3.2″	16.9	1.27	816° C	10.2

TEMPERATURES OF CIGARETTES WITH SINGLE COMPONENTS

Since most commercial cigarettes in the United States are made of blended tobacco, it appeared interesting to learn how the temperature average of a single tobacco component cigarette would compare to another one.
Cigarettes were prepared at the 100 % level from the most frequently used tobacco components in the cigarette blend, i.e. 100 % Bright, Burley and Turkish tobacco cigarettes.
The temperature averages for all three component cigarettes were very close to a normal blended reference cigarette, the Turkish tobacco cigarette being the lowest (923° C, 928° C, 908° C). Due to these results, it was decided not to pursue the matter further at the present time.

CONCLUSIONS

The scanning infrared temperature measurement technique was found to yield interesting correlations between smoking parameters, cigarette structure, smoke composition and peak coal temperature.

SUMMARY

The composition of cigarette smoke is significantly affected by the coal temperature. A new measuring technique, based on infrared techniques was used to investigate this correlation. Experimental evidence is shown for the validity of this method.
The temperature profile of a reference cigarette is presented. Peak temperature during the puff and temperatures during static burning are reviewed.
Coal temperature changes when smoking conditions change. Deviations from standard smoking conditions (35 ml puff of 2-second duration once every minute) change combustion temperature due to the higher or lower velocity of air forced through the coal during the puff. Lower puff volume means lower velocity and lower temperature and vice versa. A change in puff duration also affects the temperature. The same applies to puff frequency.
Some parametric changes also influence combustion temperature. Cigarettes with different porosity papers, but otherwise identical, burn at different temperatures. The cigarette with the most porous paper develops the lowest coal temperature. Filter dilution similarly influences coal temperature. Cigarettes with 10%, 20%, 30% and 40% filter dilution give decreasing temperature readings with increasing dilution. A definite correlation has been also observed between temperature and main stream smoke composition.
In order to establish possible temperature and delivery correlations for different tobaccos, 100% Bright, Burley and Turkish tobacco cigarettes were also tested.

ZUSAMMENFASSUNG

Die Zusammensetzung des Cigarettenrauches wird wesentlich durch die Glutzonentemperatur bestimmt. Zur Untersuchung dieser Beziehung wurde ein neues Meßverfahren benutzt, das auf der Infrarot-Technik basiert. Die Gültigkeit der Methode wird experimentell nachgewiesen.
Das Temperaturprofil einer Versuchscigarette wird dargelegt. Die Maximaltemperatur während des Zuges und der Temperaturverlauf bei statischem Abbrennen werden ermittelt und diskutiert.
Die Temperatur der Glutzone verändert sich mit den Abrauchbedingungen. Abweichungen von den genormten Bedingungen (Zugvolumen: 35 ml, Zugdauer: 2 sec., Frequenz: 1 Zug je min.) verändern die Verbrennungstemperatur durch höhere oder niedrigere Strömungsgeschwindigkeit der Luft beim Passieren der Glutzone während des Zuges. Ein kleineres Zugvolumen bedeutet niedrigere Geschwindigkeit sowie niedrigere Temperatur und umgekehrt. Eine Veränderung der Zugdauer beeinflußt ebenfalls die Temperatur. Das gleiche gilt für die Zugfrequenz.
Auch die Veränderung einiger anderer Parameter beeinflußt die Verbrennungstemperatur. Cigaretten, die sich lediglich in der Porosität ihres Papiers voneinander unterscheiden und sonst identisch sind, brennen mit verschiedenen Temperaturen. Die Cigarette mit dem porösesten Papier entwickelt die niedrigste Glutzonentemperatur. Die Glutzonentemperatur wird in ähnlicher Weise durch Filterventilation beeinflußt. Cigaretten mit Filterventilation (10, 20, 30 und 40%) zeigen abnehmende Temperaturen mit zunehmender Ventilation. Auch zwischen der Temperatur und der Zusammensetzung des Hauptstromrauches ist eine eindeutige Korrelation zu beobachten.
Um für verschiedene Tabakarten Korrelationen zwischen Temperatur und Ausbeute feststellen zu können, wurden auch Cigaretten mit jeweils 100%igem Gehalt an Virginia-, Burley- bzw. türkischem Tabak untersucht.

RESUME

La température du cône de combustion influence la composition de la fumée de cigarette de façon significative. Afin d'approfondir cette corrélation, on a employé une nouvelle technique de mesure, basée sur des techniques à infra-rouge. Les faits expérimentaux parlent d'eux-mêmes et prouvent la validité de cette méthode.
On présente le profil de température d'une cigarette référence. On passe en revue le pic de température pendant la bouffée et les températures pendant la combustion statique.
La température du cône de combustion change d'après la façon de fumer. Des déviations des conditions standard de fumage (une bouffée de 35 ml d'une durée de 2 secondes et cela toutes les minutes) provoquent un changement de température de combustion par la vitesse accrue ou diminuée de l'air passant par le cône, durant la bouffée. Un volume inférieur de bouffée correspond à une vitesse inférieure et à une température inférieure et vice versa. Une variation de la durée d'une bouffée influence également la température. Il en va de même pour la fréquence des bouffées.
Certains changements dans les paramètres peuvent également influencer la température de combustion. La température de combustion, pour des cigarettes identiques, diffère d'après la porosité du papier. La cigarette ayant le papier le plus poreux aura la température la plus basse pour son cône de combustion. La dilution du filtre influence de façon semblable la température du cône de combustion. On observe une température décroissante pour une dilution croissante, pour des cigarettes ayant des dilutions du filtre variant de 10% à 20%, 30% et 40%. Il existe aussi une corrélation très nette entre la température et la composition du flux principal de fumée.
On a aussi testé des cigarettes composées de tabacs 100% Bright, Burley et Turkish, afin d'établir une éventuelle corrélation entre la température et le rendement.

REFERENCES

1. Schlotzhauer, W. S., I. Schmeltz, and L. C. Hickey: Pyrolytic formation of phenols from some high molecular weight tobacco leaf constituents and related non-tobacco materials; Tobacco Science XI (1967) 31–34.
2. Anon.: Tobacco's pyrolytic path involves several types of intermediates; C & E. N., 38, March 11, 1968.
3. U.S. Patent No. 3,251,368, G. Neurath.
4. U.S. Patent No. 3,126,011, W. L. Haden, Jr.
5. Lam, J.: Measurement of 3,4-benzpyrene and other aromatic compounds formed by pyrolysis of the aliphatic hydrocarbons of tobacco; Acta Pathol. Microbiol. Scand. 39 (1956) 207.
6. Lam, J.: Some considerations on the mechanism of high temperature pyrolysis of aromatic and aliphatic hydrocarbons; Acta Pathol. Microbiol. Scand. 45 (1959) 237.
7. Laszlo, T. S., and F. M. Watson, III: A scanning infrared technique for cigarette coal peak temperature measurements; Beitr. Tabakf. 7 (1974) 269.

8a. Keith, C. H.: Laboratory measurements of the smoking characteristics of human beings; 16th Tobacco Chemists' Research Conference, Richmond, Va., September 26–28, 1962.

b. Adams, P. I.: Measurements on puffs taken by human smokers; 20th Tobacco Chemists' Research Conference, Winston-Salem, N. C., November 1–3, 1966.

c. Wakeham, H.: The chemistry of tobacco and tobacco smoke; Proceedings of the Symposium on the Chemical Composition of Tobacco and Tobacco Smoke held during the 162nd National Meeting of the American Chemical Society in Washington, D. C., September 12–17, 1971.

The authors' address:

Philip Morris USA, Research Center, P.O. Box 26583, Richmond, Virginia, 23261, USA.