

On the Burning Temperatures of Tobacco*

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Experimental studies in which tobacco tar has produced malignant tumors on the skin of the mouse seem to imply that a chemical carcinogen is formed by the combustion of tobacco leaf. Among the most important factors affecting the chemical structure of the smoke is the burning temperature. Not only does knowledge of this factor become essential for a study of the possibility that carcinogenic aromatic hydrocarbons are produced in this process, but the experiments described below have been performed to elucidate differences among smoking habits and to perform suitable animal experiments that simulate the process of smoking.

MATERIALS AND METHODS

The conditions studied comprise the most important smoking habits known to western civilization: pipe, cigar, American-type cigarette, and cigarette with a paper mouthpiece. The brands used were the following: (a) An American blend cigarette of medium strength, one of the most popular high price qualities—length, 68 mm.; diameter, 8 mm.; average weight, 1.015 gm.; (b) an original Turkish manufacture, corresponding to the American cigarette in size and quality of paper; (c) an original Egyptian cigarette; (d) an American-type cigarette made in Finland of blended Turkish (Smyrna) and Virginia leaf; (e) an American-type cigarette made in Finland, which had been treated with infra-red rays; (f) a cigarette with a paper mouthpiece, Finnish manufacture—length, 39 mm.; diameter, 6 mm.; mean weight of tobacco, 0.416 gm.; (g) a Havana cigar of Finnish manufacture—length, 112 mm.; diameter, 14 mm.; average weight, 4.706 gm.; (h) mixed nonaromatized pipe tobacco.

The smoking was performed in an entirely natural manner by a middle-aged, moderately smoking man, accustomed to both cigarettes and a pipe. A cigar was used only for part of the experiments. The force of the suction was not measured separately, and it is given according to the smoker's own estimate—being either normal or extremely strong. There is considerable variation in the suction force and puff volume of different individuals. However, the maximal suction used was of such a strength as to be very rarely possible in normal smoking. Thus, the method in the present work includes practically all the conditions actually in question. Controls made by another smoker were consistent.

The temperature measurements were made with a calibrated silver-constantan thermocouple constructed especially for the purpose. The error of the instrument is less than 0.5

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per cent, which is about 4° C. for the highest temperatures recorded. The experiment was conducted at an 18° C. room temperature.

RESULTS

The measuring point was introduced into the tobacco mass from the end of the cigarette or through holes bored in the walls of the pipe. The position of the instrument in the tobacco appears in Chart 1. As the combustion proceeded and the glow came nearer to the measuring point, a reading was made at each suction.

The findings concerning pipe and cigarettes appear in Chart 1. Measurements with a thermocouple inserted into the base of the tobacco comprised average temperatures (●—●) as well as variability with normal and extremely strong suction (checked area). The maximal temperature always occurred somewhat before the arrival of the actual glow, because part of the evaporating tar substances and ethereal oils develop when tobacco is burned at a very high temperature. For measuring maximal temperatures another series of experiments was therefore performed, in which the thermocouple was inserted into the middle (○—○) and into the tip (X—X) of the cigarette or pipe. The object was to avoid, as much as possible, changing the structure of the preparation, since, for instance, the density of the tobacco affects the resistance to suction and the rapidity of the combustion. Therefore, it was not possible to place several thermocouples simultaneously into the same cigarette. Each point had to be measured on different cigarettes or pipes.

In principle, three main zones are distinguishable in burning tobacco (cigarette and pipe): (a) the actual glowing point, where oxidation takes place, called in the following the "combustion zone," (b) the "distillation zone," where no actual glowing occurs but where the temperature is high and dry distillation quite strong, and (c) the zone farthest from the glow point, where the temperature is low and where, for that reason, condensation of dry distilled material can take place, and which is hence called the "condensation zone." It is naturally not possible to set any exact limits between the several zones. The ratios that these bear

to one another, although varying greatly and typically from one product to another, can, however, be ascertained retrogradely from the temperature curve. Chart 1 shows, in percentages of the quantity of tobacco in cigarette or pipe, the ratios that the zones bear to one another, the following being the delimiting temperatures: below 100° C., 100°–300° C., 300°–500° C., and higher than 500° C.

When a pipe is smoked, the temperature does not rise very high; the heat, on the other hand, spreads rapidly outside the area which is actually glowing and burning in the closed bowl. Temperature of the combustion zone was about 500° C. (variability, 380°–620° C.). The distillation zone was very large. Experiments show that, of the tobacco below that still unburnt, about 25 per cent reached a temperature exceeding 300° C. during the suction, and at least 60 per cent a temperature exceeding 100° C. The corresponding fractions of the substances in the tobacco leaf were thus distilled into the smoke without being burned and without attaining the higher temperatures at all.

With cigarettes the situation was quite different. No essential differences could be noted among the various brands of cigarette studied (Groups *a*–*f*). The highest temperature recorded, 812° C., was in a Turkish cigarette. The maximal temperature at the tip was always somewhat lower. In a thin cigarette with a paper mouthpiece, the highest temperature, 786° C., was recorded at the base. Temperature in the combustion zone was, on the average, 650° C. (variability, 470°–812° C.). Combustion and distillation zones were very small: with the glow at the tip, less than 15 per cent of the total quantity of tobacco attained a temperature of more than 300° C. and less than 25 per cent a temperature above 100° C., while the condensation zone (below 100° C.) comprised more than 75 per cent of the tobacco.

The burning process in a cigar forms a kind of intermediate stage between that of a cigarette and a pipe. The variability, however, depending partly on the quality of the cigar and partly on the manner of smoking, was so great that measurements performed in accordance with the methods used in this study did not give an adequate picture of the division into zones. For this reason, only individual temperature measurements were taken when the thermocouple was inserted through the holder. The maximal temperature varied between 380° and 630° C. The burn or glow at the tip of a cigar most nearly resembled the conditions observed in the burning of a cigarette, while the mouth end or head of the cigar came closer to a pipe in this respect.

DISCUSSION

To know the burning temperatures of tobacco is important for at least three reasons: (*a*) to find out the conditions present in burning tobacco for the formation of a carcinogen, especially aromatic hydrocarbons, (*b*) to note the part played by differences in smoking habits, and (*c*) to aid in the constructing of animal experiments. On the other hand, tobacco smoke is not an important heat irritant, unless the cigarette is smoked down the last centimeters. According to McNally (22), taking the average time for smoking a cigarette as 9 minutes, the temperature of the smoke

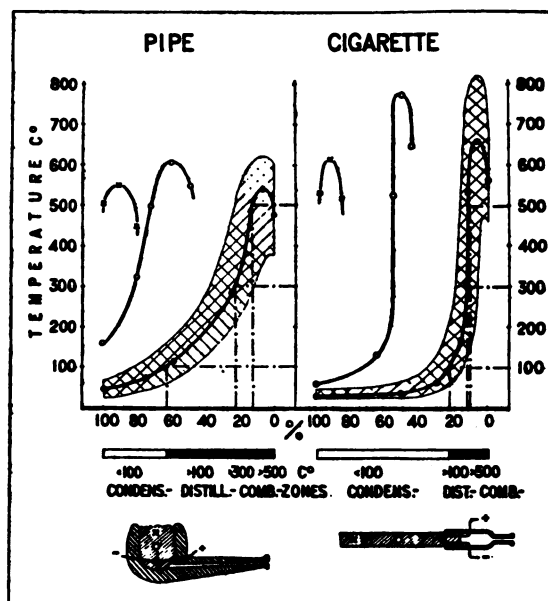


CHART 1.—Temperature in burning cigarette and pipe measured with a thermocouple inserted through the mouth-end into the base (●—●), middle (○—○) or tip (X—X) of the tobacco. Reading was made at each suction when the glowing point came nearer to the measuring point. A more detailed description is given in the text.

in the mouth remains around 30° C. until the last 2.5 cm., at which point it rises rapidly to 40°–50° C. With rapid smoking, the smoke in a mouthpiece may reach 190° C. These results are consistent with our own.

A number of facts seem to suggest that the carcinogenic factor of tobacco tar develops in connection with burning. Thus, no certain increase of pulmonary cancer has been noted among workers in the tobacco industry and tobacco merchants, who are obliged to inhale the dust developed by the tobacco leaves (11, 12, 13). Experimental work with raw tobacco dust on the nasal cavity has given negative results (Karpilow, cited in [20]). Data on tobacco chewing, however, suggest that

tobacco may not require combustion to be carcinogenic to man (8, 15-17, 24, 25, 34).

However, it has not been possible to identify with any certainty the carcinogen possibility present in tobacco tar. Roffo and Correa (26, 27) noted in the UV-absorption spectrum of tobacco tar features similar to those in the spectrum of some carcinogenic hydrocarbons, especially 3,4-benzpyrene. Other workers have been unable to confirm the findings (2, 29, 30, 34). Recently, Cooper, Lindsey, Waller, and Commins (3, 5) detected 3,4-benzpyrene (BP) in tobacco smoke with combined chromatographic and absorption photometric methods; the amount of BP, however, was very small—0.001 mg/100 cigarettes (5). A heavy smoker, in clinical studies usually one who smokes twenty cigarettes a day, thus inhales yearly about 0.025 mg. of BP. Wright and Wynder likewise discovered BP in tobacco smoke (33). According to Wynder (34) present animal experiments indicate that this amount of BP is insufficient to induce cancer in the experimental animals.

Roffo regards ergosterol and phytosterol as the source for the formation of carcinogenic aromatic hydrocarbons. Kennaway and Sampson (14) were able to produce subcutaneous sarcomas in the rat with cholesterol heated to 750°–810° C. Although the burning of tobacco is partly a matter of dry distillation of a vegetable product in a high temperature, the process is not comparable, because of low pressure conditions and oxidation, for instance, to the formation of coal tar, as has often been erroneously suggested (e.g., Roffo). In the reactions involved, even small temperature differences are decisive, so that the maximal temperatures of the tobacco are particularly important. Obviously, if tobacco tar contains carcinogenic substances, their concentration is extremely small, and they perhaps develop accidentally, depending on the conditions of combustion. The conditions theoretically necessary for the development of aromatic hydrocarbons known to be carcinogenic, e.g., temperature, thus far are not entirely known.

In animal experiments the highest distillation fractions of tobacco tar, mainly those above 350° C., have proved the most effective. Table 1 shows the results of some of the most important experimental studies for which the temperature used for preparing the tar has been given. Yet it should be noted that it is the distillation temperature that has mainly been recorded. The actual combustion temperatures of tobacco, on the other hand, have not always been measured.

A number of earlier workers have recorded markedly variable temperatures in isolated measurements. Wenusch (32) noted 500°–700° C. in a

tobacco glow; Bogen (1), 400° C.; Cooper *et al.* (4) report that the temperature of tobacco in both wooden and clay pipes may range from 300° to 700° C. Recently, Commins *et al.* (3) found that the temperature in the burning end of a cigarette fluctuates between 650° and 700° C. The highest temperature measured in a cigarette by Wynder *et al.* (35) was 966° C. Greene (9) recorded the maximum temperatures in the "hot spots" as follows: cigarettes, 610°–740° C.; cigars, 580°–600° C.; and pipe, 420°–590° C. The most extensive measurements have been made by Lam (18); the temperatures found were generally higher than those previously reported. Lam noted temperatures in the combustion zone of cigarettes ranging from 795° to 950° C., with an average temperature of 824°–897° C. when the thermocouple was inserted through the mouth end. The highest temperature, 970° C., was measured in the combustion point of a cigarillo when the thermocouple was inserted through the ash. The maximum temperatures were somewhat lower in pipe (530°–596° C.) as well as in cigars (705°–895° C.).

Clinical statistics show great differences among smoking habits. For instance, Levin, Goldstein, and Gerhardt (19), as well as Mills and Porter (23) and Schrek *et al.* (28), demonstrated a significant parallelism between heavy cigarette smoking and cancer of the lower respiratory tract from the pharynx downward, and, on the other hand, between pipe smoking and the upper respiratory tract (lips, oral cavity). The majority of cigarette smokers inhale the smoke, which, being acid, is not so irritating as the more alkaline pipe smoke (32). Yet this does not fully account for the differences. In an earlier work we studied the distribution of tobacco tar in various parts of the respiratory tract (6). The differences noted in the temperatures are reflected in the consistency of the tobacco tar and its distribution in the organism, and account for the previous results. Relatively more tar is seen in the lower respiratory tract in cigarette smoking than in pipe smoking, in which most of the tar, especially the unburned lower and middle fractions, remains in the oral cavity. Besides, the physical structure of the smoke varies. The rapidly cooling upper fractions of the combustion residue of the cigarette, especially resin substances, are sublimated in a very stable smoke which reaches even the deepest respiratory channels, whereas the abundant oily tar substance condenses in the oral parts of the respiratory tract.

In experimental work on animals, performed mainly on the skin, some cancers have been produced (Wynder *et al.*). Because of the relative tissue specificity noted among the carcinogens, no

TABLE 1

Author (year)	Method of tar production	Fractions of tar	Experimental animals	Mode of application	Results
Helwig (1928)	Tobacco heated to 400°-500° C.	The resulting tar extracted with ether and chloroform and denicotinized Total tar from briar pipes, temp. not given. Ethereal extract Tar from briar pipes, the ethereal extract mixed with olive oil. Tobacco tar produced at combustion temp.: 400°-500° C., wooden pipe 400°-500° C., clay pipe 700°-800° C., wooden pipe (all in alcoholic solution) Distilled at 400°-500° C.	mic mic rabbits mic	Painting 8 months Painting 1 year Injection in the ear Painting 16 months	Ulceration Ulceration Atypical proliferation Epithelioma in one mouse of 50
Cooper <i>et al.</i> (1932)	Smoking apparatus, wooden and clay pipes		mic mic	Painting Painting	Negative Negative
Lu-Fu-Hua (1934)	Tar from burning tobacco, temp. not given		rabbits	Painting ears, 148-182 days.	Carcinoma in three of four rabbits
Schürch & Winterstein (1935)	Smoking apparatus, cigars. Burning temp. not given	The tar distilled at various temperatures. 1. Total tar with and without nicotine 2. Denicotinized tar heated to 130° C. prior to paint 3. Denicotinized tar+traumatization with "Schmirgelpapier" 4. Tar distilled at 100° C. 5. Tar dist. at 160°-170° C. 6. Tar distilled at 180° C. 7. Tar distilled over 300° C. 8. Total tar 9. Total tar 10. Total tar+cholesterol-rich diet	mic mic mic mic rabbits rabbits rabbits rabbits	Painting 258-280 days Painting, 635 days Painting, 270 days Painting, for 2 months 190 days 6 months 480 days 220 days (ear) Oral cavity, 7-18 months Painting (ear)	Atrophy of skin, hyperkeratosis, perivascular infiltration Atrophy of skin, chronic inflammation Negative Negative Negative Negative Negative Negative Negative One carcinoma
Roffo (1936)	Heated tobacco in a still	The tar distilled at: 1. 100°-120° C. 2. 120°-350° C. 3. the residue	rabbits rabbits rabbits	Painting (ear), 10 months Painting (ear), 10 months Painting (ear), 10 months	Negative Tumors (papillomas and carcinomas) in 94 per cent Tumors (papillomas and carcinomas) in 70 per cent
Sugiura (1940)	Heated leaf tobacco in an iron retort	The tar distilled at: 1. 100°-500° C. 2. 500°-900° C.	mic mic	Painting 90-500 days Painting 90-500 days	Negative One carcinoma among 168 mice
Flory (1941)	a) Heated dry tobacco in a still to 700° C. b) Smoking apparatus, pipe; burning temp., 520°-750°	3. oily mixture of both distillates Destructive distillates, three fractions. Wholepipe tar. 1. Destructive distillate, 120°-350° C. 2. Destructive distillate 350°-700° C. 3. Pipe tar 4. Fraction of the 350°-700° C. tar 5. Denicotinized destructive distillate, 300°-700° C. 6. 350°-700° destructive distillate 7. 350°-700° C. denicotinized destructive distillate 8. 120°-350° denicotinized destructive distillate 9. Mixture of watery parts of distillates 10. Denicotinized whole pipe tar	rats, rabbits rabbits rabbits rabbits rats mic mic mic mic mic	Painting ears Painting ears Painting 50-190 days Painting Painting Painting Intrascapular injection Painting Painting, 7-11 months. Painting Painting	Negative Negative Negative Negative Negative Negative 40 papillomas, five carcinomatoids/seventeen animals 68 papillomas, five carcinomatoids/twelve animals 36 papillomas, two carcinomatoids/24 animals 22 papillomas and five carcinomatoids Negative Four papillomas/thirty mice Eight papillomas, one carcinoma/46 mice One papilloma/76 mice
Wynder <i>et al.</i> (1953, 1955)	Smoking apparatus, cigarettes. Burning temp. 682° C. average	1. Total tar in acetone 2. Total tar/croton oil	mic, three strains mic, three strains	Painting Painting Painting 24 months max. Painting 24 months max.	Negative Two papillomas, one carcinoma/60 mice. 2, 14, 44 per cent carcinomas 11, 26, 59 per cent papillomas 4, 8, 10 per cent carcinomas 8, 33, 42 per cent papillomas

definite conclusions can yet be drawn from this with regard to the lungs. In the endeavor to direct the combustion residue of tobacco directly into the respiratory tract, the fact that animals usually breathe through their nostrils makes it impossible to achieve natural conditions. The chamber method, for instance, which is so often used, is not fully satisfactory, because smoke, being an air colloid, soon changes in both its physical and chemical properties. It, therefore, becomes necessary to divide the experiment into component phases (for instance, by fractioning the tar) so that the tobacco is burned under unnatural conditions. The effect of the tar upon the organism depends partly on its absorption properties and thus on the solvents, the most important of which occur among the sub-fractions. The separate use of the upper fractions or some component parts of the tar may thus introduce a source of error. Furthermore, the tar should not be fractionated by distillation alone at different temperatures; it is advisable instead to follow the natural fractionation which occurs in the respiratory tract in connection with smoking.

SUMMARY

The temperatures produced when tobacco was burned in pipe, cigarette, and cigar smoking have been measured by a calibrated thermocouple.

Temperature of the combustion zone in a pipe was about 500° C. (variability, 380°–620° C.). The maximal temperature was thus relatively low, but the heat spread over an extensive area outside the actual glow. Because of this, strong dry distillation took place, and the corresponding fractions from the evaporating substances escaped into the smoke without being pyrolyzed. With a cigarette, the situation was found to be quite different. The temperature was high, averaging 650° C. (variability, 470°–812° C.), but over a very limited area. The amount of dry distillation was slight, and the low and middle fractions were burned more completely. No essential differences could be noted among the different brands of cigarette studied.

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