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STUDIES ON SMOKE TEMPERATURE DURING CIGARETTE SMOKING

by

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Several authors suggest that, among the harmful effects of tobacco smoke on the mucous membranes of the mouth, the direct influence of the heat of the smoke may be of importance in causing gingivitis and leucoplakia (*McCarthy* 1936, *Thoma* 1941). According to *Pindborg* (1947) causes other than the direct influence of heat have also been suggested in order to explain the pathological changes in the oral mucous membranes, e.g. the tar of the smoke as a direct irritant, the toxic effect of some poisonous substances (pyridine etc.), the vasoconstrictor effect of nicotine. *Wade* (1960) writes, "It has long been recognized that smoking can irritate mucosal tissue producing a leucoplakia, probably more by the effect of heat of combustion rather than by any specific irritant in the products".

The theory of the harmful effect of the smoke temperature does not seem to have an adequate experimental background. Further, when studying the complex influences of the tobacco smoke on the oral mucous membranes it seems essential first to determine the smoke temperature and find out whether the smoke is so hot that the heat can damage the mucous membranes.

PREVIOUS METHODS

Smoke temperature

Lux (1933) determined the smoke temperature during smoking of cigarettes with the aid of a thermoelement which pierced the cigarette paper or was mounted within a cigarette-holder, in both cases at a distance of 20 mm from the oral end. No information was given about the dimensions of the thermoelement used.

Chapman & Redish (1960) used mercury thermometers for the same type of investigation.

Puff volume

To judge from a perusal of the literature, *Pfyl* (1933) seems to be the only author who has determined the puff volume during ordinary smoking. His device (Fig. 1) consists of a mouthpiece (5) connected to a cigerette, airtightly mounted within a glass tube (1). During sucking at the mouthpiece a T-piece (2) was closed by a finger and water tended to be sucked from the water container (4) into the graded sampling tube (3), and then both

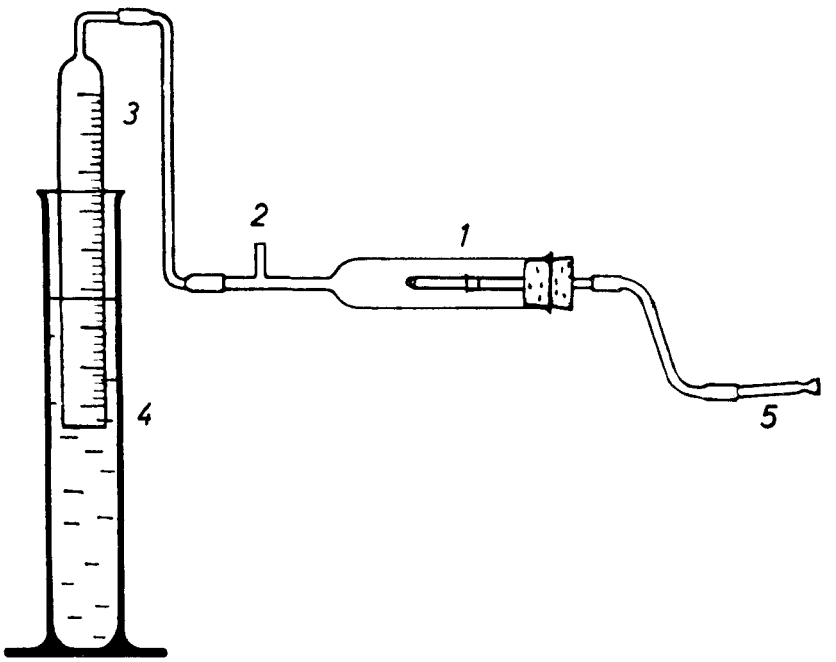

Fig. 1. Pfyl puff volume apparatus (for details, see text).

water levels were manually equalized. In this manner the volume of each puff could be determined. The duration of the puffs was assessed with the aid of a stop watch.

Discussion

In all temperature studies using thermoelements, the dimensions of their soldering junctions and the diameters of the wires of which the thermoelements are manufactured must be described. Suppose the junction has a diameter of 0.4 mm or more, it has been shown by *Ingelstedt* (1956) that the thermal inertia is under certain conditions too great for accurate temperature studies of a gas. The heat sensing element cannot follow the rapid changes in temperature which may be expected to occur in the smoke during a single puff (duration 1.5—2 seconds). Further, the error caused by heat radiation from the burning zone of the cigarette or from the walls of the cigarette-holder can seriously reduce the accuracy of the real smoke temperature recording. Again, the thermal inertia of the thermoelements as used by *Lux* is still greater when the junction is not freely suspended but placed within a cigarette completely covered and in direct contact with tobacco particles. The thermoelement in *Lux's* experiments must have been very solid since he could force it through a cigarette paper without damaging the element. His conclusion that the smoke temperature does not rise sufficiently to damage the mucous membranes of the mouth is not a valid conclusion from his experiments. Mercury thermometers as used by *Chapman & Redish* give quite incorrect results (very great thermal inertia and error by heat radiation).

It appears from puff volume experiments that the method of *Pfyl* does not permit a reproduction of normal smoking conditions.

An ideal method for studying smoke temperature must at least satisfy the following demands:

Temperature measurements must be performed with the aid of very quick-responding heat sensing elements in order to follow rapid changes in the temperature of the smoke.

The influence of variations in the flow velocity on the smoke temperature during each single puff makes it necessary for these two to be recorded simultaneously.

The experimental device should reproduce normal smoking as nearly as possible.

The smoker must not be informed about the purpose of the investigation.

AUTHORS' INVESTIGATION

A cigarette-holder of ordinary dimensions was manufactured, within which was mounted a thermoelement and a flowmeter recording simultaneously the smoke temperature and the smoke flow velocity during smoking of cigarettes (Fig. 2).

Method for temperature measurement

The thermoelement was made of constantan and nickel-chromium wires, 0.03 mm in diameter. The wires were soldered end-to-end so that the soldering junction did not exceed the diameter of the wires, *Ingelstedt* (1956). It was possible with the aid of this thermoelement to obtain a practically instantaneous recording of the variations in the temperature of the smoke leaving the cigarette during a single puff. The element was placed in the centre of the tube formed by the holder 2 mm from the oral tip of the cigarette (Fig. 2, 2). The cold junction was immersed in ice at a temperature of 0° C. In order to increase the sensitivity within a small range of temperature, bucking voltage was inserted into the thermoelectric circuit in such a way that in all recordings

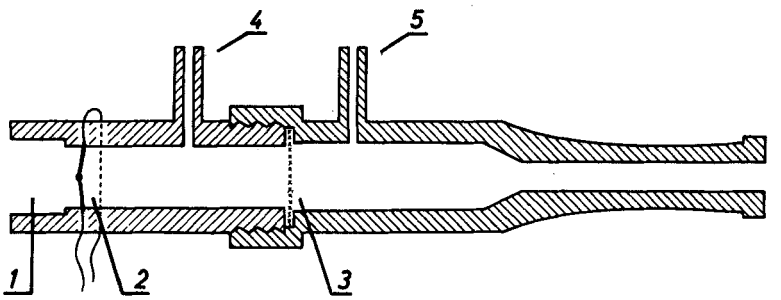

Fig. 2. Schematic diagram of cigarette-holder device for simultaneous smoke flow and smoke temperature measurements.

1, Channel for insertion of oral tip of cigarette.

2, Thermoelement.

3—5, Flowmeter. 3, metal screen flow resistor.

4—5, Pressure taps for measuring pressure difference across the resistor.

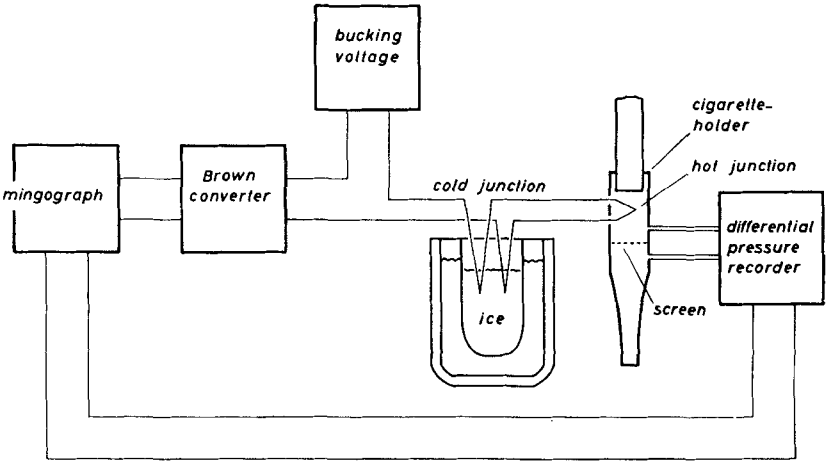

Fig. 3. Schematic diagram of the circuits for obtaining temperature and flow recordings.

the zero line was shifted to 35° C. The temperature range was between 0° C and 70° C and the recording of 35 degrees centigrade above or below zero line yielded the same amplitude. The potentials which arose in the hot junction were converted to a 50 c/s alternating current by means of a Brown converter. The output voltage was recorded with a direct writing ECG recorder (Fig. 3). (Mingograph, Type 230. Elema Ltd., Stockholm).

Method for measurement of smoke flow velocity

The flowmeter is principally a pneumotachograph, which records instantaneous smoke flow through the holder. During smoking a pressure loss occurs across a metal screen (60-mesh, wirediameter 0.25 mm) (Fig. 2, 3) and this pressure loss varies with the flow. (The principle has been described by *Silverman & Whittenberger* in 1950). Pressure loss was recorded by means of a differential pressure manometer (pneumomanometer, Elema Ltd, Stockholm) and was registered on the mingograph (Fig. 3). The flowmeter was tested with the aid of a calibrated rotameter connected directly to the cigarette-holder both before and after smoking experiments at various known flow levels (range 0—3 litres/min.) with air (temperature 22° C—24° C, relative humidity about 40 per cent).

Performance of the normal smoking experiments

The oral tip of a cigarette is first covered with a nylon net (derived from a fine-meshed ladys' stocking). The cigarette is then inserted into the holder and the connection is made airtight

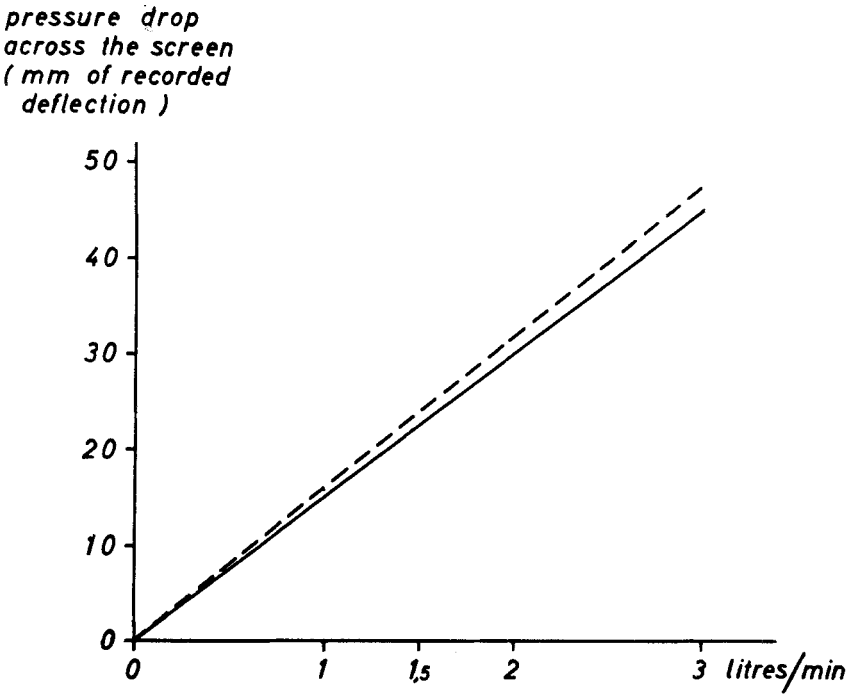

Fig. 4. Pressure flow calibration curves. Solid line: calibration obtained before smoking. Dotted line: calibration obtained after smoking of three cigarettes.

(Fig. 2, 1). The nylon net prevents solid particles of tobacco from getting caught in the metal screen of the flowmeter. Such particles would change the pressure flow calibration curve. On the other hand, it is impossible to prevent tar and other products of combustion formed during the smoking from getting caught in the screen during the smoke passage and thus changing the pressure flow calibration curve performed before the experiment.

Therefore a new calibration was made after smoking three cigarettes in succession. In Fig. 4 the solid line represents the

pressure flow calibration curve before, and the dotted line after, such a smoking experiment. It appears that there is a linear pressure flow relation in both cases. It is then possible to estimate each single puff volume from the smoke flow recording by determination of its area. For each such calculation the calibration curves, obtained both before and after the smoking experiments, were used and the maximal difference of the calculated volumes was 10 per cent.

The calculations of the smoke temperature curves were made directly from the amplitude of the recordings. The maximal measuring error of this smoke temperature method was calculated at $\pm$ 0.° 5 C.

The cigarette-holder was made of a material which is insoluble in acetone (Nylon 6 plastic), the reason being that acetone must be used for washing thermoelement, screen and the whole inside of the holder in order to remove tar and other products of combustion. This washing process was made after each single smoke experiment.

The cigarettes used in all experiments were ordinary Swedish blend cigarettes (Ritz). They have a total length of 70 mm and the diameter is 8.25 mm. Each cigarette was divided into zones, 10 mm in length (zone 1 burning end—zone 6 near the oral end, Figs. 5 and 6). The smokers were instructed to smoke one puff every 30th second but were otherwise ignorant of the purpose of the investigation.

Method for artificial smoking

To investigate further the influence of variations in the smoke flow velocity on the smoke temperature the following model experiments were made:

The same device was used as in the normal smoking experiments but the smoking was now performed with the aid of a sucking fan and variations in flow velocity were regulated by a variable autotransformer. This experimental device yields short smoking periods by means of an electromagnetic valve, which opens during 1.8—2 seconds every 30 seconds. The smoke flow curves obtained are of the square wave type and are thus fundamentally different from those obtained during ordinary smoking (cf. Figs. 5 and 6).

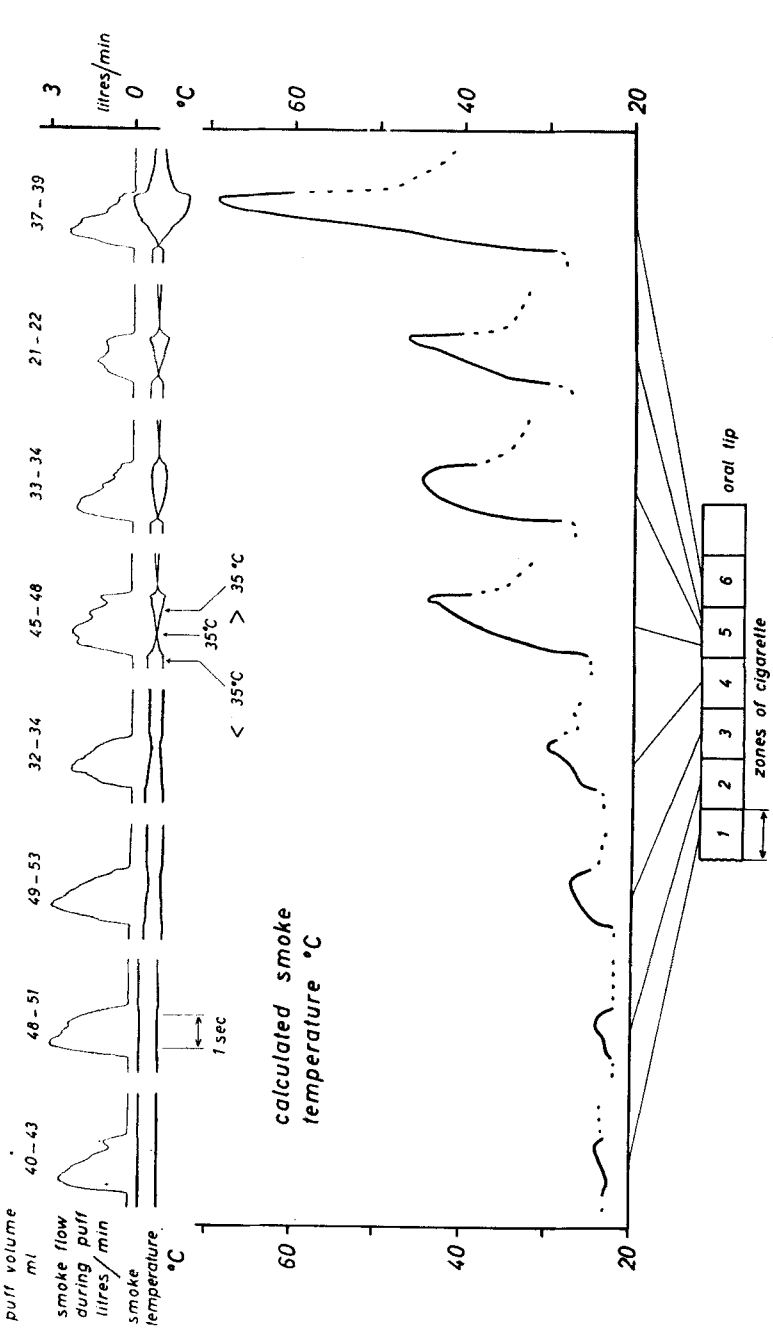

Fig. 5. Smoke flow and temperature curves obtained during normal smoking. In the calculated smoke temperature curves the solid lines indicate the temperature changes during puff flow and the dotted lines indicate these changes when there is no flow through the holder.

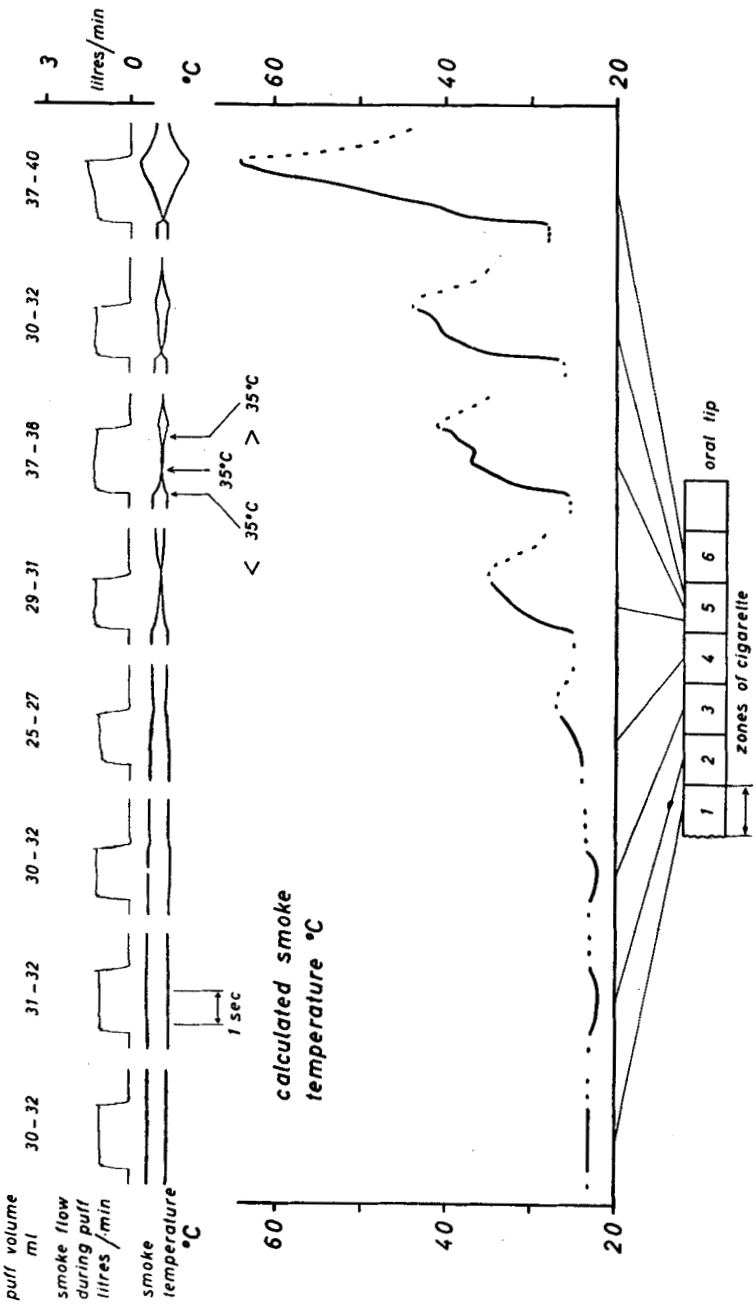

Fig. 6. Smoke flow and temperature curves obtained with a constant puff flow device.

RESULTS

Normal smoking:

Table I.

Zones of cigarette	Room temp. °C	Smoke temp. °C
1	23	23
2	23	23
3	23	28
4	23	31
5	23	43—47
6	23	68

Puff volumes: 21—53 ml
Puff duration: 1.5—2 sec.
The peak flow velocity during puffs: 2.6—2.8 litres/min.

Artificial smoking:

Table II.

Zones of cigarette	Room temp. °C	Smoke temp. °C
1	23	23
2	23	23
3	23	23
4	23	28
5	23	35—44
6	23	65

Puff volumes: 25—38 ml
Puff duration: 1.8—2 sec.
The constant flow velocity during puffs: 1.2—1.4 litres/min.

DISCUSSION

One of the theories for the genesis of oral leucoplakia and gingivitis stresses the damage by smoke heat during tobacco smoking. Temperature studies in this field have hitherto been inaccurate from a physical point of view. The heat sensing element must be quick-responding, i.e. it must have very small dimensions. Our knowledge of the volume of puffs during smoking is founded on *Phyl*'s investigation. His method, however, did not reproduce ordinary smoking conditions. The smoke flow velocity has not yet been determined.

Figures 5 and 6 illustrate smoking experiments with the recorded smoke flow curves at the top and the recorded temperature curves underneath. Each puff volume, calculated from the flow curves, is seen above and the calculated temperature changes are below the temperature recordings. At the bottom a cigarette is sketched, divided into zones, and reference lines are drawn to the calculated temperature curves within corresponding zones.

Figure 5 and Table I illustrate normal smoking. When a 70 mm long cigarette is smoked with one puff every 30 seconds, the smoke temperature mounts from 23° C to 31° C when the burning zone is within the first 40 mm of the cigarette (zones 1—4). When the burning zone spreads along zones 5 and 6 the temperature of the smoke rises to 47° C and 68° C, respectively. According to *Hilding* (1956), however, ordinary smokers only smoke about 35 mm of a cigarette (total length 70 mm), which corresponds to zones 1—4 in the present investigation. The temperature of the smoke entering the oral cavity is then about 30° C.

The duration and volume of puffs are of the same orders as those found by *Phyl.* The peak flow velocities during the puffs are 2.6—2.8 litres/min. and these peaks always come at the beginning of the puffs (see Fig. 5).

Figure 6 and Table II illustrate artificial smoking. This type of smoking with square wave flow curves was performed for investigating the influence on the smoke temperature of a constant flow during the puffs. As seen from Fig. 6 the experimental sucking device was able to smoke with a steady flow during the whole puff, and only within zone 6 was there an increasing flow velocity. This was due to the fact that the air resistance of the cigarette rapidly decreased when the burning zone reached the last two centimeters. Despite a constant flow velocity, which was only of half the order of the peak flow during normal smoking, the smoke had about the same temperature as in the normal smoking experiments.

It can be concluded from the present investigation that heat damage of cigarette smoke on the oral mucous membranes seems highly improbable under ordinary smoking conditions. Mucosal heat damage is more likely to occur for example as a result of the drinking of hot coffee (temperature 60° C—65° C).

SUMMARY

A method was described for simultaneous recordings of smoke temperature and smoke flow variations during normal and artificial cigarette-smoking. When up to 40 mm of a blend cigarette (total length 70 mm) was smoked with one puff every 30 seconds, the smoke had a temperature of about 30° C on leaving the oral tip. It was concluded that a noxious effect from smoke heat on oral mucous membranes seems highly improbable during ordinary smoking conditions.

RÉSUMÉ

ÉTUDES SUR LA TEMPÉRATURE DE LA FUMÉE DES CIGARETTES PENDANT QU'ON LES FUME

Une méthode a été donnée ici pur l'enregistrement simultané de la température de la fumée et des variations du flux de fumée pendant le temps qu'une cigarette est fumée d'une manière normale et d'une manière artificielle. Lorsqu'on a fumé 40 mm d'une cigarette de type "blend" ordinaire (d'une longueur de 70 mm) à raison d'une bouffée toutes les trente secondes, la température de la fumée quittant la cigarette par le bout oral est d'environ 30° C.

La conclusion doit être qu'un effet calorifique nuisible de la fumée sur la muqueuse orale paraît être extrêmement invraisemblable lorsqu'on fumé de la manière habituelle.

ZUSAMMENFASSUNG

UNTERSUCHUNGEN DER BEIM ZIGARETTENRAUCHEN AUFTRETENDEN RAUCHTEMPERATUREN

Eine Methode zur gleichzeitigen Registrierung der Rauchtemperatur und der Strömungsgeschwindigkeit des Rauches bei natürlichem und künstlichem Zigarettenrauchen wurde beschrieben und untersucht. Beim Rauchen von 40 mm einer normalen Blend-Zigarette (70 mm Totallänge), wobei der Rauchzug alle 30 Sekunden durchgeführt wurde, war die Temperatur des Rauches beim Verlassen der Zigarette ca. 30° C.

Zusammenfassend kann gesagt werden, dass unter normalen Rauchbedingungen die Wärme des Rauches aller Wahrscheinlichkeit nach keine schädliche Einwirkung auf die Mundschleimhaut ausübt.

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