SS 6 - Colard - Draw resistance during smoking

Author: COLARD S.

Draw resistance during smoking.

Stéphane Colard
ALTADIS Research Centre, 4 rue André Dessaux, 45404 Fleury-Les-Aubrais, France

Summary

Draw resistance is felt by the consumer when his cigarette is lit, not before. In spite of this obvious fact, this physical parameter is usually measured on unlit cigarette. In order to assess more accurately the smoker's feeling, the theoretical aspects of the draw resistance measurement during smoking have been studied and an experimental device has been developed.

During a puff, the pressure drop across the cigarette is influenced by several parameters which are independent on the characteristics of the cigarette itself. Theory and experiments show that the dead volume and the clogging up of the Cambridge filter, in the sample holder, significantly modify the measured pressure at the mouth end. The minimization of these effects can be reached by the calculation of a single parameter, more specifically characteristic of the draw resistance of the cigarette, and derived from the evolution of pressure versus time. In addition, another way for the draw resistance assessment can be proposed. This way consists in the integration of the measured pressure profile during each puff, and gives a value related to the necessary energy to supply for the generation of each of them.

Using a mono-canal smoking machine, a cigarette holder with a connection for a pressure sensor, an A/N converter and a computer, an experimental device has been developed. For the calibration of the system, a procedure using pressure drop standards composed of capillary tubs has been proposed.

Finally, the developed device enables the measurement and the recording of the draw resistance during smoking, and then a better assessment of the smoker's feeling.

1. Introduction

Draw resistance is felt by the consumer when his cigarette is lit, not before. In spite of this obvious fact, this physical parameter is usually measured on unlit cigarette. For a better assessment of the smoker's feeling it could be interesting to measure in laboratory a parameter directly linked to the draw resistance during smoking. Experimental and theoretical aspects of this measurement have been studied.

2. Experimental device

The measurement of the pressure drop during smoking (mechanical) can be carried out with an experimental device composed of the following elements: a generator of puff (smoking machine), a sample holder, a pressure sensor and a system for the measured pressure recording.

Puffs are generated by a mono-canal Borgwaldt smoking machine (RM1/G-R58 type). This machine is composed of a syringe which can create a negative pressure *P(t)*, and so, a suction across the cigarette with a volumetric airflow at the exit $Q_v(t)$. The usual standardized puff parameters of smoking have been used: sinusoidal profile, duration of 2.00±0.02 s, a puff each 60.0±0.5 s and volume of 35±0.3 ml.

In order to obtain a tight connection between the sample and the smoking machine, a standardized holder with labyrinth seals such as those currently installed on smoking machine has been used. This sample holder has been slightly modified for the measurement of the draw resistance: a small orifice allows the link sample holder – pressure sensor, and then the measurement of the pressure at the mouth end extremity during the smoking.

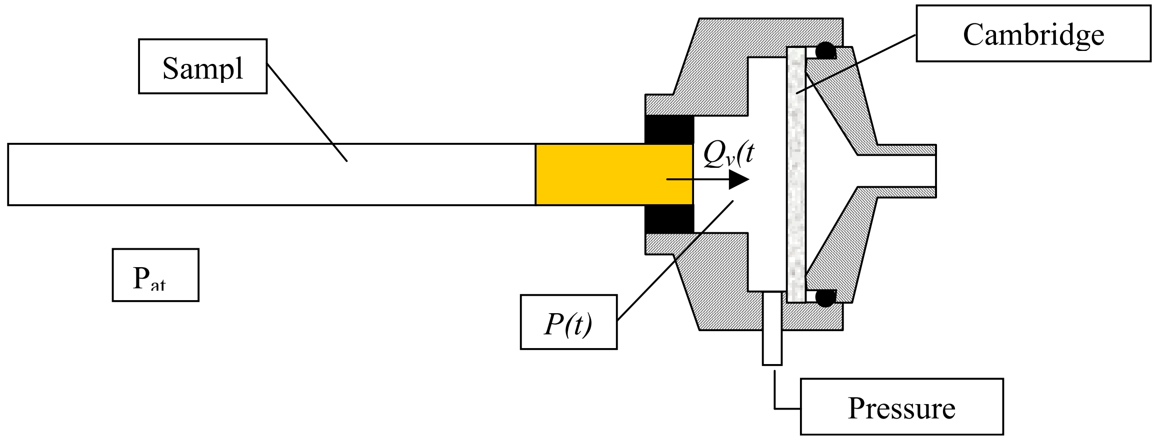

Figure 1 – Sample holder and pressure probe

The system of pressure recording is composed of a computer in which two electronic cards developed by Sodim have been installed: an analogical card including the pressure sensor and a card for the Analogical/Numerical conversion. The software named "AFC" (developed by Sodim) allows the data recording, and the drawing in real time, of the pressure evolution. A diagram showing the essential features of this system is shown in Figure 2.

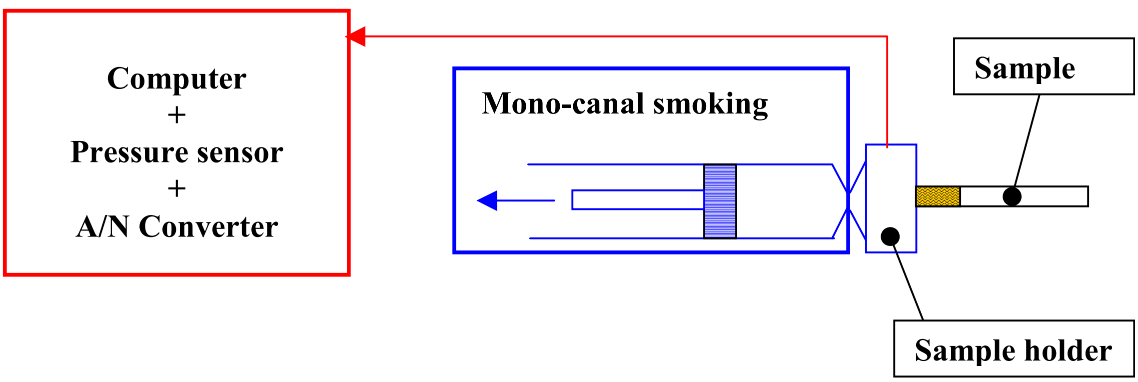

Figure 2 – Experimental device

3. Modelling

By using the model proposed by Dwyer and Chen [1], it can be shown that the relation across volumetric airflow and draw resistance is quite linear, so it can be approximated that:

$$\boxed{Q_v = k \times (P_{atm} - P) = k \times \Delta P} \qquad (1)$$

With P_{atm}: Atmospheric pressure P: Pressure at the sample exit
k: Constant

The volumetric airflow depends on the number of mole n which enters in the volume $V(t)$ behind the sample, and $V(t)$ depends on the syringe movement. From the perfect gas law, the following differential equation can be derived:

$$\boxed{\frac{\partial \Delta P}{\partial t} = \frac{(P_{atm} - \Delta P)}{V} \times \left[\frac{\partial V}{\partial t} - k \times \Delta P\right]} \qquad (2)$$

Knowing the movement of the piston of the syringe, i.e. the equation of $V(t)$, the value of $\Delta P(t)$ can be calculated.

3.1. First step: Start of the piston movement

Let consider a syringe which creates a volume $V_c(t)$ such as:

$$V_c(t) = \frac{V_c(T)}{2} \times \left[1 - \cos\left(\frac{\pi}{T} \times t\right)\right]$$

with T: duration of the piston displacement

If a dead volume V_{dead} is assumed (volume before the piston displacement):

$$\boxed{V(t) = V_{dead} + \frac{V_c(T)}{2} \times \left[1 - \cos\left(\frac{\pi}{T} \times t\right)\right]} \qquad (3)$$

The differential equation (2) can be numerically solved assuming that $\frac{\partial \Delta P}{\partial t} \approx \frac{\Delta P_i - \Delta P_{i-1}}{\Delta t}$. The equation (2) becomes:

$$\boxed{\frac{k\Delta t}{V} \times \Delta P_i^2 - \left[1 + \frac{\Delta t}{V} \times \left(\frac{\partial V}{\partial t} + kP_{atm}\right)\right] \times \Delta P_i + \left(\frac{P_{atm}\Delta t}{V} \times \frac{\partial V}{\partial t} + \Delta P_{i-1}\right) = 0}$$

(4)

The limit conditions, i.e. at t=0, ΔP_0=0, allow the iterative calculation of each ΔP_i.

3.2. Second step: End of the piston movement

When the piston stops his movement, the pressure inside the sample holder is still negative:

$$\Delta P = \Delta P(T);\frac{\partial V}{\partial t} = 0 \ ; \ V = V(T) = V_{dead} + V_c(T)$$

The equation (2) becomes:

$$\frac{\partial \Delta P}{\partial t} + \frac{k \times P_{atm}}{V} \times \Delta P - \frac{k}{V} \times \Delta P^2 = 0$$

and the solution is:

$$\Delta P(t) = \frac{\Delta P(T) \times P_{atm}}{\left(P_{atm} - \Delta P(T)\right) \times \exp\left[\frac{k \times P_{atm}}{V} \times (t - T)\right] + \Delta P(T)}$$

(5)

3.3. Draw resistance assessment

For the standardized measurement of the draw resistance of unlit cigarette, a constant volumetric airflow of 17.5 ml/s is sucked across the cigarette. It is not the case for the draw resistance measurement during smoking for which the puff profile is sinusoidal. The parameter k defined previously (Eq. 1) characterizes the product, and is directly linked to the draw resistance-airflow relation. So, it seems interesting to determine k from the measurement of the pressure profile.

Let consider the time $t=t_{max}$ at which $\Delta P(t)=\Delta P_{max}$ and $\frac{\partial \Delta P}{\partial t} = 0$.

The eq. (2) becomes $\left.\frac{\partial V}{\partial t}\right|_{t=t\,max} = k \times \Delta P_{max}$, from which k can be deduced independently on V_{dead}:

$$k = \frac{\pi . V_c(T)}{2.T.\Delta P_{max}} \times \sin\left(\frac{\pi}{T} \times t_{max}\right) \qquad (6)$$

An equivalent draw resistance with airflow of 17.5 ml/s is given by:

$$\Delta P_{equi} = \frac{17.5}{k} \qquad (7)$$

4. Results and discussion

4.1. Comparison Model/Measurements

Model and measurements have been compared in Figure 3.

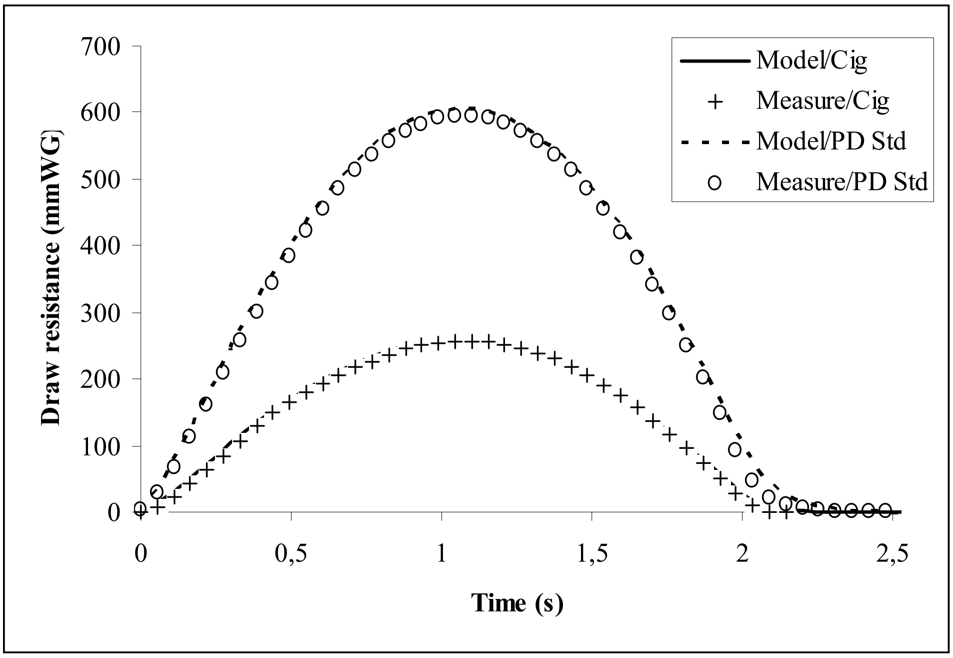

Figure 3 – Comparison Model/Experiment

Measurements have been carried out with a pressure drop standard of 391 mmWG and with a lit cigarette. Then, the pressure profiles deduced from the model developed in part 3 have been superposed to the recorded data. A good fitting is observed, the relative difference between the maximum pressures (model and measurements) is less than 2%. This result validates the assumption of linearity made (Eq. 1) for lit cigarettes like for pressure drop standards.

This kind of comparison with pressure drop standards can be used for the calibration of the pressure sensor, and then, for the improvement of the accuracy.

4.2. Repeatability of the measurement

The repeatability of the measurement can't be estimated with a lit cigarette which is continuously modified by the combustion. A pressure drop standard of 391 mmWG level has been used for this estimation. Figure 4 shows the superposition of 10 pressure profiles. The coefficient of variation of the maximum pressures is less than 0.3%.

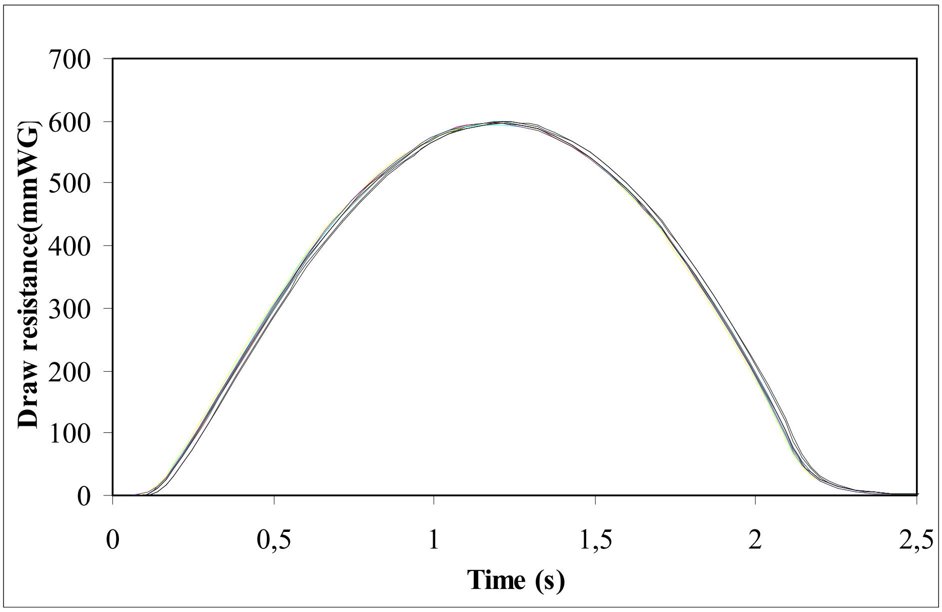

Figure 4 – Superposition of 10 pressure profiles measured with a pressure drop standard of 391 mmWG.

4.3. Effect of the dead volume

Figure 5 represents the solutions of the equation (2) for two dead volumes (0 and 200 ml) and T=2 s, $V_c(T)$=35 ml, k=0.175 ml.s^{-1}.mmWG^{-1}, Δt=0.05 s.

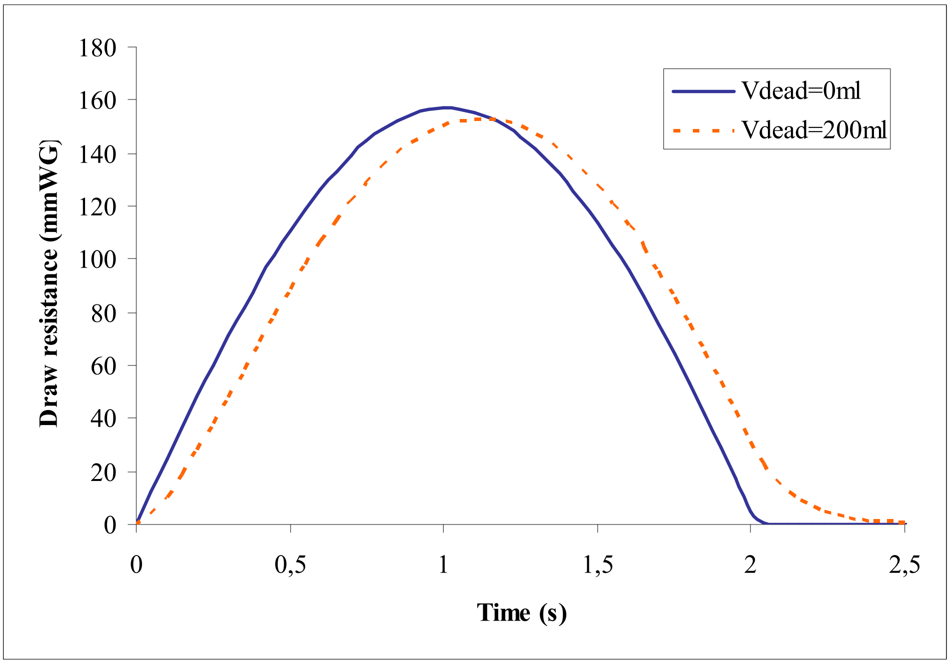

Figure 5 – Effect of the dead volume (0 and 200 ml) on the profile of pressure

It appears that the dead volume induces an inflexion point at the beginning of the puff, a decrease of the maximum pressure and a shift of the profile.

For a dead volume varying from 0 to 40 ml (current range), the area of the pressure profile and the maximum value (ΔP_{max}) have been calculated. Results represented in Figure 6 clearly show that the area has the advantage to be significantly less sensitive to the dead volume than the maximum of pressure. Moreover, the integration has the advantage to smooth the variability of the individual measurements.

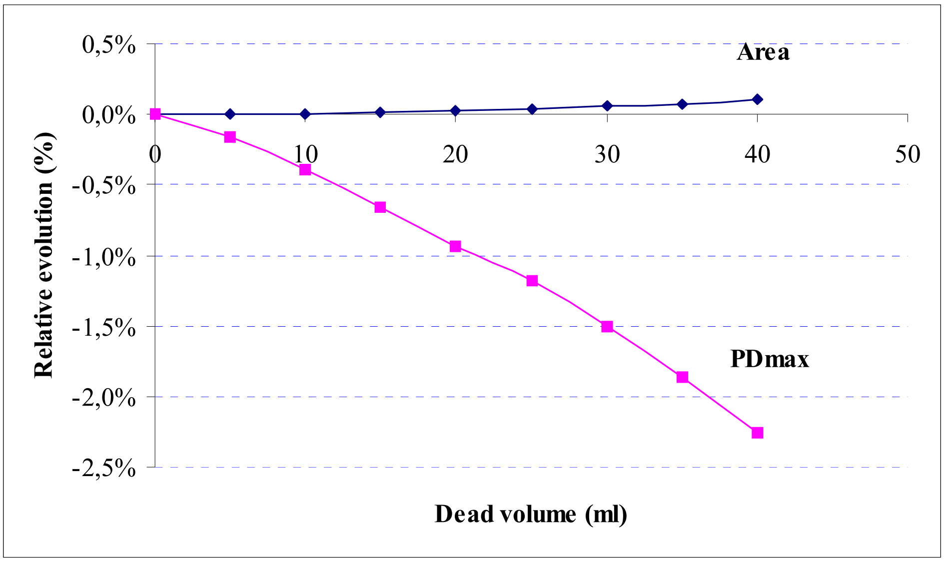

Figure 6 – Profile area and maximum pressure versus dead volume

4.4. Cambridge filter effect

Before the measurement of the draw resistance of lit cigarettes, it is necessary to put a Cambridge filter in the sample holder in order, at least, to protect the smoking machine mechanism. During the smoking, the clogging up of the filter induces an increasing additional pressure drop in the sample holder. Experiments showed that the effect of this pressure drop can be neglected when the filter is clean, but it becomes more and more significant when the number of puff increases. This effect has been estimated by an alternative measurement of a lit full flavor cigarette and a pressure drop standard. After 40 puffs, the maximum pressure is decreased of about 1%. It means it is necessary to change regularly the Cambridge filter when the measurement is carry out with lit cigarettes.

4.5. Cigarette draw resistance assessment

As it has been demonstrated in the part 3.3, an equivalent draw resistance can be calculated after the determination of ΔP_{max} and t_{max} for each profile. However, in the part 4.3, it has been shown that the pressure profile area was also an interesting parameter. This area is directly linked to the energy to supply to generate a puff, and then this characterizes particularly well and easily the draw resistance during smoking. Figure 7 represents the three parameters which can be used to characterize the draw resistance of a cigarette during smoking. The first point of each curve corresponds to the unlit cigarette. After lighting, an increase of draw resistance for the two first puffs and then a decrease until the middle of the tobacco rod are observed. Finally, the draw resistance increases once again, probably due to a gas temperature effect.

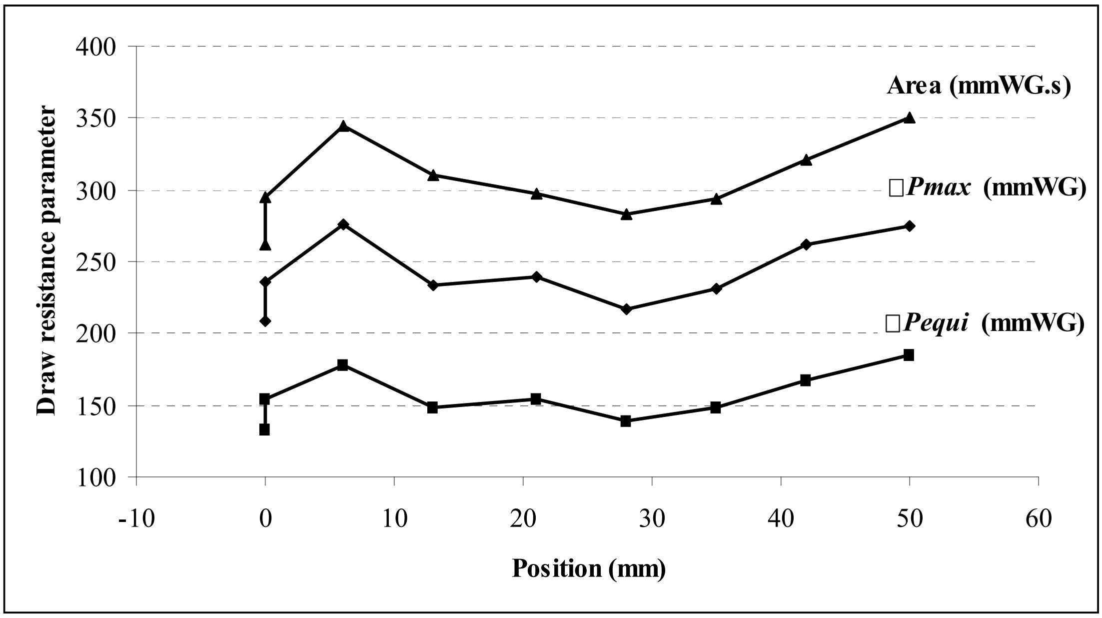

Figure 7 – Draw resistance of a cigarette during smoking

5. Conclusion

Theoretical and experimental studies have been carried out in order to develop an experimental device for the draw resistance measurement during smoking. These studies allowed underlining some important parameters which influence the pressure drop measurement during smoking, as the dead volume behind the sample and the clogging of the Cambridge filter. From these results, we concluded the interest to measure for each puff the pressure profile area. This area presents a low sensitivity to the dead volume, to the Cambridge filter clogging and to experimental noises.

Using a mono-canal smoking machine, a modified cigarette holder for the pressure measurement, two electronic cards inserted in a computer (Pressure sensor card and converter A/N) and using the software AFC distributed by Sodim, we developed an experimental device able to measure and record the draw resistance during smoking. This device has been calibrated using a pressure drop standards.

References

[1] R.W. Dwyer and P. Chen: Prediction of Pressure Drop and Ventilation in a Lit Cigarette; Beitr. Tabakforsh. Vol 18 N° 5 (1999) 205-211.