Development of a model linking TNCO emissions with filter ventilation in conventional cigarettes

E Konstantinidis\textsuperscript{1}, N Matsouki\textsuperscript{1}, C Tsipa\textsuperscript{1}, Z Gareiou\textsuperscript{1}, E Drimili\textsuperscript{1}, L Vatikiotis\textsuperscript{1} and E Zervas\textsuperscript{1,2}

\textsuperscript{1}Hellenic Open University, 26335, Patras, Greece

\textsuperscript{2}zervas@eap.gr

Abstract. One of the main parameters for the design of cigarettes is filter ventilation. As filter ventilation increases, the concentrations of Tar, Nicotine and CO (TNCO) emissions decrease. This work examines the correlation between filter ventilation and TNCO emissions, using the data of the cigarettes notified in the French market. The average values of filter ventilation, pressure drop with open and close vents and also of TNCO emissions remain quite constant during the three years examined (2018-2020). A mathematical model linking the value of filter ventilation with the values of TNCO emissions is developed. According to this model, the values of filter ventilation estimated from this model show a very good agreement with the measured values in the case of cigarettes with filter ventilation higher than 50%. Now such model could be established for lower ventilation values. These results show that the proposed model can be effectively used to correlate filter ventilation with TNCO emissions, in the case of ventilation values higher than 50%.

1. Introduction
Filter ventilation is a parameter related to the air flow passing through the filter of a cigarette. The air passing through the filter holes dilutes the concentrations of compounds found in mainstream smoke [1]. This method is used by the tobacco industry in order to reduce the concentrations of Tar, Nicotine and CO (TNCO) emissions of conventional cigarettes [2], due to the fact that the European legislation concerning these emissions is becoming more and more strict [3].

Literature reports that filter ventilation affects the concentrations of the chemical compounds found in the mainstream smoke; the increase of filter ventilation reduces the concentrations of carbonyl compounds [4], of acids, such as formic acid and acetic acid [5] and of phenol and o-, m- and p- cresol [6]. Moreover, the increase of filter ventilation decreases the concentrations of flavor constituents of mainstream cigarette smoke [7] and also reduces TNCO emissions [8]. Moreover, it is reported that the blocked vents in a filter of a conventional cigarette (i.e. when filter ventilation is 0%) increases the concentration of carbon monoxide [9].

Previous work analyzed the correlation between filter ventilation and the physical parameters of cigarettes [10]. Other works used the values of filter ventilation to estimate other physical parameters of cigarettes, such as pressure drop [11, 12, 13]. Another work reported models for the estimation of TNCO concentrations using as input the values of filter ventilation, of number of puffs and of paper porosity [14].
Even if it is reported that TNCO emissions depend on filter ventilation [15], there is an absence of works reporting mathematical models linking the TNCO concentrations with filter ventilation of conventional cigarettes. In this work, we fill this gap by developing a specific model that links TNCO emissions with filter ventilation of a great number of different cigarettes.

2. Methodology
The data used in this work are contained in the files published on the internet site of the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [16]. These files contain data on several physical and chemical parameters concerning the conventional cigarettes, as is reported in a previous work [17]. The data used here are tar, nicotine and CO emissions (in mg/cigarette) and also filter ventilation (in %). The data used concern the notifications of cigarettes from May, 28th 2018 to December 1st, 2020. The data contained in these files were retrieved and used without any involvement of ANSES.

According to the Directive 2014/40/EU [18], the upper limits of the values of the TNCO emissions of the cigarettes are 10mg/cig. for Tar, 1mg/cig. for Nicotine and 10mg/cig. for CO. In some cases, the notifications have TNCO emission values exceeding those upper limits. These data are excluded and not used in this work. Also, the average values reported here are based on the number of notifications and don’t take into consideration the sales volume of each product.

Taking into account the values of filter ventilation and of TNCO emissions of the French tobacco market during the period 5/2018 to 12/2020, it is developed a mathematical equation linking the values of Tar, Nicotine and CO (TNCO) emissions with the values of filter ventilation of cigarettes.

3. Results
According to ANSES files, 18,348 different cigarettes were notified in French tobacco market during the studied period: 3,760 cigarettes in 2018, 8,393 in 2019 and 10,267 in 2020.

3.1. Filter ventilation, pressure drop and TNCO emissions
The average filter ventilation of all notified cigarettes is 35.15% (13.43% Standard Deviation (SD), 38.21% Relative Standard Deviation (RSD)). As it is shown in Figure 1, 77 different filter ventilations are found in the French market during the studied period. The 87.37% of the cigarettes have filter ventilation between 16 and 50%, while the most common values are 23% (8.55% of all) and 32% (6.83% of all). The mean filter ventilation remains quite constant during 2018 to 2020, as the mean average value of each year differ less that ±1.59% of the all years mean value.

There are two different types of pressure drop in cigarettes, one with open vents and one with close vents shows that the values of both pressure drops are quite scattered. As it is shown in Figure 2 and Figure 3, open vents have 119 different values with the most common value of 75mm Hg (11.71% of all notifications) and those with close vents in 162, in which the most common is 120mm Hg (13.18%). The average pressure drop with open vents and close vents is 127.18 mm Hg (39.46mm Hg SD, 31.03% RSD) and 90.39mm Hg (17.92mm Hg, 19.82% RSD), respectively. Figures 2 and 3 shows that the majority of pressure drop values are found between 100-150mmHg in the case of close vents and 75-100mgHg in the case of open vents.

The average values of the two pressure drops remain quite constant during the 3 years studied here, as the mean average values per year differ from the average of all years less than ±6.2% for the pressure drop with open vents and less than ±4.59% for the pressure drop with close vents. In CORESTA method, the calculation of the pressure drop with open vents in cigarettes based on the filter ventilation and the pressure drop with close vents [13]. Figure 4 shows that, as expected, the difference of the two pressure drops, ΔP (ΔP= Pressure drop_{cl. vents}− Pressure drop_{op. vents}) increases with filter ventilation.
During the studied period, 69, 67 and 66 different distinct values are reported respectively for tar, nicotine and CO emissions (Figures 5-7). The most common value for tar emissions is 10mg/cig. (54.18% of all notifications), while for nicotine emissions and CO emissions are 0.8mg/cig (42.12% of all notifications) and 10mg/cig. (51.75% of all notifications), respectively. It is clear that the majority of cigarettes have TNCO emissions just at the regulatory limits or just below it.

The average value for tar emissions is 8.57mg (±2.06mg SD, 24.04% RSD), the average value for nicotine emissions is 0.69mg (±0.16mg SD, 23.19% RSD) and the average value for CO emissions value is 8.77mg (±1.96mg SD, 22.35% RSD). For the emissions of all three smoke constituents, the mean values remain quite constant during the 3 years studied, as the mean value of each year differs less than 3.5%, 2.9% and 3.5% for tar, nicotine and CO emissions values respectively of the all years mean value.
3.2. Correlation between filter ventilation and TNCO emission

Figure 7 shows the correlation between TNCO emissions and filter ventilation and the two pressure drops (open and close vents). As expected, there is a decrease of TNCO concentrations with filter ventilation [7, 8, 9]; however, there is no clear link with the two pressure drops.
3.3. Model linking TNCO emissions with filter ventilation

A mathematical model linking TNCO emission with filter ventilation is developed. Taking into account the fact that the three emissions decrease with filter ventilation, the following equation is proposed:

\[
\text{Filter ventilation} (\%) = \frac{a}{b + \text{Tar}^c + d + \text{Nicotine}^e + f + \text{CO}^g}
\]  

(1)

The data of all cigarettes notified in France during the studied period are used to estimate the parameters of this equation. Totally, 18,348 points are used. After several error and try searches, equation (2) is obtained for the ventilation values higher than 50%:

\[
\text{Filter ventilation} (\%) = \frac{14}{0.01 + \text{Tar}^{0.1} + 0.15 + \text{Nicotine}^{0.05} + 0.01 + \text{CO}^{1.2}}
\]  

(2)

Figure 9 shows the ventilation values estimated from this equation versus the measured ones. Totally, 2,312 points are included in this figure. As it is shown in this Figure, there is a good agreement between the estimated and the measured values of filter ventilation for the cigarettes notified with a ventilation higher than 50%. The best fit line of these points are very close to the y=x line (y=1.0012x+0.73), with a r²=0.743. A group of 28 cigarettes with ventilation=76% give an estimated ventilation of 44-45%. As this group is found quite far from the other points, they don’t follow the general trend and must correspond to products with a specific design. The elimination of these products from the calculations gives even better results, as the r² of the estimated versus measured values is now 0.826.
Figure 9. Estimated ventilation values versus measured ventilation values for all cigarettes notified in the French market during the examined period. Ventilation values >50%.

This model is not suitable for filter ventilation values lower than 50%. Figure 10 shows the application to this model to ventilation values lower than 50%. Unfortunately no such model could be established for this range of ventilation.

Figure 10. Estimated ventilation values versus measured ventilation values for all cigarettes notified in the French market during the examined period. Ventilation values <50%.

The above results indicate that the proposed model can be effectively used to link the filter ventilation values with TNCO emissions of a cigarette, for filter ventilation values higher than 50%.

4. Conclusions
The analysis of the 18,348 cigarettes notified in the French market during 2018-2020, concerning the filter ventilation and the pressure drops with open or with close vents, tar, nicotine and CO emissions and their correlations, is performed.

The average filter ventilation of all notifications is 35.15%. The average tar, nicotine and CO emission value is 8.57, 0.69 and 8.77mg respectively. The most common values of tar, nicotine and CO emissions are 10mg/cig, 0.8mg/cig. and 10mg/cig., respectively, just at the regulatory limits or
very close to them. For all these parameters, the average values remain quite constant during the 3 years examined.

The relation between filter ventilation versus TNCO emissions show a general linear relationship between the filter ventilation and those three pollutants, but no such correlation exist between these emissions and pressure drops with open or close vents.

A model linking TNCO emissions with filter ventilation is developed for ventilation values higher than 50%. The values of filter ventilation estimated from this model show a very good agreement with the measured values. This indicates that this model can be effectively used to correlate TNCO emissions with filter ventilation.

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