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# Effect of puffing intensity on cigarette smoke yields

S.W. Purkis [a,*], V. Troude [b], C.A. Hill [c]

[a] Imperial Tobacco Limited – P.O. Box 525, Winterstoke Rd., Bristol BS99 1LQ, UK
[b] SEITA – Imperial Tobacco Group, 48 rue Danton, 45404 Fleury-les-Aubrais, France
[c] Independent Consultant, 29 St. Marys Park, Nailsea, Bristol, BS48 4RP, UK

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ABSTRACT

Two US blend style cigarette products, one ventilated, were smoked under 16 smoking regimes. 'Tar', nicotine, carbon monoxide (TNCO) and water smoke yields determined with these regimes, are shown to form part of continuous functions linked with puffing intensity (the product of puff volume and puff frequency) and total puff volume (the product of puff volume and puff number). This allows the prediction of yields for any regime and leads to the conclusion that the characterisation of cigarette products with these analytes is achievable from using a single smoking regime.

The rate of increase of TNCO yields decreases as the puffing intensity increases, due to the more rapid burning of the tobacco available for smoking, although (particulate phase) water yield, relative to TNCO, increases considerably with intensity.

Total puff volume is linearly related to TNCO machine yields from a range of regimes, to duplicated human yields and to the nicotine and solanesol retained in spent filters. The concentration of these smoke components is essentially independent of the regime used to generate them. This is not the case with water for which the yield in smoke increases exponentially with the total puff volume and its concentration increases rapidly with intensity.



## 1. Introduction

Smoke yield data were previously collected under different smoking regimes for research purposes from two UK cigarettes, commercially available in the 1980s, containing flue-cured blends. Although not published at that time, the data were presented to the UK Independent Scientific Committee on Smoking and Health (ISCSH) to illustrate how the rank order for smoke yield was maintained over a wide range of smoking regimes. These data were revisited and presented (Hill, 2011) at a meeting of Working Group 10 of Technical Committee 126 (TC126) of the International Organization for Standardization (ISO). It investigated the relationship between smoke yields and different puffing intensities obtained over a wide range of puff volumes and puff frequencies with fixed puff duration.

Cigarette specifications have changed since the 1980s in line with the current lower tar yields and regulatory requirements (European Commission, 2001). In this work, data were produced to represent current commercial cigarettes, in this case with an American style instead of a flue-cured style blend, with lower tobacco weights and higher filter ventilation levels than those previously studied to investigate whether similar relationships were found. The two commercially available cigarette products used in this work have been recently studied in relation to other aspects of cigarette smoking regimes (Purkis et al., 2010a). This paper analyses the nicotine free dry particulate matter (NFDPM)[1], nicotine, carbon monoxide (CO) and water yields generated under 16 different smoking regimes carried out on these two products in a similar way to the earlier study on 1980s cigarettes. The data are put in context with related studies previously discussed in the literature. Thus, the objective of this work is to establish if TNCO smoke yields form part of a continuous function linking yields with puffing intensity and total puff volume. The provision of such functions would make possible the prediction of yields for any regime and the characterisation of cigarette products by using a single smoking regime. The paper also provides a comparison between machine smoking and human smoking yields duplicated on a smoking machine.

*Abbreviations:* CO, carbon monoxide; CI, Canadian intense machine smoking regime; CORESTA, Cooperation Centre for Scientific Research Relative to Tobacco; ISCSH, UK Independent Scientific Committee on Smoking and Health; ISO, International Organization for Standardization; NFDPM, nicotine free dry particulate matter; PI, Puffing intensity; SWVP, saturated water vapour density; TC126, ISO Technical Committee 126 on Tobacco and Tobacco Products; TNCO, "tar", nicotine and CO smoke yields; TPM, total particulate matter; TPV, total puff volume.

* Corresponding author. Tel.: +44 117 300 4163; fax: +44 117 300 4150.
*E-mail address:* steve.purkis@uk.imptob.com (S.W. Purkis).

[1] NFDPM is sometimes referred to as 'tar'.

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## 2. Experimental

### 2.1. Cigarette types

Two commercial products, one with filter ventilation (Product L) and one unventilated (Product F), were chosen as described in previous publications (Delarue et al., 2001; Purkis et al., 2010a). The product specifications are given in Table 1. Product L was also studied with its ventilation holes fully blocked thus providing a third product designated as Product LVB.

### 2.2. Smoking regimes

Smoke yields were obtained after smoking on a linear smoking machine (Cerulean, SM450) equipped with a vent block holder (Cerulean) for Product LVB. The number of cigarettes per run was adjusted to avoid any overloading of the 44-mm Cambridge filter pad. Either 3 or 5 replicates were obtained on 16 different smoking regimes for each of the 3 cigarette types giving a total of 152 runs (3 replicates for 44 runs and 5 replicates for 4 runs) providing data for all the studied smoke yield parameters and measurements on filter tips from the machine regimes. Measurements of total particulate matter (TPM), smoke nicotine, smoke water, CO and puff numbers were made according to ISO standards (ISO 3402, 1999; ISO 4387, 2000; ISO 10315, 2000 and ISO 10362-1, 1999) and NFDPM yields were calculated accordingly. The smoking parameters for each regime are given in Table 2. Two replicates (5 cigarettes per run) from each of the duplicated human smoking regimes were also obtained. The average data are shown in the following figures.

### 2.3. Human smoking yields

Human smoking data had been obtained for 30 panellists who had smoked Products L and F according to the procedures already described in the literature (Delarue et al., 2001; Purkis et al., 2010a). In summary, panellists had smoked the products in a special holder in the laboratory and due to the set up, no human vent blocking could have occurred with the special holder attached. The smokers' behaviour was recorded in the laboratory and profiles were duplicated on the Duplicator machine (Sodim DFC D-87) to determine human yields either from collected smoke or from the spent filter tips. Data from each of the panellists were compared with that from the 16 different machine smoking regimes.

For this study, nicotine and solanesol levels were measured in the filter tip for all the machine smoking and for duplicated human smoking runs according to the part filter methods similar to those methods described in the literature (St Charles et al., 2009; CORESTA, 2009; Polzin et al., 2009). A 1 cm portion of filter material, measured from the mouth end, was removed from the cigarette butts and the part filter method was used for these determinations made after 2 weeks storage at −20 °C. The filter tips from all replicates were pooled and extracted with methanol (4 mL/tip) for 30 min then analysed for nicotine by gas chromatography with a flame ionisation detector (Trace; ThermoElectron on Supelcowax column) and quantified for solanesol by high performance liquid chromatography with ultra violet detector ($\lambda$ = 206 nm).

## 3. Results and discussion

Studies have been carried out on two modern day products, one ventilated (Product L) and one unventilated (Product F); and also the ventilated product with filter ventilation blocked (Product LVB), to investigate the yields obtained under different puff volumes ranging from 17.5 mL to 70 mL; puff frequencies ranging from 1 to 3 per minute with the puff duration fixed at 2 s. Most of the paper will focus on data from the ventilated Product L since data from the ventilation blocked product (LVB) can be closely compared to Product F. Data and findings were similar to those on two products manufactured and tested in 1980s. One was an unventilated 15 mg NFDPM and the other was a 7 mg NFDPM yielding cigarette with 28% filter ventilation that was reported at ISO Working Group 10 (Hill, 2011) in relation to current regulatory proposals (World Health Organization, 2008).

### 3.1. Effect of puffing intensity on burn rate

Data for any cigarette type can be plotted graphically showing the relationship of a single parameter of puffing intensity (PI) defined as the product of puff volume and puff frequency to other parameters.

It is recognised that the process by which smoke is formed and transferred through a cigarette is extremely complex and is dealt with in a simplified manner in this paper. The smoke volume drawn from a cigarette during a puff can be divided into several components. Whilst this paper deals with two, the puff volume leaving the cigarette coal and the ventilation at the cigarette filter, it is recognised that there are additional components, for example, the dead volume in the cigarette, paper ventilation and the volume of combustion gases produced at the coal. These extra components have not been included as they are either minor in magnitude or do not impact on the analysis of the data.

The relationship between burn rate and PI is considered first. The burn rate can be calculated as described in the literature (St Charles, 2000) and according to the simple formula given below.

**Table 1**
Cigarette specifications.

| Cigarette code | F | L | LVB |
|---|---|---|---|
| Commercial brand name | Gauloises Blonde Blue | Gauloises Blonde Yellow | Gauloises Blonde Yellow |
| Source market | Morocco | Arabic countries | Arabic countries |
| Blend style | US | US | US |
| NFDPM yield* (mg/cig) | 10.5 | 3.3 | 7.9 |
| $PD_{VB}$ (mmWG) | 125 | 95 | 148 |
| PD Tip (mmWG) | 67 | 95 | 95 |
| Cigarette length (mm) | 83 | 83 | 83 |
| Butt length (mm) | 29 | 35 | 35 |
| Filter ventilation (%) | 0 | 49.3 | 0 |
| Filter length (mm) | 21 | 27 | 27 |

NFDPM yield* is given as determined under the smoking parameters described in ISO 3308, 2000+A1:2009.
LVB = Product L with ventilation holes blocked.
PD = Cigarette pressure drop.
$PD_{VB}$ = Cigarette pressure drop with ventilation holes blocked.