A prediction model for effects of atmospheric pressure on deliveries of tar and carbon monoxide in mainstream smoke based on ventilation rate of cigarette

ZHAO Hui (1), XIONG Wen (1), CHEN Zaigen(2), et al.
1.R&D Center of Hongta Tobacco (group) Co. Ltd., Yuxi, Yunan Province, 653100, P.R. China
2.China National Tobacco Quality Supervision & Test Center，Zhengzhou, Henan Province, 450001, P.R. China

Abstract

Multiple smoke analysis laboratories of China are located in high altitudes, where atmospheric pressures below 86kPa. To modify the effect of atmospheric pressure on the detection results for tar and carbon monoxide in mainstream smoke, based on cigarette ventilation, a prediction model was explored.

With the drop of atmospheric pressure, cigarette ventilation increased gradually, result in the lower deliveries of tar and carbon monoxide.

Cigarette ventilation was selected as a variable, the effect of atmospheric pressure on the deliveries of samples with different tar can be reasonably interpreted. The prediction model was proved to be effective for revising the tar and carbon monoxide deliveries obtained under different atmospheric pressure.

This work provided valuable reference for further investigation of the mechanism of the effect of atmospheric pressure on cigarette mainstream smoke delivery and the establishment of a more precise model for a burning cigarette.

1. Theoretical Background

When the atmospheric pressure is decrease, or the cigarette ventilation is increase, are all led to the similar result. So, we selected the cigarette ventilation as the intermediate variable to built our model.

The effect of air density (ρ) on the flow rates of filter (Q_f) and cigarette paper (Q_p) had been studied by Baker[1] and Keith[2] respectively:

$$Q_f = \frac{\alpha \cdot j \cdot a \cdot S_f \cdot \Delta p_f^{1/2}}{60 \cdot \sqrt{\rho}} \cdot 8.3 \times 10^3 \quad [1] \qquad Q_p = \frac{N_R \cdot \mu \cdot S_p}{D \cdot \rho} \quad [2]$$

In these two equations , the air density(ρ) is the only parameter which dependent on atmospheric pressure:

$$\rho = \rho_0 \cdot (\frac{P}{P_0}) \cdot (\frac{273.15}{T + 273.15}) \quad [3]$$

When a same sample tested under the condition of standard(P_0) and off-standard atmospheric(P_1) pressure, the relationship of the vent flow(Q_f , Q_p) could be shown as follows:

$$Q_{f1} = Q_{f0} \cdot \sqrt{\frac{P_0}{P_1}} \quad [6] \qquad Q_{p1} = Q_{p0} \cdot \frac{P_0}{P_1} \quad [7]$$

2. Modeling

Step 1. The effect of atmospheric pressure on cigarette ventilation

By the definition of unlit cigarette ventilation (ISO) :

$$V = \frac{Q_f + Q_p}{Q} \times 100\ \% = V_f + V_p \quad [8]$$

Substituting equation [6],[7] into [8]:

$$V_1 = \sqrt{\frac{P_0}{P_1}} \cdot \frac{Q_{f0}}{Q} \times 100\ \% + \frac{P_0}{P_1} \cdot \frac{Q_{p0}}{Q} \times 100\ \% = \sqrt{\frac{P_0}{P_1}} \cdot V_{f0} + \frac{P_0}{P_1} \cdot V_{p0} \quad [9]$$

Step 2. The effect of ventilation on the deliveries of NFDPM and CO

By combining the influence factors of Dilution and Mass-transfer, we should be able to fit the data by an equation of the form:

$$\frac{Y}{Y^*} = (1 - \frac{V}{100}) \cdot f(V) \quad [10]$$

Under the condition of standard and off-standard atmospheric pressure , it becomes:

$$\left. \begin{cases} \frac{Y_0}{Y^*} = \left(1 - \frac{V_0}{100}\right) \cdot f(V_0) \\ \frac{Y_1}{Y^*} = \left(1 - \frac{V_1}{100}\right) \cdot f(V_1) \end{cases} \right\} \rightarrow Y_0 = Y_1 \times \left(\frac{100 - V_0}{100 - V_1}\right) \cdot \frac{f(V_0)}{f(V_1)} \quad [11]$$

Step 2.1 The model of NFDPM

For NFDPM, the mass-transfer factor (f(V)) can be formed by the efficiency of filtration [3] :

$$Y_{Tar\ 0} = Y_{Tar\ 1} \times \left(\frac{100 - V_0}{100 - V_1}\right) \times Exp[\Delta P_0 \cdot (6.47 \times 10^{-6} \cdot (V_1 - V_0) + 8.45 \times 10^{-3} \cdot ((100 - V_1)^{-2/3} - (100 - V_0)^{-2/3}))] \quad [13]$$

Step 2.2 The model of CO

For CO, the mass-transfer factor (f(V)) is dependent on the diffusion [4] :

$$Y_{CO0} = Y_{CO1} \times \left(\frac{100 - V_0}{100 - V_1}\right) \times Exp\left(F \times \left(\frac{1}{17.5 - 0.175 \times V_1} - \frac{1}{17.5 - 0.175 \times V_0}\right)\right) \quad [15]$$

Combining the equation [9] and [13]/[15], the result of NFDPM/CO could be corrected.

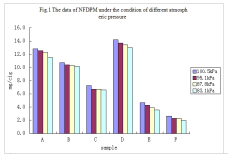
3. Experimental Validation

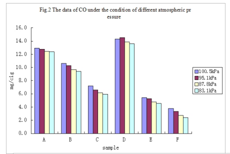
Six samples were selected, with Intended ISO Tar level from 3-14 mg/cig, and filter-vent level from 0.5-62.9%，tested in 4 laboratories in various area, under the atmospheric pressure from 83.1-100.5 kPa.

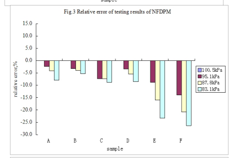
As Figure 3-6 show that:

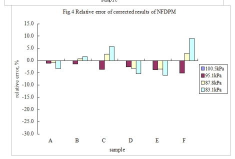
(1) For target lab, the corrected data did not change.

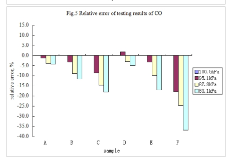
(2) For other labs, the relative error of corrected data were significantly reduced, most of them are no more than 5%.

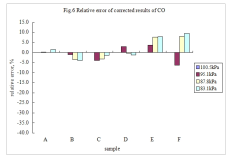












4. Conclusions

(1) Choosing cigarette ventilation as a variable, the effect of atmospheric pressure on the deliveries of samples with different tar can be reasonably interpreted.

(2) The prediction model was proved to be effective for revising the NFDPM, and Carbon Monoxide deliveries obtained under different atmospheric pressure.

(3) For cigarette without perforated tipping paper, the corrected results are on the low side, and for cigarette with ventilation above 60% are on the high side.

Reference

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