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Measurement of the Apparent Density of Shred and Void Fraction in a Tobacco Column

In-Hyeog Oh*, Byong-Kwon Jeh, Do-Young Ra, Dae-Keun Kwak, Byeoung-Ku Kim, Si Hyung Jo and Moon-Soo Rhee
KT&G Central Research Institute

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ABSTRACT : The measurement of physical properties such as apparent density and void fraction of tobacco materials, which is so bulky, is a main theme with regard to tobacco process, quality control, cigarette combustion and smoke generation. Except Solution Impregnation Method, there was no alternative method for measuring those properties in the porous material so far. However, experimental processes of that method are so complicated as to cost much time and labor, the main solution such as mercury to apply to the method is usually very hazard. Therefore, we had developed a new method to determine them easily in our other paper by the mathematical equations derived from the Ergun equation for the purpose of it, and then already evaluated our method through applying some basic data from Muramatsu *et al.* (1979) with regard to our developed equations. Then, we found our method best fit to experimental one (Oh *et al.*, 2001). In this study we tried to establish our method to conveniently determine those physical properties. Especially, we have focused on the development the easy way to measure surface area and the volume of single shred in a tobacco column. As a result of that, we found that the computer image analyzer was best fit for it. Then, we have finally determined apparent density and void fraction for our domestic tobacco shred.

Key words **: tobacco, apparent density of shred, void fraction**

In the tobacco industry, the physical properties of the tobacco shred as one of bulk materials has been considered to be main factors of process control and final product quality control. Apparent density and void fraction in a tobacco column of those physical properties is especially important, because two properties are directly related with various physical transport phenomena which happen in porous materials. In the manufacturing processes of agricultural, biological or food materials with porosity, those properties have great influence on the variables to control the system, and also various characteristics of final products.

In the course of tobacco primary processes, moisturizing and drying are very frequently applied to manufacture cigarette products, ethanol solutions with various volatile flavorings and aromatic components are also sprayed over the tobacco for its taste. Movement of each component

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*연락저자 : 305-805, 대전광역시 유성구 신성동 302 번지, KT&G 중앙연구원
*Corresponding author : *KT&G Central Research Institute, 302 Shinseong-dong, Yuseong-gu, Daejeon 305-805, Korea(Phone : 82-42-866-5609 ; fax : 82-42-866-5426 ; e-mail : ihoh@ktng.com)*

through the tobacco internal structure is quite dependent on the physical properties such as real density, apparent density, and pore size distribution. In particular, the transfer mechanism for moisture is a direct function of the physical properties of the tobacco. Moisture content of cigarettes has a significant impact on the shelf life and the taste of the products. Various physical properties of a piece of cigarette including loose ends, burning rate, hardness, and pressure drop could be affected by moisture (Marian *et al.*, 1978). The physical properties of tobacco leaves have also direct effects on the above listed physical properties of a piece of cigarette.

Therefore, the determination of the values for real density, apparent density, and pore size experimentally is so important that many research works have been reported. As one of them, Masuo *et al.* (1971) determined the real density, apparent density, pore volume and porosity of tobacco leaves. They developed relationship among these characters and other physical and chemical properties, and also measured real density with a Beckman Air Pycnometer, and apparent density with an oil impregnation method. Several researchers (Nakanishi and Kobari, 1989; Nakanishi, 1991; Samejima *et al.*, 1977; Samejima *et al.*, 1984) have studied the moisture transfer mechanism in the cured tobacco leaf. Both the specific surface area and the specific pore volume distribution of tobaccos were determined by various methods (Nakanishi and Kobari, 1989; Samejima *et al.*, 1977; Samejima *et al.*, 1984). In order to optimize tobacco flavoring processes, Nakanishi (1991) also measured the specific surface and the pore size distribution as necessary physical properties. Muramatsu *et al.* (1979) determined the real density and the apparent density so as to use these data for simulating the evaporation pyrolysis processes inside a naturally smoldering cigarette. Also, Okada and Ota (1975) investigated those properties to get the draw resistance of a cigarette using the Ergun equation.

Apparent density of shredded tobacco has been conventionally measured by a complicated and difficult method like the Solution Impregnation Method. Thus, in our last study (Oh *et al.*, 2001) we successfully developed a new and easy method of determining the apparent density of shredded tobacco, and evaluated our method through applying some basic data from Muramatsu *et al.* (1979) with regard to our developed equations. And the results showed that our method best fit to experimental one. In this study we tried to establish our method to conveniently determine those physical properties. Especially, we have focused on the development the easy way to measure surface area and volume of single shred in a tobacco column. Our efforts aim to do tobacco process control, quality control, and understanding of physical mechanism inside a cigarette. As a result of that, we found that the computer image analyzer was best for it. The apparent density and the void fraction of domestic tobacco shred were successfully determined by using this method.

MATERIALS AND METHODS

Analytical Development

Our new method developed for determining easily the apparent density of shred and void fraction in a tobacco column using the Ergun equation (1952) was briefly explained below. In general, the Ergun equation can be applied to calculate the pressure drop of fluid flow through packed columns.

$$\frac{\Delta P}{L} = 150\frac{(1-\Phi)^2}{\Phi^3}\frac{\mu v}{D_p^2} + 1.75\frac{1-\Phi}{\Phi^3}\frac{\rho v^2}{D_p} \qquad [1]$$

In the equation [1], the characteristic dimension (D_p) generally used is the diameter of a sphere having the specific surface (S_v) which is expressed by

$$D_p = \frac{6}{S_v} \qquad [2]$$

The specific surface can be written as follows

$$S_v = \frac{\text{total surface area}}{\text{total volume}} = \frac{A_t}{V_t} \qquad [3]$$

The value for void fraction (ϕ) inside a tobacco column (here, the pores of tobacco shred are not regarded as void space) was determined as follows:

$$\phi = 1 - \frac{\text{packing density of shred}}{\text{apparent density of shred}} \qquad [4]$$

The value for total void fraction (Φ) inside a tobacco column (here, the pores of tobacco shred are regarded as void space) was calculated using:

$$\Phi = 1 - \frac{\text{packing density of shred}}{\text{real density of shred}} \qquad [5]$$

And the values for ϕ' and Φ' are defined as

$$\phi' = 1 - \phi \qquad [6]$$

$$\Phi' = 1 - \Phi \qquad [7]$$

In equation [3], the terms for A_t and V_t are given by

$$A_t = n \times A_s \times \left\{ 1 + \left(\frac{\Phi - \phi}{\phi'} \right)^{2/3} \right\} \qquad [8]$$

$$V_t = n \times V_s \times \frac{\Phi}{\phi'} \qquad [9]$$

Therefore, equation [3] can be rewritten as

$$S_v = \frac{A_s \left\{ 1 + \left(\frac{\Phi - \phi}{\phi'} \right)^{2/3} \right\}}{V_s \left(\frac{\Phi}{\phi'} \right)} \qquad [10]$$

Experimental Procedure

In order to predict the apparent density (ρ_a) and the void fraction (ϕ) basic physical properties of used cigarettes are shown in Table 1. We are generally able to determine the other properties besides the pressure drop, the shred thickness and the real density in the middle of cigarette sorting process. The pressure drop was measured by the Pressure Drop Tester (Draw Resistance Meter A11, Borgwaldt KC, Germany), and the real density was obtained using Ultra Pycnometer 1000 (Quantachrome, USA). In this study three non blended tobacco columns (57 mm (L) × 24.5 mm (C)) were tested (Table 1). The cigarette samples were selected depending on the weight and the pressure drop at an airflow of of 17.5 cm^3/sec after conditioning at 20℃ and 60% relative humidity, and each cigarette sample was divided into tobacco column for the test and filter by the cutter. The cut width of a shred of three samples was 0.9 mm.

Table 1. Properties(I) of test cigarettes

Cigarette (symbol)	Tobacco type	Weight (g/cig.)	Pressure drop (mmH_2O)	Packing density (g/cm^3)	Moisture content (wt. %, wet base)	Shred thickness (cm)	Real density of shred (g/cm^3)
F	Flue cured	0.790	63	0.290	13.6	0.019	1.578
B	Burley	0.504	45	0.185	10.7	0.015	1.705
R	Reconstituted	0.748	41	0.275	12.4	0.025	1.705

Table 2. Physical properties of inlet air into the Pressure Drop Tester at 20℃

Contents	Properties
Air density (g/cm^3)	1.204×10^{-3}
Air viscosity (g/cm sec)	1.8×10^{-4}
Air superficial velocity (cm/sec)	36.6

When the pressure drop of tobacco columns are measured by the Pressure Drop Tester

Table 3. Properties(Ⅱ) of test cigarettes

Cigarette (symbol)	Tobacco type	n (-)	A_i (cm^2)	A_s (cm^2)	V_s (cm^3)	Φ (-)
F	Flue cured	1357	71	0.130	$9.93\mathrm{x}10^{-4}$	0.816
B	Burley	1147	63	0.131	$8.24\mathrm{x}10^{-4}$	0.891
R	Reconstituted	874	63	0.189	$1.80\mathrm{x}10^{-3}$	0.839

Fig. 1. Example of an image analysis of shreds' number and total surface area.

operating at 20℃, the physical properties of inlet air are shown in Table 2.

The total void fraction (Φ) the average surface area of a single shred (A_s) and the average volume of a single shred (V_s) are shown in Table 3. The total void fraction can be calculated by putting the values of packing and real density from Table 1 into equation [5].

Here, the average surface area and the average volume of a single shred are too difficult to measure with human eyes, and we need to do it carefully because those data influence the accuracy of our final determination of ϕ and ρ_a. Thus, we apply a new methodology, a computer image analyzer (Image Pro Plus ver. 4.5.1.22, Media Cybernetics, Inc., USA). After getting the image by the scanner we analyze the number (n) and total surface area of shreds (A_i) inside a tobacco column by the software. One example of the image analysis method is presented in Fig. 1.

RESULTS AND DISCUSSION

The procedures of obtaining the void fraction, ϕ, and the apparent density, ρ_a are shown in Fig. 2. And, the results are shown in Table 4. Equations [1] and [10] were solved by a program, which used the Newton Raphson algorithm (Press *et al.*, 1992). The values of D_p and S_v in Table 4, which is necessary for getting the void fraction, ϕ, and the apparent density, ρ_a were obtained by equations [1] and [2].

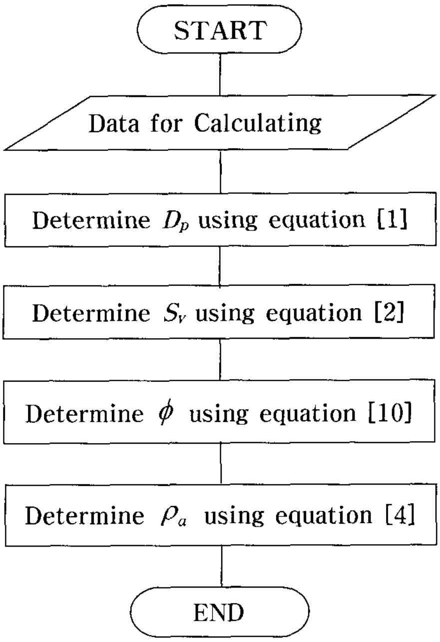

Fig. 2. Flow chart of obtaining the void fraction, ϕ, and the apparent density, ρ_a.

Comparison between the real density in Table 1 and the apparent density in Table 4 shows that the burley tobacco of three tobacco types is most porous, second for the reconstituted, and third for the flue cured. Even though the packing density of the reconstituted is larger than that of the burley, the pressure drop shows opposite trend. Since the porosity inside the tobacco material and the total number of shreds inside the tobacco column affects air flow, these two main factors make bigger friction factor of air stream. However, the calculated values of A_t, V_t and $\Phi - \phi$ in Table 5 is not directly related to the pressure drop. This fact suggests that the exact sorting process of cigarettes would require another step to test the pressure drop besides the cigarette weight.

CONCLUSIONS

Measurement of various physical properties of cigarettes such as weight, pressure drop, size of a shred, density and void fraction are necessary for the development of new brand cigarette or cigarette quality assurance. In order to predict the void fraction and the apparent density for three kinds of our domestic tobacco without various complicate experiments, we applied the newly developed method in our last study. In this study, we especially focused on easy measurement of total number and total surface

Table 4. Calculated D_p, S_v, void fraction and apparent density of test cigarettes

Cigarette (symbol)	Tobacco type	D_p (cm)	S_v (cm^{-1})	ϕ (-)	ρ_a (g/cm^3)
F	Flue cured	0.00801	749.1	0.409	0.491
B	Burley	0.00497	1207.2	0.548	0.409
R	Reconstituted	0.00837	716.8	0.394	0.453

Table 5. Calculated A_t, V_t and $\Phi - \phi$ of test cigarettes

Cigarette (symbol)	Tobacco type	A_t (cm^2)	V_t (cm^3)	$\Phi - \phi$ (-)
F	Flue cured	176	1.35	0.407
B	Burley	150	0.945	0.343
R	Reconstituted	165	1.57	0.445

area of shred inside the tobacco column using the image analysis method. Finally, we set up the process for determining the apparent density of shred and the void fraction in a tobacco column using the Ergun equation.

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NOMENCLATURE

ΔP = pressure drop (g/cm·sec^2)
L = length of tobacco column (cm)
Φ = total void fraction inside a tobacco column (—)
μ = air viscosity (g/cm·sec)
υ = superficial velocity (cm/sec)
D_p = effective diameter of shred (cm)
ρ = air density (g/cm^3)
S_v = specific surface (cm^{-1})
A_t = total surface area of shreds inside a tobacco column (cm^2)
V_t = total volume of shreds inside a tobacco column (cm^3)
ϕ = void fraction inside a tobacco column (—)
Φ' = defined value from equation (7) (—)

ϕ' = defined value from equation (6) (—)

A_s = average surface area of a single shred (cm^2)

V_s = average volume of a single shred (cm^3)

n = number of shreds inside a tobacco column (—)

ρ_a = apparent density of shred (g/cm^3)

A_i = total surface area of shreds inside a tobacco column detected by computer image analyzer (cm^2)