Adsorption of the Vapor Phase Components in Cigarette Smoke by Activated Carbon in Vented Filters

Atsushi Tokida, Ichiro Atobe and Kazuo Maeda

Central Research Institute, Japan Tobacco Inc., 6-2, Umegaoka, Midori-ku, Yokohama 227, Japan
Received January 29, 1985

Using vented charcoal filters, the adsorption efficiencies of acetaldehyde, isoprene and acetone, the major components in the vapor phase of cigarette smoke, were studied. Filter ventilation was found to raise the adsorption efficiency of the adsorbent. The effect of increasing the ventilation rate through the filter was greatest for the adsorption of acetaldehyde. In order to clarify the effects of decreases of the flow rate and the concentration caused by ventilation, the adsorption by unvented charcoal filters under varied conditions was also measured. Although both raised the adsorptions of the three components, the lowered concentration was contributed to mainly by an increase of adsorption by the vented charcoal filters. Regardless of whether the filter was perforated or not, the adsorptions of the three components depended on the volume of the air drawn in at the top of the lighted end of the cigarette.

The adsorption efficiency of cigarette smoke by charcoal filters has been reported in several papers, but these filters were unvented ones. Recently, vented cigarettes and especially those with vented filters have come onto the market. Accompanying this trend, charcoal filters with perforations have also begun to be sold on the domestic market.

In another paper, the reduction of cigarette smoke by perforated mouthpiece tubes was investigated in order to elucidate the effects of ventilation in the filter section of cigarettes containing no filter materials. Both the concentration of smoke and the flow rate in the filter were lowered by this ventilation. Therefore, the adsorption efficiency of activated carbon is presumed to be different from that in unvented filters.

This paper describes the adsorption efficiency of the vapor phase components in the smoke by activated carbon in both vented and unvented filters under standard and varied smoking conditions. The effects of filter ventilation on the adsorption are discussed.

MATERIALS AND METHODS

Two kinds of charcoal filters were used. One was a so-called cavity filter, in which 20, 30 or 40 mg of activated carbon, made from coconut shell, was placed between 6 and 11 mm lengths of acetate filter in a perforated ceramic tube. The other was a dual filter in which 5 or 10 mm lengths of acetate filter amongst which activated carbon had been distributed (40 mg/10 mm) and 10 mm of plain acetate filter were placed in series in the tube. As described in another paper, all or some of the holes in the tube could be sealed to control the ventilation.

The plain filterless cigarettes, measurements of the ventilation rates of the cigarettes with vented charcoal filters, smoking conditions, and the determination of acetaldehyde, isoprene and acetone were the same as those described in the previous paper. The ventilation rates through cigarette paper were small enough to be negligible. Cigarettes with unvented charcoal filters were also smoked under varied conditions in addition to the standard ones.

Reductions of component i ($R_i$) by vented charcoal filters under the standard smoking conditions are defined by Eq. (1).

$$R_i = 100(C_{io} - C_{iv})/C_{io}$$

(1)

where $C_{io}$ and $C_{iv}$ are the relevant amounts of component i for cigarettes with an unvented acetate filter and for those with a vented charcoal filter, respectively. Adsorptions of component i ($E_i$) by unvented charcoal filters under varied smoking conditions are defined by Eq. (2).
A. Tokida, I. Atobe and K. Maeda

\[ E_i = 100\left(\frac{C_{ip} - C_{ia}}{C_{ip}}\right) \]  

where \( C_{ip} \) and \( C_{ia} \) are the relevant amounts of component i for cigarettes with an unvented acetate filter and for those with a charcoal filter, respectively.

RESULTS AND DISCUSSION

Reduction efficiency

The reduction efficiencies of acetaldehyde and isoprene by five kinds of charcoal filters are plotted against the ventilation rate through the filters (\( V_f \)) in Fig. 1. Dot–dash lines represent the reductions by vented acetate filters. The reduction of acetone was almost the same as that of isoprene. Interaction between the acetate filter and the three components has not been observed when tested in a separate experiment, even though acetate is soluble in acetone. The solid and dashed lines reflect the effects of both ventilation and adsorption by the adsorbent. The reduction efficiency is influenced by the amount of the adsorbent and the type of charcoal filter used. A plasticizer, triacetin, was added on acetate tow in the process of plug manufacture and was partly adsorbed by the activated carbon in the dual filters, because activated carbon had been scattered on the acetate tow soon after the plasticizer. Therefore, the adsorption ability of the dual filter for cigarette smoke was decreased. The difference of the reduction efficiency between the cavity and the dual filters resulted largely from the plasticizer.

The correlations of reduction between acetaldehyde and isoprene, and between acetone and isoprene are shown in Fig. 2. In the relationship between acetaldehyde and isoprene, every charcoal filter gave a straight line and all the correlation coefficients were over 0.99. The amount of acetaldehyde relative to the other two components decreased with the increase of ventilation rate through the filter. For the relationship between acetone and isoprene, however, all data could be plotted on one line. Reductions of isoprene and acetone varied linearly.

If the activated carbon had no effect on the smoke reduction, each relationship in Fig. 2 could possibly be plotted on one line. However, it can be seen that the adsorption of acetaldehyde varied with the increase of venti-
Adsorption of Vapor Components by Vented Charcoal Filters

Adsorption by activated carbon in the vented filter

The filtration efficiencies of nicotine and tar by vented acetate filters were determined by a so-called direct method in which the smoke diffused through the filter perforations is ignored. It is difficult to determine the amounts of smoke diffused or adsorbed by the activated carbon.

The adsorption efficiency of the three components by activated carbon in the vented filter was obtained by assuming the driving force of diffusion to be the difference in concentration between the inside and the outside of the filter. It was also assumed that the smoke adsorbed by the activated carbon did not contribute to the diffused components. Muramatsu et al. have derived an equation for the diffusion of gas components through perforated cigarette paper.

\[
\log \frac{A_i}{A_0} = -2DL/\sigma r(U_0 - U_1) \log \frac{U_0}{U_1} + \log A_0
\]

where \(A_0\) and \(A_1\) are the concentrations of a component at the inlet and outlet of a tobacco column, \(U_0\) and \(U_1\) are the flow rates at the outlet and the inlet, \(D\) is the diffusion coefficient, \(\sigma\) is the thickness of the paper, and \(r\) is the cigarette radius. According Eq. (3), the ratios of concentrations \(A_1/A_0\) are constant for cigarettes of the same constituents and of the same ventilation rates.

A vented filter is a similar diffusion system with an extremely small area of pores instead of perforated cigarette paper. Under constant smoking conditions, the volume and the time of puff are constant, and therefore, ratios of the amounts of a smoke component diffused through the perforations of the tube to that at the inlet of the filters are also constant for cigarettes of the same ventilation rates through the filter. The smoke distribution at the filter portion of acetate or charcoal is defined as shown in Fig. 3 and by

\[
C_i = C_d + C_o
\]

(4)

\[
C_i = C_a + C_d + C_o
\]

(5)

The ratios of amounts diffused through the perforations for the two filters are the same, and therefore

\[
C_d/C_i = C_d/C_i = (C_i - C_a)
\]

(6)

Substitution of Eqs. (4) and (5) into Eq. (6) and subsequent rearrangement gives

\[
(C_i - C_a)/C_i = C_o/C_o
\]

(7)
The left hand side of Eq. (7) equals the permeability through an activated carbon layer, so that the adsorption efficiency \( E \) can be calculated by the amounts of component \( i \) in the main stream smoke for both the acetate and the charcoal filter.

\[
E = 100 \left( 1 - \frac{C'_o}{C_o} \right)
\]  

(8)

The adsorption efficiencies of acetaldehyde and isoprene by the charcoal filters obtained from Eq. (8) are shown in Fig. 4. Adsorption of the three components increased with \( V_f \) values. The adsorption of isoprene was consistent with that of acetone, but the charcoal filters, with the exception of the dual filter with a 5 mm charcoal layer, showed larger increments for acetaldehyde than for the other two components.

**The effect of ventilation on the adsorption efficiency of the adsorbent in the vented filters**

The variation of adsorption efficiency caused by filter ventilation is mainly due to the decrease of both the concentration and the flow rate of smoke through the filter. To evaluate the dependence of the efficiency on the flow rate and the concentration, the adsorption by unvented dual charcoal filters containing a 10 mm charcoal layer under varied smoking conditions was measured.

In Fig. 5, the adsorption of the three components is plotted against the puff duration, which was varied from 1.5 to 8 sec with a fixed puff volume of 35 ml. The adsorption efficiency increased linearly, but the increment for acetaldehyde was small. Regardless of the length of the puff duration, the amounts of the three components in the smoke varied within only 7% of each other compared with the standard conditions. Puff numbers were also almost the same as those observed under standard conditions. Therefore, changes in the concentration are thought to be so small as to have no practical influence on the adsorption. A drop in the flow rate raised the efficiency of the charcoal filters.

In Fig. 6, adsorptions measured with a 2-sec puff duration and 10~35 ml of puff volume are plotted against the puff volume \( (Q_t) \). In this case, both the concentration and the flow rate decreased. At small puff volumes, the adsorption efficiency of acetaldehyde came close to that of the other two components. The influence of puff volume on the acetaldehyde adsorption was greater than that on isoprene and acetone adsorptions, unlike the case when the puff duration was changed.

Maeda et al.\(^4\) have reported that decreases of the adsorption ability of a filter during smoking were found for small molecular weight components during the smoking of the final half of the cigarette. That is to say, the
Adsorption of acetaldehyde would be less efficient than that of benzene. Competitive displacement of the volatile components by the less volatile ones is thought to be the main reason. Desorption by a temperature increase in the last few puffs, of course, is another reason for this drop. For the longer puff durations, isoprene and acetone were preferentially adsorbed because of their low volatility, longer contact time with the adsorbent, and the unchanged concentration of the smoke.

Under different conditions of varied puff volumes with a unvented charcoal filter, the decrease, not of the flow rate, but of the smoke concentration contributed largely to the increase of adsorption, as can be seen by considering the increase of acetaldehyde adsorption. One of the reasons for this increase is thought to be the lower deterioration of the adsorption ability due to the smaller amount of the smoke. But no attempt has been made to elucidate the relationship between the adsorption efficiency and the smoke concentration until now. It is difficult to obtain adsorption isotherms of cigarette smoke by activated carbon because of variations in the amount and temperature of the smoke with puff number, and because of other limitations inherent in the smoking process.

The adsorption abilities of the activated carbon used in this experiment for isoprene and acetone were almost equal to each other, but the ability to adsorb acetaldehyde was less than that for the other two components. This is because ventilation raised the adsorption of the acetaldehyde most efficiently amongst these three components, due to the decrease of competition with high boiling point components which is caused by the decrease of concentration of the smoke. This tendency became significant in charcoal filters containing a much activated carbon. For isoprene and acetone, which activated carbon has a similar ability to adsorb, the efficiencies concomitantly varied with the ventilation. Therefore, in Fig. 2, it appears that only the relationship between the reductions of acetaldehyde and isoprene was influenced by the ventilation.

Adsorption by the vented charcoal filter with a 10mm charcoal layer is also plotted against $V_f$ using filled symbols in Fig. 6. It was found that adsorptions by the two filters coincided. Regardless of whether the filter was perforated or not, the adsorptions of the three components depended on the volume of the air drawn in at the top of the lighted end of the cigarette. As already discussed, the increase of adsorption efficiency by vented charcoal filters depends on the decreases of both the concentration and the flow rate. However, a lowered concentration has a large effect on the increased adsorption ability. The validity of the assumptions used in the derivation of Eq. (8) is supported by this consistency. It is considered that the amount diffused through the perforations was too small to have an effect on the adsorption. Using these simple assumptions, the adsorption efficiency of activated carbon in vented filters can be clarified. Effective removal of the cigarette smoke is expected, even with a small amount of charcoal in the vented filters.

REFERENCES