SELECTIVE REMOVAL OF SEMIVOLATILE COMPONENTS OF CIGARETTE SMOKE BY ACTIVATED CARBON FIBERS

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ABSTRACT

In order to examine the relationships between micropore radius and adsorption efficiency, removal of Total Particulate Matter (TPM), tar, water and semivolatiles in cigarette smoke by five kinds of activated carbon fibers (ACF) with micropore radii from 8 to 16 Å was measured. An ACF having wider micropores reduced TPM and tar effectively but, the water reduction was in opposition to this tendency. Molecular sieving effect was observed in AFC's having narrow micropores, while competitive effect due to the differences in the volatilities of smoke components was observed in those having wide micropores. AFC's having micropores wider than 10 Å had high adsorption abilities for semivolatiles, especially for components of boiling points between 100 and 200°C. The enhanced reduction for high boiling point components due to adsorption was detected in the last half of smoking.

INTRODUCTION

Activated carbon is one of the most typical additives in cigarette smoke filter because it can reduce the irritant and physiological effects of the smoke. Although it is well established that activated carbon adsorbs the vapor phase of the smoke, detailed behavior of the adsorption has not been elucidated.

Williamson and Allman analyzed the change of the adsorption efficiency with the increase of puff number and found the apparently negative adsorption at the last few puffs. von P. Ceschini measured the effect of the moisture content of activated carbon on the adsorption efficiency. Maeda et al. analyzed the adsorption efficiency of various activated carbons having various physical properties. Baggette and Morie reported the selectivity factor of cigarette filters, including charcoal filter, on the semivolatile fraction of particle phase in cigarette smoke. In the studies so far mentioned, no attention was paid on the physical properties of activated carbon except for the one of Maeda et al., who gave an explanation, however, on part of the ability of activated carbon.

The micropore distribution of adsorbents is the most important factor among the physical properties that affect the adsorption efficiency. ACF has micropores on the surface, the size distribution of which can be controlled intentionally. In general, the chemical natures of the surfaces of activated carbons are liable to be changed by the condition of the activation and also by raw materials selected for the preparation of various pore distributions. This disadvantage can be avoided by the use of carbon fibers. Thus, ACF can be an ideal model substance in the study of adsorption of cigarette smoke by porous materials.

In this paper the removal by ACF of semivolatiles, which include acidic, basic and neutral compounds important to the flavor, taste and in some cases physiological effects of the smoke, is discussed in comparison with the tar reduction.

EXPERIMENTAL

ACF

Five kinds of Kuractive ACF, felt type, thickness ca. 3 mm, made from phenolic resin, were kindly supplied by Kuraray Chemical Inc. Micropore distribution and micropore volume of the
ACF's were measured by the water vapor adsorption method. The specific surface areas were measured by the BET method with a Micrometrics Acuusorb 2100-01 apparatus filled with nitrogen. The mean pore radii, pore volumes and specific surface areas are listed in Table 1. The micropore distribution curves are shown in Fig. 1.

Table 1  Physical properties of activated carbon fibers

<table>
<thead>
<tr>
<th>ACF radius (nm)</th>
<th>Pore volume (ml/g)</th>
<th>Specific surface area (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 0.8</td>
<td>0.12</td>
<td>530</td>
</tr>
<tr>
<td>B 0.8</td>
<td>0.26</td>
<td>990</td>
</tr>
<tr>
<td>C 1.0</td>
<td>0.45</td>
<td>1510</td>
</tr>
<tr>
<td>D 1.2</td>
<td>0.74</td>
<td>2190</td>
</tr>
<tr>
<td>E 1.6</td>
<td>0.91</td>
<td>2770</td>
</tr>
</tbody>
</table>

Fig. 1 Micro pore distribution curves of activated carbon fibers.

Cigarette and smoking

Lamina cigarettes of domestic flue-cured tobacco leaves, 70 mm in length, 25 mm in circumference, 1.10±0.02 g in weight and 35±5 mm H2O in pressure drop, were used. A given amount of ACF was filled in a plastic tube attached to one end of the cigarette. All cigarettes were smoked under the standard condition (one 35 ml, 2 sec puff/min). The smoke of a whole cigarette or one puff at a prescribed number was collected on a glass fiber filter (Toyo Roshi, GB100R).

Analysis and identification of the smoke components

TPM, tar, and water: The smoke collected on the glass fiber filter is defined as TPM. The amount was measured gravimetrically. Water content in TPM was measured by gas chromatography. Amount of tar was obtained by subtraction of the water content from the amount of TPM.

Semivolatile components: Semivolatile components in TPM were analyzed based on the method reported by Ishiguro and Sugawara. The smoke was dissolved in 220 μl of an extracting solution (methanol + dichloromethane, 1:4 w/w) which contained 31.0 μg of ethyl phenylacetate as an internal standard. The analysis of the semivolatiles was made on a Shimadzu GC-9A gas chromatograph equipped with a flame ionization detector and a glass capillary column (0.28 mm i.d. x 30 m) coated with PEG 20M. The column temperature was programed from 60 to 180°C at a rate of 2°C/min. Flow rate of Herium, the carrier gas, was 1.0 ml/min and the split ratio was 1:50. The chromatogram was recorded with a Shimadzu Chromatopac C-R2AX. The GC/MS measurements were carried out on a Hitach M-80 mass spectrometer coupled with a Hitach GC-663 gas chromatograph. Identification of peaks of the chromatogram was carried out by comparison of the mass spectra and GC retention time with those of authentic compounds.

Reduction and selectivity

Reduction of a component i is defined by eq. (1).

\[ E_i = \frac{100(R_{ci} - R_{fi})}{R_{ci}} \]  

Where \( R_{ci} \) and \( R_{fi} \) are the relevant peak area ratios, (area of peak i)/(area of internal standard), calculated for cigarettes without ACF and with ACF, respectively. Reductions of TPM, tar and water were calculated with eq. (1) in which \( R_{ci} \) and \( R_{fi} \) were substituted by the corresponding weights, per se, respectively.

Selectivity factor \( Sx \) was calculated according the definition given by Davis and George:

\[ Sx = \frac{1 - Er}{1 - Ei} \]  

Where \( Er \) is the reduction of a standard component, TPM or tar. \( Sx \) values larger than unity mean that ACF has higher affinity for component i than for the standard.
RESULTS AND DISCUSSION

1. Reduction and selectivity of TPM, tar and water

Reductions of TPM, tar and water by ACF, and the selectivities based on the TPM reduction are shown in Table 2. Reductions of both tar and water depend on the mean pore radius. Tar reductions by ACF-A, -B and -C are lower than water reductions by the three ACF's, whereas the reductions by ACF-D and -E show an opposite relation. $S_x$ values indicate this clearly. Selectivities of ACF-D are similar to those of ACF-E in spite of the differences in their physical properties. If the reductions listed in Table 2 are attributed only to the particle filtration, tar and water reductions should show similar values. As it is not the case, adsorption mechanism should collaborate to give the observed results.

Table 2 shows that tar reduction becomes large with the pore size of ACF. Tar is a mixture of organic compounds of which boiling points and molecular weights are distributed in wide ranges. It can be seen in Table 2 that many constituents in tar are effectively adsorbed by ACF's having large pores and wide surface areas.

Table 2 also shows that $S_x$ values for tar and the values for water are in reversed trends in their variations with the pore size of ACF’s. This apparent competition may be explained as follows. The shape of adsorption isotherms for ACF/water vapor\(^\text{11}\) depends on the micropore size distribution: the saturation value becomes high with the pore size. TPM contains a large quantity of water. It is thought that relative humidity of cigarette smoke is fairly high. The rate of diffusion of water vapor in micropore is faster than that of tar constituents. The presence of a small quantity of mesopores on ACF gives rise to a disadvantage for the diffusion of tar constituents. Consequently, on ACF having relatively small micropores, water vapor is readily condensed in the capillaries against the competitive adsorption of tar constituents. In ACF having relatively large micropores, however, exclusion of water vapor results from sizable tar adsorption.

2. Reduction and selectivity of semivolatile components

2.1 Reduction efficiency

The chromatogram of the semivolatile phase of the genuine cigarette smoke is shown in Fig. 2. According to reports of Ishiguro and Sugawara\(^\text{9}\) and Ishiguro\(^\text{12}\), where cigarettes made of domestic flue-cured lamina were examined, components giving smaller peak numbers than 22 (pyridine) are considered to be distributed mainly in vapor phase.
Therefore these components are not discussed in this work. Reductions of each component by 20 mg of ACF-B, -C and -D are shown in Fig. 3 against the elution order in the chromatography. Semivolatiles having low boiling points are adsorbed to varying degrees according to the relevant physical and chemical properties of the components and also according to the grades of the ACF’s. Among typical semivolatiles, reductions for the high boiling point components are relatively small. Relations between the reduction and the amount of ACF are shown in Fig. 4.

Semivolatiles are presumed to be both in vapor and particle phases when they enter into the ACF filter. Therefore, both adsorption and filtration are concerned with the retention of them. In the discussion of the adsorption efficiency of ACF, the ability can be expressed more clearly by selectivity than by reduction efficiency. Selectivities based on tar reduction are summarized in Table 3-7 after classification into five kinds of the components: hydrocarbons are listed in Table 3, organic acids in Table 4, nitrogen containing compounds in Table 5, phenolic compounds in Table 6 and oxygen containing compounds in Table 7.

2.2 Relation between ACF property and selectivity

For the components eluted before nicotine (peak No. 137, mw 162.2 and bp 247°C) on GC, the adsorption efficiency of ACF-A is low because increment of Sx with that of the amount added in the filter is small. ACF-B, which has the same mean micropore radius as ACF-A but has a larger specific surface area, reduces smoke more efficiently than ACF-A. But, the selectivities exhibited by ACF-B are similar to those of ACF-A. This indicates that the increment of specific surface area does not appreciably influences the value of Sx. ACF-C has a higher ability than ACF-B and the effect of the increment of the added amount is remarkable. ACF-D and -E adsorb semivolatiles quite efficiently even with their small amounts. But reduction and Sx of ACF-E are not so different from those of ACF-D in spite of the wider specific surface area of the former.

In the case of semivolatiles with high boiling points, on the other hand, Sx values of ACF-A and -B which are close to or smaller than unity, vary concomitantly with the increment of the amount. While Sx values of ACF-D and -E for high boiling point components are lowered by the effective adsorption of low and intermediate boiling point ones. Contrary to ACF-A and -B, the increase in their amount reduces their selectivity.

As found in Table 5, all the selectivity values for nicotine (bp 247°C) or nicotyrine (bp 273°C) are close to unity. This invariance and the small difference in the selectivity values between these two nitrogen containing components offer another interesting point to discuss. Selectivity for components that enter into ACF filter not in vapor but as a particle should become less than unity. The temperature of the smoke that comes out of
tobacco column is not so much higher than ambient temperature\textsuperscript{13).} To a certain components with high boiling points in vapor phase, condensation cannot follow the steep temperature gradient between burning cone and the mouth end of the cigarette.

Selectivity values of ACF-D and -E for nicotine are slightly but definitely larger than unity. This indicates that a fraction of nicotine is in vapor phase in the filter, so that the adsorption contributes sizably to the selectivity values. ACF-A, -B and -C have the selectivity values for nicotine smaller than unity. It seems that their small specific surface areas and narrow micropores

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Compound</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Limonene</td>
<td>1.00</td>
<td>1.05</td>
<td>0.91</td>
<td>0.83</td>
<td>1.19</td>
</tr>
<tr>
<td>30</td>
<td>n-Propylbenzene</td>
<td>1.01</td>
<td>1.20</td>
<td>0.93</td>
<td>0.96</td>
<td>1.39</td>
</tr>
<tr>
<td>40</td>
<td>Styrene</td>
<td>1.01</td>
<td>1.20</td>
<td>0.95</td>
<td>0.96</td>
<td>1.47</td>
</tr>
<tr>
<td>78</td>
<td>Indene</td>
<td>0.91</td>
<td>1.14</td>
<td>0.88</td>
<td>1.06</td>
<td>1.66</td>
</tr>
<tr>
<td>118</td>
<td>Naphthalene</td>
<td>0.95</td>
<td>1.18</td>
<td>1.02</td>
<td>1.37</td>
<td>1.72</td>
</tr>
<tr>
<td>147</td>
<td>Neophytadiene\textsuperscript{1}</td>
<td>0.98</td>
<td>1.05</td>
<td>0.94</td>
<td>1.09</td>
<td>0.96</td>
</tr>
</tbody>
</table>

\textsuperscript{1} 3-Methylene-7,11,15-trimethyl-1-hexadecane

Selectivity is calculated on the basis of tar reduction.

The value 10.00 means that S\textsubscript{x} value is equal or greater than 10.00.

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Compound</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>Acetic acid</td>
<td>1.04</td>
<td>1.14</td>
<td>1.01</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>87</td>
<td>Propionic acid</td>
<td>1.01</td>
<td>1.11</td>
<td>0.97</td>
<td>1.10</td>
<td>1.28</td>
</tr>
<tr>
<td>104</td>
<td>Acrylic acid</td>
<td>0.93</td>
<td>1.08</td>
<td>0.88</td>
<td>1.08</td>
<td>0.98</td>
</tr>
<tr>
<td>108</td>
<td>iso-Butyric acid</td>
<td>1.00</td>
<td>1.05</td>
<td>0.92</td>
<td>1.06</td>
<td>1.16</td>
</tr>
<tr>
<td>128</td>
<td>8-Methylvaleric acid</td>
<td>0.98</td>
<td>1.03</td>
<td>0.96</td>
<td>1.12</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Selectivity is calculated on the basis of tar reduction.

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Compound</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Pyridine</td>
<td>1.05</td>
<td>1.38</td>
<td>1.06</td>
<td>1.22</td>
<td>1.59</td>
</tr>
<tr>
<td>46</td>
<td>8-Picoline</td>
<td>1.04</td>
<td>1.27</td>
<td>1.04</td>
<td>1.25</td>
<td>1.67</td>
</tr>
<tr>
<td>76</td>
<td>3-Vinylpyridine</td>
<td>0.98</td>
<td>1.13</td>
<td>1.11</td>
<td>1.43</td>
<td>2.04</td>
</tr>
<tr>
<td>85</td>
<td>Pyrrole</td>
<td>0.91</td>
<td>1.12</td>
<td>0.91</td>
<td>1.07</td>
<td>1.29</td>
</tr>
<tr>
<td>137</td>
<td>Nicotine</td>
<td>0.96</td>
<td>1.00</td>
<td>0.93</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>179</td>
<td>Nicotyline</td>
<td>0.95</td>
<td>1.08</td>
<td>0.92</td>
<td>0.96</td>
<td>0.91</td>
</tr>
<tr>
<td>183</td>
<td>3-Hydroxypyridine</td>
<td>0.93</td>
<td>1.09</td>
<td>0.88</td>
<td>0.89</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Selectivity is calculated on the basis of tar reduction.

The value 10.00 means that S\textsubscript{x} value is equal or greater than 10.00.
Table 6 Selectivities for phenolic compounds

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Compound</th>
<th>ACF/mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>151</td>
<td>Phenol</td>
<td>0.98</td>
</tr>
<tr>
<td>157</td>
<td>p-Cresol</td>
<td>0.98</td>
</tr>
<tr>
<td>159</td>
<td>m-Cresol</td>
<td>1.00</td>
</tr>
<tr>
<td>169</td>
<td>4-Vinylguaiacol</td>
<td>0.95</td>
</tr>
<tr>
<td>182</td>
<td>4-Vinylphenol</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Selectivity is calculated on the basis of tar reduction.

Table 7 Selectivities for oxygen containing compounds

<table>
<thead>
<tr>
<th>Peak No.</th>
<th>Compound</th>
<th>ACF/mg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>47</td>
<td>Acetol</td>
<td>1.20</td>
</tr>
<tr>
<td>56</td>
<td>2-Cyclopentene</td>
<td>1.02</td>
</tr>
<tr>
<td>58</td>
<td>2-Methyl-2-cyclopentene</td>
<td>1.01</td>
</tr>
<tr>
<td>74</td>
<td>2-Furfural</td>
<td>1.17</td>
</tr>
<tr>
<td>82</td>
<td>2-Acetilfuran</td>
<td>0.89</td>
</tr>
<tr>
<td>83</td>
<td>2,3-Dimethyl-2-cyclopentene</td>
<td>0.99</td>
</tr>
<tr>
<td>93</td>
<td>5-Methylfurfural</td>
<td>1.07</td>
</tr>
<tr>
<td>94</td>
<td>Protoanemonin</td>
<td>1.13</td>
</tr>
<tr>
<td>106</td>
<td>Acetophenone</td>
<td>0.91</td>
</tr>
<tr>
<td>107</td>
<td>Furfuryl alcohol</td>
<td>1.04</td>
</tr>
<tr>
<td>120</td>
<td>Solanone</td>
<td>1.05</td>
</tr>
<tr>
<td>122</td>
<td>Cyclopentane-1,2-dione</td>
<td>1.00</td>
</tr>
<tr>
<td>131</td>
<td>Cyclotene</td>
<td>0.99</td>
</tr>
<tr>
<td>143</td>
<td>2-Hydroxy-3-ethyl-2-cyclopentene</td>
<td>0.99</td>
</tr>
<tr>
<td>173</td>
<td>2,3-Dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one</td>
<td>0.93</td>
</tr>
<tr>
<td>190</td>
<td>5-Hydroxymethylfurfural</td>
<td>0.95</td>
</tr>
</tbody>
</table>

1 1-Hydroxy-2-propanone
2 4-Hydroxy-2,4-pentadienoic acid r-lactone
3 2-Methyl-5-isopropyl-1,3-nonadien-8-one
4 2-Hydroxy-3-methyl-2-cyclopentenone

Selectivity is calculated on the basis of tar reduction.

The value 10.00 means that SX value is equal or greater than 10.00.

### 2.3 Selectivity for semivolatile components

Selectivities for semivolatiles eluted before nicotine are found in Tables 3-5 and 7. Characteristics of the indicated values and of those for phenolic compounds (Table 6) are discussed below.

For the components having relatively small molecular weights and low boiling points among the semivolatiles of the same kind, SX values of...
an ACF with smaller micropore is larger but the relative magnitudes decrease with the increase in the micropore radius. Selectivities for such components become the smallest in the case of ACF-D and -E. Styrene, acetic acid, pyridine and acetol are examples of such components. For the components with intermediate boiling points among semivolatiles, selectivities increase with the increase in the micropore radius. But, for the components with relatively high boiling points at near or above 200°C, selectivities become lowered again.

These tendencies are seen for the five derivatives of 2-cyclopentenone, 2-cyclopentenone as the low boiling point components, 2-methyl- and 2,3-dimethyl-2-cyclopentenone as the intermediate ones, and cyclotene and 2-hydroxy-3-ethyl-2-cyclopentenone as the high boiling point ones. In multicomponent adsorption, competitive displacements of volatile components by less volatile ones are observed: the selectivities for styrene by ACF-D and -E stand for this. Molecular sieving effect also contributes to the selective adsorption in the cases of ACF-A and -B. It seems that components having molecular weights higher than 90 but having relatively low boiling points are adsorbed effectively by ACF-D and -E. In fact, no dependence of selectivity on the component concentration in the smoke is found in Tables 3–7.

It is a remarkable feature that $Sx$ values of ACF-B for hydrocarbons except naphthalene are smaller than those of ACF-A. In the binary adsorption system of water and methanol, the latter dissolves in water adsorbed on activated carbon, resulting in the increased adsorbed amount of methanol in some cases. As reduction efficiency of ACF-B for water is the highest among the ACF's, relatively small $Sx$ values of ACF-B for hydrocarbons are considered to be an indication against the above mentioned dissolution: adsorbed water effectively shields the ACF surface. Although most of the acids in the smoke dissolve well in water, promotion of adsorption of the acids by adsorbed water, an opposite effect to the observed hydrocarbon case, is not found in the comparison of the selectivity values of ACF-A and -B. Other kinds of water-soluble components give the same results.

Acrylic acid, which has an unsaturated bond, is less adsorbed than propionic acid. Organic acids, when compared with other kinds of semivolatiles with boiling points similar to those of the acids, have smaller molecular weights and higher polarities. Hence, the acids have small $Sx$ values to compete with other components. Dependence of the reduction efficiency on the dissociation constant of the acids is not found in Table 5.

Ishiguro and Sugawara reported that peak No. 151 consists of phenol in a large excess to o-cresol. $Sx$ values of ACF-D and -E for cresols are 1.8–1.9. These values indicate that appreciable amounts of components even with boiling points above 200°C are present in vapor when the smoke passes through the filter as mentioned above.

Curran and Miller reported that a quarter of nicotine added into an acetate filter eluted out of it in the main stream smoke and that the proportion of the elution increased with the lowering of the boiling point of the added component in the filter. This means that high boiling point components can revaporize from the surface of the fibers. In comparison of three components, 2-methyl-2-cyclopentenone, phenol and nicotine as examples of semivolatiles, molecular weights of the first two are similar to each other, boiling points increase and $Sx$ values decrease in the above mentioned order. If the elution out of the surface of the ACF's is considerable, contribution of the eluted vapor on adsorption or selectivity should not be negligible. Chemical affinities of the ACF's to these components are not so different. It can be said that differences in selectivities for these components arise from the concentrations both of vapors at the outlet of tobacco column and of the revaporized ones in the filter.

By the control of micropore distribution of ACF, fractional molecular sieving effect is expected. The nature of semivolatiles changes dynamically in cigarette filter and the change has considerable effects on removal efficiency of adsorbents in the filter. Only qualitative understanding is possible for the adsorption of such an extreme multicomponent system as cigarette smoke.

3. Variation of semivolatile reduction with puff number

Among the components with molecular weight
higher than 90 and with intermediate boiling points in semivolatiles, variations of the reductions with the puff number for \( \beta \)-picoline and furfuryl alcohol are shown in Fig. 5. Most of the components having smaller peak number than nicotine exhibit similar variations shown in Fig. 5. The average reduction decreases in the order of ACF-C (40mg), -D (15mg), -D (10mg), -C (20mg) and -A (60mg). But, the above mentioned components show that the reduction of ACF-C (20mg) is greater than that of -D (10mg) at initial puffs and the reduction of -D (10mg) at a final puff decreases drastically.

Tar reduction by 60 mg of ACF-A at 8–14 puff is 30–35%. Therefore, ACF-A has an adsorption ability in the first half of smoking with saturation reached at the intermediate number of puffing. By the increases of smoke temperature and TPM concentration\(^{16,17}\) at the last few puffs, the components become easy to desorb.

Tar reductions by ACF-C (20mg) and -D (10mg) at the last half of smoking are 15 and 10% respectively. Under the addition of only a small amount in the filter, these ACF’s retain their adsorption ability except at the final puffs. The deterioration of ACF-D (10mg) at 14 puff arises from the increase of temperature and the drop of holding ability due to the wide pore radius.

Variations of the reductions of acetic acid and acetol, of which molecular weights and boiling points are relatively low among semivolatiles, are shown in Fig. 6. Differences found between Fig. 5 and 6 are as follows. The reduction of acetic acid with ACF-D (10mg) is smaller than that with -C (20mg) and that of acetol with the former is almost equal to that of the latter. Further, deterioration at the last half is large. For the two components, ACF’s show molecular sieving and competitive effects. They also show decreased retention abilities for the smaller molecular weight components.

Variations of the reductions for phenol and nicotine are shown in Fig. 7. Characteristically for phenol, variations of the reduction with puff number and with ACF species are small. Temperature gradient between burning cone and filter becomes steep with smoking so that the ratio of vapor/particle for high boiling point component increases\(^{18}\). The increase of smoke temperature does not influence on their elimination so much as on that of the small components. Therefore, the contribution of adsorption to the reductions becomes greater with puff number.

It seems that the variation of the vapor/particle ratio with puff number is more influential in the reduction of nicotine than that of phenol, because
nicotine reductions by ACF-C and -D exceed the tar reductions at 8–11 puff. ACF-A (60mg) reduces more effectively nicotine than phenol because of the filtration to the former.

The dynamic change of cigarette smoke nature in passing through ACF filter is indicated here by the measurements not only of the component reductions for a whole cigarette but also of the variation of the reductions with puff number. The measured puff by puff reduction efficiencies confirms the overall abilities of ACF’s obtained for a whole cigarette and helps the elucidation of the detailed adsorption mechanism of them.

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