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Physical Properties of Carbon Prepared from a Coconut Shell by Steam Activation and Chemical Activation and the Influence of Prepared and Activated Carbon on the Delivery of Mainstream Smoke

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ABSTRACT : Several activated carbon in different specific surface area was prepared by steam and chemical activation of coconut shell. Products were characterized by BET (N_2) at 77K, and probed to be highly specific surface area of 1580m^2/g and pore volume that had increased with activating conditions. And also we have analyzed the adsorption efficiency of vapor phase components in cigarette mainstream smoke in order to evaluate the relationship between thesmoke components and the physicochemical properties of activated carbons. As a result of this study, the delivery of mainstream smoke was directly affected by the specific surface area and the pore size of activated carbon.

The activated carbon prepared by steam activation exhibited better adsorption efficiency on the vapor phase components in mainstream smoke compared with activated carbon prepared by $ZnCl_2$, due to the higher micro-pore area of 66%. But the adsorption efficiency of semi-volatile matters such as phenolic components in a main stream smoke by the activated mesoporous carbon prepared by $ZnCl_2$ is more effective. From the these results, we can conclude that specific surface area by the micropore area increased the adsorption efficiency of activated carbon on vapour phase components, but semi-volatiles or particulate matter was affected by the ratio of mesopore area in total specific surface area.

Key words **: carbon, coconut shell, mainstream smoke**

Mainstream smoke of cigarette is a complex system composed of particulate phase and volatile phase. The method for selectively removing gas, volatile compounds and semi-volatile compounds in the mainstream smoke are to add adsorbent into cigarette filter (Xue *et al.*, 2002). The adsorbent should have a properties like high specific surface area, micropore volume and mesopore volume. As an adsorbent satisfying these conditions, the activated carbon is commonly used in the cigarette industry.

Activated carbon is commonly used to adsorb and remove pollutants from gas and liquid manufactured and has been used since 19th century (Jankowska *et al.*, 1991). It has many uses as adsorbent in the area of separation and

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purification of gaseous and liquid stream derived from its highly porous microstructure and the higher surface area. The adsorption efficiency of adsorbents used in an adsorption of pollutants is influenced by micopore at low partial pressure, while mesopore is more important at high partial pressure and concentration.

The major factor in the adsorption process is the surface area of adsorbent because the most important characteristic of a sorbent is its high porosity, physical property is more important than chemical property. These properties depend on various factors like raw material, activation method, chemical agents, temperature and activation time, other operating conditions (Sai and Krishnaiah, 2005).

In this study, we report that the physical properties of activated carbon from a coconut shell by steam and $ZnCl_2$ activation, and the influence of prepared activated carbon on the delivery of mainstream smoke.

MATERIALS AND METHODS

Cigarette Manufacturing & Sample Selection

Commercial cigarettes (Tar 5.5 mg/cig, Nicotine 0.55 mg/cig) with various activated Nicotine 0.55 mg/cig) with various activated carbons were used in this study. Samples were selected depending on an encapsulated pressure drop (EPD) in the range of 150 ± 3 mmH_2O and ventilation rate of 50 ± 2 %.

Activated carbon preparation

Activated carbon is prepared through steam and chemical activation of coconut shell using $ZnCl_2$ as chemical agents. The experimental procedure in the preparation of differently structured and activated carbon in detail is as follows (Table 1).

Smoke analysis

For smoke analysis, the selected filter and tobacco column were connected to a connector and then kept for 2 days in an oven with a CORESTA standardized condition (22±1℃, 60±2% RH). Using a smoking machine (Cerulean SM 410), the cigarette samples were smoked in compliance with CORESTA methods and then TPM was collected.

Measurement of activated carbon characteristics

The specific surface area and pore size distribution of the samples were determined by nitrogen adsorption using a BET method. Before starting the BET measurements, the samples were degassed at T=350℃in a vacuum for 24h and mass was recorded before and after degassing.

Table 1. Treatment conditions of activation carbon

Sample	Treatment	Temp. (℃)	Time (h)	Temp. (℃)	Time (h)
A	Steam activation	500	1	950	4
B					8
C					16
D					24
E	Chemical activation ($ZnCl_2$)	X		700	4
F					8
G				850	

Measurements were carried out with an ASAP 2020 (Micromeritics Instruments).

RESULTS AND DISSUSSION

The physical properties of the various activated carbons prepared from a coconut shell by steam and $ZnCl_2$ activation were investigated and the results are presented in Table 1. The specific surface area was increased as increasing activation time due to the increase of the mesoporous surface area. And also, the results clearly indicated that the surface area of mesopore was arranged in the following order, irrespective of the type of activating method: D > C > B > A and G > F > E. The increase of surface area of mesopore indicates that the raw materials treated with steam and $ZnCl_2$result in increased mesoporosity due to the each reaction mechanism. Also, the steam activated carbon (A, B, C and D) has higher micro surface area and micropore volumes than those of $ZnCl_2$activated carbon (E, F and G) results from the more micoroporous structures.

Fig. 1. shows the effect of the activation time on the nitrogen adsorption and desorption isotherms of the steam activated carbons and $ZnCl_2$ activated carbons. The quantity of absorbed nitrogen through the entire pressure range increases as increasing activation time. The desorption curve of fig. 1(a) has the same general shape as the adsorption, but fig. 1(b)

Table 2. Physical properties of activated carbon

Sample	Density (g/cm^3)	Iodine number (mg/g)	S_{BET} (m^2/g)	S_{micro} (m^2/g)	S_{meso} (m^2/g)	V_{micro} (cm^3/g)
A	0.50	1072	1312	1080	233	0.42
B	0.44	1320	1496	1056	257	0.40
C	0.40	1610	1792	1001	792	0.38
D	0.36	1723	2192	1082	1110	0.41
E	0.43	1280	1295	520	776	0.20
F	0.37	1580	1484	544	941	0.21
G	0.35	1810	1582	508	1074	0.20

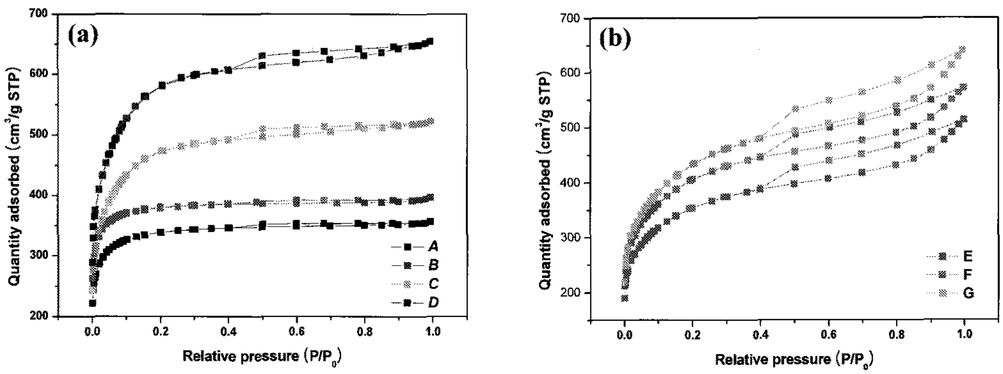

Fig. 1. Nitrogen adsorption and desorption isotherms of activated carbons; (a) steam activated carbon and (b) $ZnCl_2$ activated carbon.

shows a wide hysteresis loop instead of nearly retracing the adsorption curve. The former behavior is typical microporous materials, and later one is typical mesoporous and macroporous materials. Also, a hysteresis loop is becoming wider as increasing of activation time in case of steam activated carbon as shown in fig. 1(a).

The adsorption isotherm of microporous materials is quite different from that of mesoporous materials. The isotherms of the steam activated carbon clearly shows that the initial step's region is abruptly followed by a plateau indicating that the samples are overwhelmingly microporous clearly to investigate the isotherm

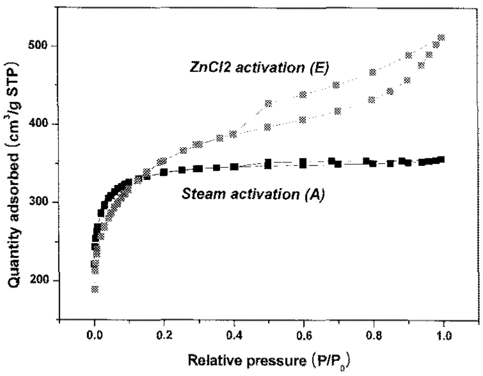

Fig. 2. Nitrogen adsorption and desorption isotherms of activated carbon specific surface area:about 1300 m^2/g.

curves at same specific surface area for steam and $ZnCl_2$ activated carbon presented in fig. 2.

Fig. 3. shows the effect of the activation time on the pore size distribution of the activated carbon for two different treatments of the carbon for steam and chemical activation. The range of development of the mesoporous region noticeably increased as increasing activation time.

It is well known that an increase in the specific surface area of activated carbon affects the increase of adsorption efficiency of the delivered vapor phase compounds in mainstream smoke through a cigarette filter. Fig. 4. and 5(a) show the amount of delivered HCN, carbonyl compounds and VOCs through the carbon dual filter, respectively. Also, the delivered HCN, carbonyl compounds and VOCs through the carbon dual filter used steam activated carbon were compared with that used $ZnCl_2$ at same iodine number (i.e., comparing B with E, C with F and D with G).

The tendency of delivery behavior is very similar for both the delivered HCN and carbonyl compounds. The delivery amount of vapor phase compounds like HCN, carbonyl compounds and VOCs would be strongly related to the increase of specific surface area of activated carbon for two different groups (i.e., steam activated

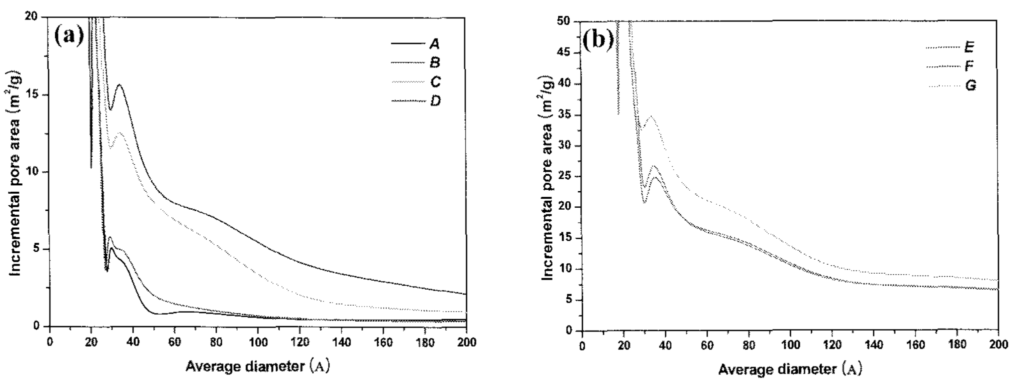

Figure 3. Pore size distribution of activated carbon (a) steam activated carbon and (b) $ZnCl_2$ activated carbon.

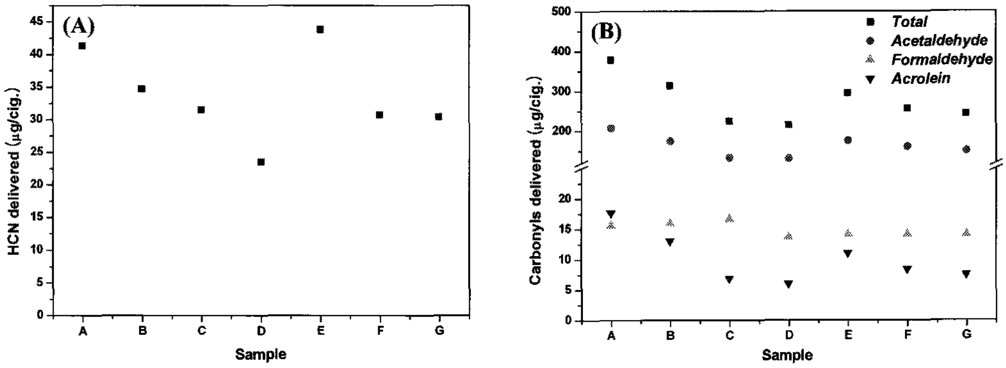

Fig. 4. Delivery amountsof HCN and carbonyl compounds (Totalcarbonyls including formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, MEK and butylaldehyde).

carbon; A, B, C and D, and $ZnCl_2$ activated carbon; E, F and G), as shown infigure 4 and 5(a). However, steam activated carbon is more efficient for removal of vapor phase compounds than $ZnCl_2$ activated carbon at the same iodine number. This is largely because the removal efficiency of vapor phase compounds was significantly influenced by the micropore of activated carbon. However, the formaldehyde is not affected by the specific surface area. This may be explained in terms of unique physical and chemical properties resulting from the small molecular size and low boiling point.

In fig. 5(b), semi-volatile compounds including pyridine, quinoline, 3-vinylpyridine and styrene delivery profiles can depend on the external surface area (including the mesopore area). The surface area of mesopore increases as the reaction time elapses, and it can be seen from table 1 and fig. 3. The removal efficiency of semi-volatile compounds was significantly influenced by the mesopore of activated carbon, and the delivery behavior of each semi-volatile component is very similar to that of total semi-volatile compounds. Therefore, the results clearly indicated that the removal efficiency of semi-volatile compounds in the mainstream smoke was arranged as following order:

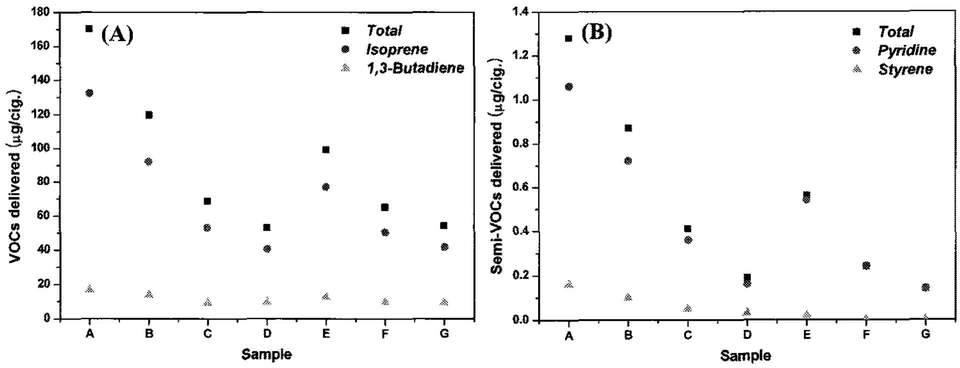

Fig. 5. Delivery amounts of VOCs and semi-VOCs (TotalVOCs including 1, 3-butadiene, isoprene, acrylonitrile, benzene and toluene).

$ZnCl_2$activated carbon > steam activated carbon (i.e., G > D, F > C and E > B).

The delivery amount tar, nicotine and CO in mainstream smoke at various activated carbons are represented in fig. 6. The physical and chemical property of activated carbon is not major factor for controlling tar, nicotine and CO. Also, a cellulose acetate filter has been most commonly used for reducing and controlling tar and nicotine delivery since 1953 and the most effective method of reducing CO is dilution or using catalyst (Baker, 1987 Morie, 1977). Therefore, delivery levels of the tar, nicotine and CO are in similar tendency as shown in fig. 6.

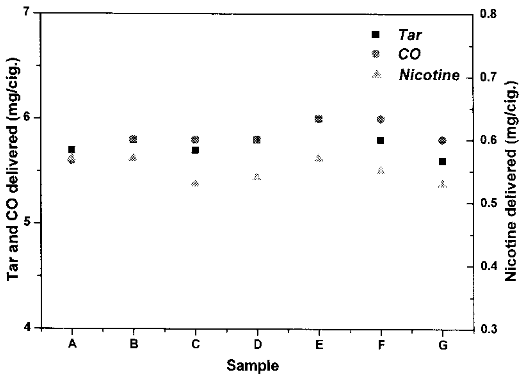

Fig. 6. Delivery amounts of tar, nicotine and carbon monoxide.

In this study, we investigate the effect of activation time and method on the micropore and mesopore structure of activated carbon and the influence of prepared activated carbon on the delivery of mainstream smoke. Further work will be carried out the selectivity index of delivered mainstream smoke when we apply a new adsorbent and tow material used as a filter.

CONCLUSIONS

High specific surface area activated carbons are prepared from steam and $ZnCl_2$ activation of coconut shell. It was found that the activated carbons prepared by steam activation produced slightly better results in terms of BET surface area and pore volume than those prepared by chemical activation in microporous region. And the range of development of the mesoporous region noticeably increased as increasing activation time. The volatile matters such as HCN and carbonyl compounds in a main stream smoke is adsorbed in a micropore but, the semi volatile matters are adsorbed in a mesopore easily. Therefore, the adsorption efficiency of semi-volatile matters in a main stream smoke by the activated mesoporous carbon prepared by chemical activation is more effective. From this study, we can conclude that the specific surface are by the micropore area increased the adsorption efficiency of activated carbon on vapor phase compounds, but semi-volatiles or particulate matter was affected by the ratio of mesopore area in total specific surface area.

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