THE EFFECT OF DIFFERENT SMOKING REGIMES ON THE PERFORMANCE OF DIFFERENT WEIGHTS AND ACTIVITIES OF CARBON IN CIGARETTE FILTERS

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Summary

For any adsorption process the efficiency of adsorption usually depends on the activity of the adsorbate and the contact time and concentration of the compounds being adsorbed. In a cigarette filter carbon is exposed to a complex mixture of compounds for relatively short periods of time. For more intense smoking regimes smoke passes through filters at higher velocities (shorter contact times) and generally higher yields of smoke compounds are generated. To investigate the effect this has on the performance of carbon in a filter the activity of carbon filters towards a range of smoke compounds including the major vapour phase aldehydes, ketones and hydrocarbons has been studied. Two smoking regimes have been used the standard ISO regime and the Canadian intense regime. Data will be presented showing cigarette yields and filter retentions, measured by gas chromatography, for the different smoking regimes for filters containing between 15 to 150 mg of carbon for a range of smoke compounds. Also comparisons are made for two different types of coconut shell carbon a more standard material with a surface area of 1100 m^2/g and a high activity coconut shell carbon with a surface area of 1600 m^2/g.

The Effect of Different Smoking Regimes on the Performance of Different Weights and Activities of Carbon in Cigarette Filters

For adsorption processes the efficiency of adsorption depends upon the weight and activity of the adsorbate and the contact time with the compound being adsorbed. A number of studies have been carried out on the performance of carbon in cigarette filters during standard ISO smoking (1, 2). However, for more intense smoking regimes higher yields of smoke compounds are generated and the smoke passes through the filter at higher velocities. A comparison has been made of the performance of two different activity carbons using two different smoking regimes (ISO and Canadian intense) for the retention or yield of a range of smoke vapour phase compounds. Carbon weights in the range 15 to 150 mg per filter were studied and the properties of the carbons tested are given in the table below.

Property	Standard Activity Carbon	High Activity Carbon
Feedstock	Coconut Shells	
Particle size mm	0.21 to 0.60	
BET Surface Area m^2/g	1100	1600
Water Content %	14.7	7.7
Bulk Density g/ml	0.57	0.42
Activity CTC %	60	100
Activity Cyclohexane %	30	49
pH	9.7	9.9
Macropore Volume cm^3/g	0.191	0.208
Mesopore Volume cm^3/g	0.142	0.205
Micropore Volume cm^3/g	0.515	0.706

Table 1 Carbon Properties

All work was carried out using hand filled cavity type filters with a full bed of carbon between two cellulose acetate segments as shown in Figure 1 below.

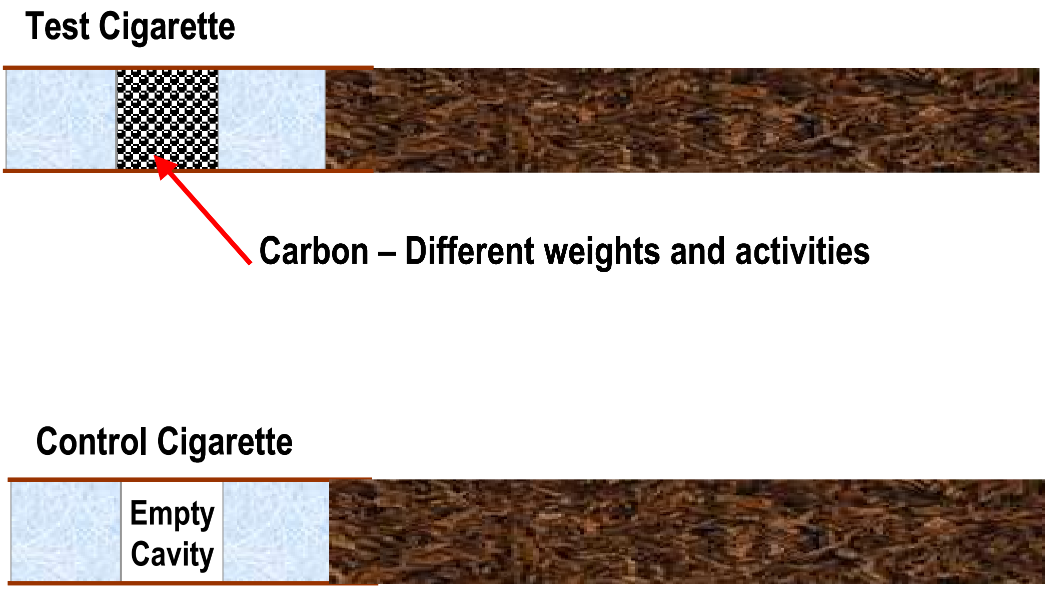


Figure 1 Cigarettes Tested

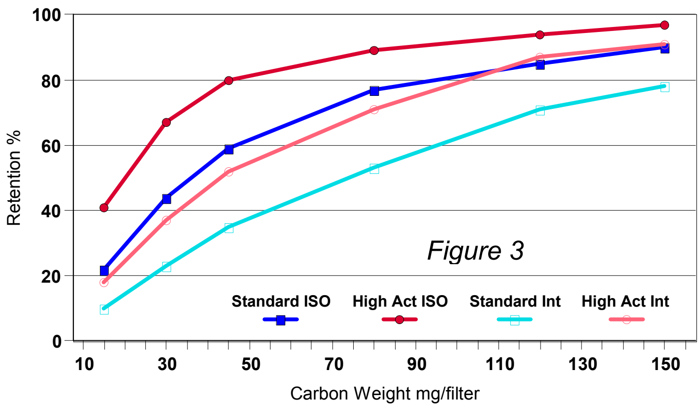
The vapour phase analysis involved smoking 8 cigarettes with all tests performed in at least triplicate, thus a total of 24 cigarettes were smoked per determination. Particulate phase matter was trapped on a Cambridge filter pad and the vapour phase collected in a tedlar bag and injected directly into a GC (2). Twelve compounds were measured and these were acetaldehyde, 1, 3-butadiene, propionaldehyde, acrolein, acetone, acrylonitrile, isoprene, butyraldehyde, methyl ethyl ketone, crotonaldehyde, benzene and toluene. The vapour phase yield of each compound was determined by calibrating the gas chromatograph with a range of calibration mixtures and the retention of each compound was calculated via an indirect calculation (Figure 2) against a monoacetate control cigarette. Results are then expressed as the yield or percentage retention of a particular compound or total yield or average retention of the 12 compounds measured.

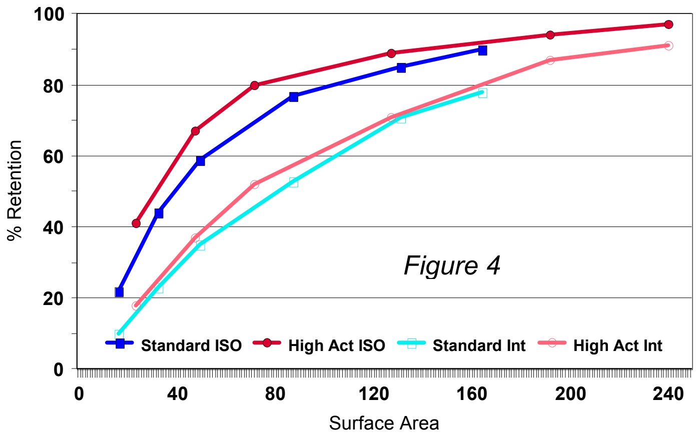
$$\%\ \text{Retention} = \left(\frac{\text{Control Peak Area} - \text{Test Peak Area}}{\text{Control Peak Area}} \right) \times 100$$

Figure 2 – Calculation used for % vapour phase retention

The cigarettes used were nonventilated, American blend products with yields of 13 mg tar, 1 mg nicotine and 13 mg carbon monoxide for ISO smoking. When tested using the Canadian intense regime the yields increased to 26 mg tar, 1.8 mg nicotine and 23 mg carbon monoxide. For ISO smoking the total yield of the twelve vapour phase compounds measured was about 2 mg which increased to approximately 4.2 mg for the Canadian intense regime. For example, the yield of benzene increases from 49 to 125 μg per cigarette when comparing ISO and intense regimes and that for acetaldehyde increases from 798 to 1472 μg per cigarette. Typically, therefore, the carbon was exposed to around twice the amount of smoke when tested at the intense regime and for the intense smoking the smoke velocity in the filter would be higher and hence the contact time lower.

For the retention of the twelve compounds the plots below, figures 3 and 4, show the mean retention plotted against carbon weight (figure 3) and carbon surface area (figure 4). As would be expected the high activity carbon gives more retention for both smoking regimes. For both carbons the measured retention falls by similar amounts when comparing ISO and intense smoking. As these carbons are different densities the same weight has a different volume. If the mean vapour phase retention is expressed as a function of carbon surface area in square meters (figure 4) it appears that available surface area alone could be the major factor in determining carbons retention ability.





However, retention does vary according to the properties of the individual compounds. In general the more volatile the compound the lower the level of retention and the greater the reduction in retention when comparing ISO and intense smoking. Figure 5 below shows the retention of four compounds for 45 mg of both activity carbons and both smoking regimes. The compounds were chosen to give examples of compounds with high and low volatility (acetaldehyde boiling point 21 C to toluene boiling point 111 C). For acetaldehyde the retention for both activity carbons is more than halved when comparing ISO and intense smoking regimes and a similar pattern is seen for acetone. For

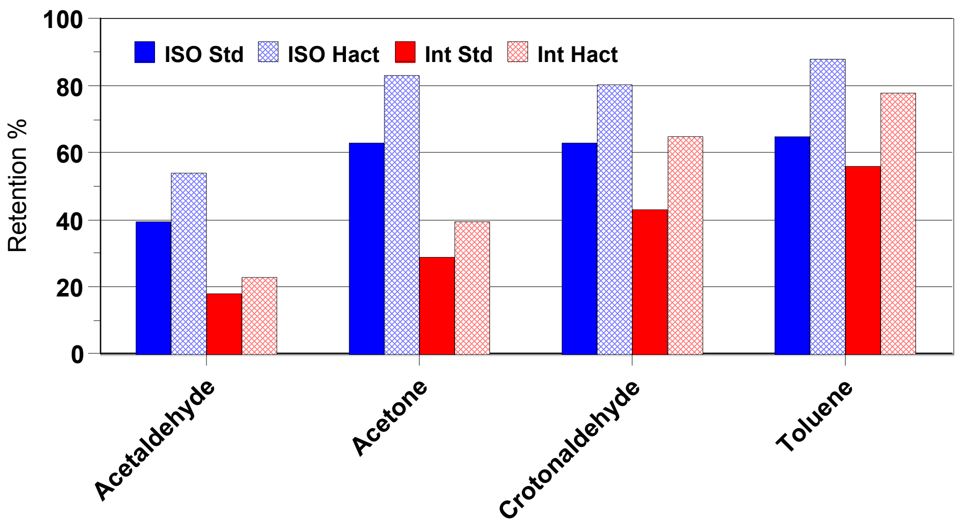


Figure 5 Retention of Smoke Compounds by 45 mg Carbon

less volatile compounds the fall in retention when comparing ISO and intense regimes is much smaller. For toluene and standard activity carbon the retention only falls from 62 to 56 % and for high activity carbon 86 to 78 % for ISO and intense smoking regimes respectively.

Although retention is often a very useful indicator of filter performance the actual yields of compounds are perhaps of more interest to a cigarette designer. The total yields of the twelve compounds of interest are shown plotted against filter carbon weight in figure 6.

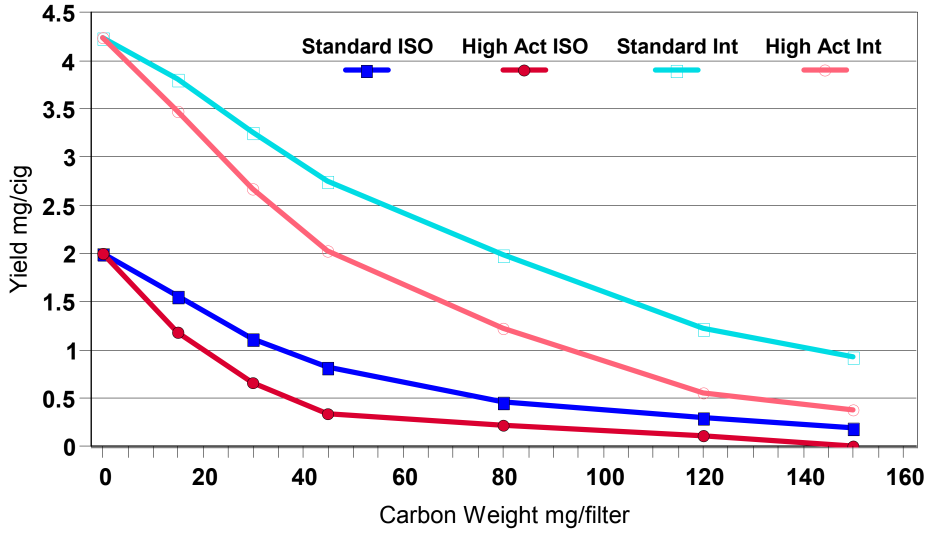


Figure 6 Effect of carbon Weight on Total Yield

For ISO smoking initially addition of carbon causes a steady fall in the total measured yields, however, for the high activity carbon at about 45 mg carbon per filter the slope of the plot changes so that at carbon weights above 45 mg adding more carbon gives less increase in compound reduction. For the standard activity carbon the change in the slope of the plot occurs at a much higher carbon loading between 60 to 80 mg. To reduce the total yield of the twelve compounds to less than 0.5 mg requires just under 40 mg of high activity carbon or around 80 mg of standard carbon. The shape of similar plots for each individual compound seems to depend on the volatility of the compound considered.

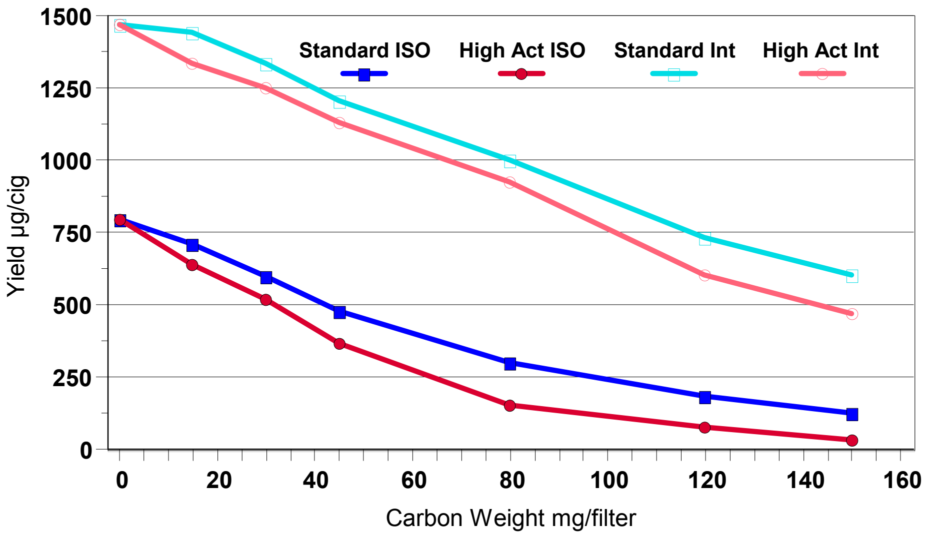


Figure 7 Effect of Carbon Weight on Acetaldehyde Yield

For acetaldehyde much larger carbon weights are required before any change in the slope of the plot is observed. During ISO smoking the yield falls in more or less a linear fashion for carbon loading up to about 80 mg per filter. Above 80 mg per filter the slope slightly flattens and adding extra carbon gives less increase in acetaldehyde removal. As expected the higher activity carbon removes more acetaldehyde. For intense smoking the reduction in yield is approximately linear with carbon loading even for carbon weights up to 150 mg. Again the higher activity carbon removes more acetaldehyde. For toluene the shape of the plots is different. The initial fall in yield is much more pronounced and during ISO smoking only about 30 mg of carbon is needed before the slope of the plots change. During intense smoking again the initial fall in yield is quite steep and for the high activity

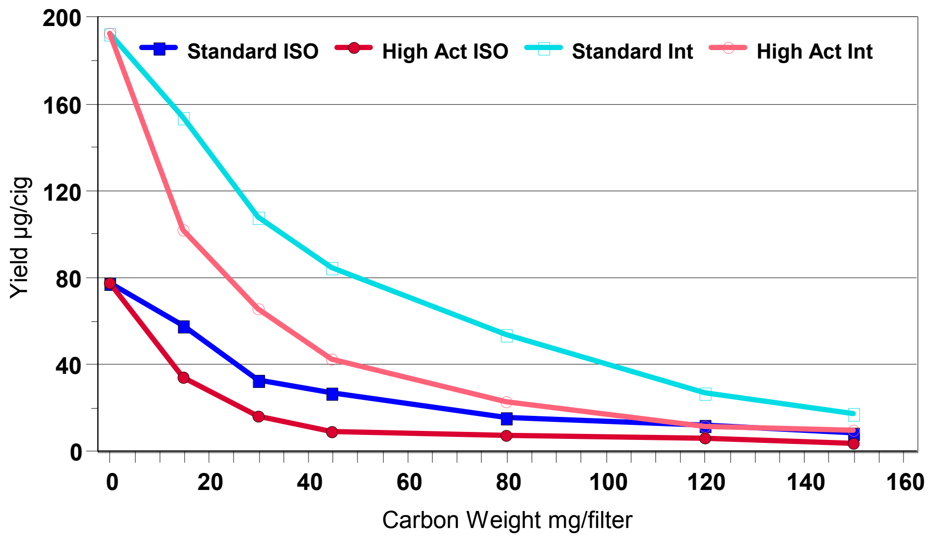


Figure 8 Effect of Carbon Weight on Toluene Yield

carbon the slope of the plot changes at carbon loading above 45 mg per filter. Even for the standard activity carbon it can be seen that the plot is more of a curve than a linear relationship and the initial rapid decrease in yield as carbon loading increases flattens out as carbon loading increases. Other more volatile compounds such as acetone show similar relationships to acetaldehyde whereas less volatile aldehdyes such as crotonaldehdye are similar to toluene. As mentioned earlier the two carbons are different densities meaning the same weight has a different volume. The yields of two aldehydes are expressed as a function of carbon surface area in square meters in figure 9 below.

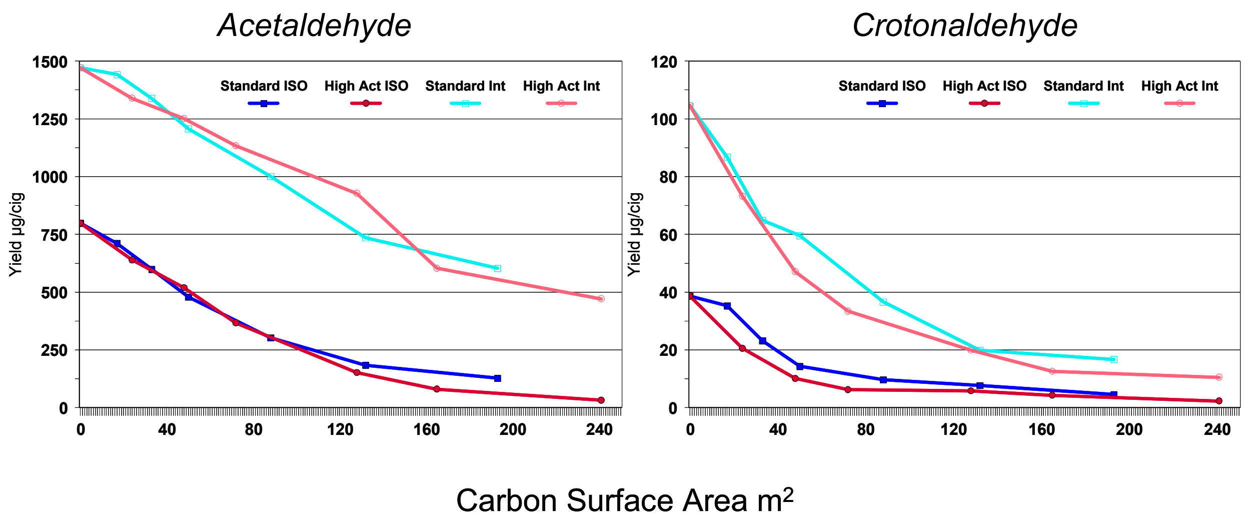


Figure 9 Effect of Carbon Surface Area on Compound Yield

For both compounds it can be seen that the measured yield of the compound is closely related to the surface area of the carbon. A similar plot is given if the total yield of all twelve compounds is considered.

The general effect of carbon in filters is to reduce harmful smoke compounds and although carbon is still effective when tested using intense smoking regimes more carbon is needed to reduce the levels in smoke by the same percentage for intense regimes when compared to standard ISO smoking. If the target was to reduce the amounts of compounds in smoke by say 50 % the weights of standard carbon required would be quite different for different smoking regimes and different compounds. The table below gives values for the weight of standard carbon needed to give 50 % retention of various compounds.

Compound	Carbon Weight for 50% Retention	
	ISO	Intense
Mean VP	38	75
Acetaldehyde	60	120
Acetone	38	82
Crotonaldehyde	32	60
Toluene	27	38

Table 2 Carbon Weight Required for 50% Retention of Various Compounds

Typically twice as much carbon is needed to retain about 50 % of a particular compound when using intense smoking. It may be that the less volatile the compound the lower the amount of extra carbon needed to reduce the yield of the compound by 50 % when using intense smoking. For example, for toluene the standard carbon weight needed for 50 % retention only increases from 27mg for ISO smoking to 38mg for intense smoking.

The data presented suggests that surface area does seem to be a good indicator of compound reduction for coconut shell carbon. Smoking at more intense regimes does reduce the measured efficiency of carbon. But during more intense smoking carbon is retaining a smaller percentage of a much larger yield so it is actually adsorbing more material. The minimum weight of carbon required to give 50 % retention varies according to the compound considered and can be much higher for volatile compounds and intense smoking regimes. For example, for acetaldehyde 120 mg of standard activity carbon is needed compared to only 60 mg for crotonaldehyde to give 50 % retention during intense smoking. Generally more active or higher surface area carbons give greater reductions in smoke compounds when compared on a weight basis but similar reductions when compared on a surface area basis.

References

1) Hasegawa T.; Sasaki T.; Atobe I.; Sakaki T. CORESTA Congress Paris 2006. Review and future prospects of charcoal filter for cigarette.

2) Walker J.; Taylor M. CORESTA Study Group Meeting Jeju 2007. The activity of different carbon weights in a cigarette filter and the effects of triacetin.
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