SUPERSLIM CARBON FILTERS – EFFECT OF CARBON WEIGHT AND SMOKING REGIMES

CORESTA Smoke Science and Product Technology Joint Study Group Meeting. Aix-en-Provence, 18 – 22 October, 2009

McCormack A. D. and Taylor M. J.

Filtrona Technology Centre, Shaftesbury Avenue, Jarrow, Tyne and Wear NE32 3UP, United Kingdom

Summary

Super slim cigarettes are increasing in popularity globally and are probably at the moment showing the most rapid growth of any market segment. These products are generally defined as less than 17 mm circumference and typically use longer filters and much lower tobacco weights. The lower circumference means that smoke velocities passing through the filter are much higher than in standard products. Typically the smoke velocities in super slim cigarettes are more than twice that of standard products. Smoke velocity is an important parameter governing the performance of filters in terms of both particulate retention and vapour adsorption. The smoke velocities for intense smoking of super slim cigarettes are much higher than any experienced in standard products. More super slim products are using special filters including those containing carbon so how does the carbon perform at such high smoke velocities?

Experimental findings follow for the measurements of yields and retentions of selected vapour phase compounds measured by gas chromatography for a range of carbon weights and activities tested using two smoking regimes (ISO and Canadian intense). Comparisons will be made with previous work carried out with standard circumference products.

Superslim Carbon Filters – Effect of Carbon Weight and Smoking Regimes

Smoke velocity is considered an important parameter governing the performance of filters for both particulate retention and vapour adsorption. The relationship between smoke velocity and particulate retention is well known (1) and particulate retention decreases as smoke velocity increases. For adsorption processes the efficiency of adsorption depends upon the molecular weight and activity of the adsorbate, the contact time and the concentration of the molecules to be adsorbed. The reduction of harmful compounds in smoke by carbon has been studied previously (2, 3) and it is well known that many harmful compounds are adsorbed by carbon. The velocity of smoke in a filter depends principally upon the filter circumference, the volume of the puff and the packing density of the filter. As filter circumference decreases and puff volume increases the smoke velocity increases. Previous studies have looked at the performance of carbon in filters (4) for both ISO and intense smoking regimes for standard circumference products. Smoke velocities are higher in slimline products. 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 for filters of 16.7 mm circumference. Carbons weights in the range 15 to 90 mg per filter were studied and the properties of the carbons tested are given in table 1 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 (5). 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 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 twelve compounds measured.

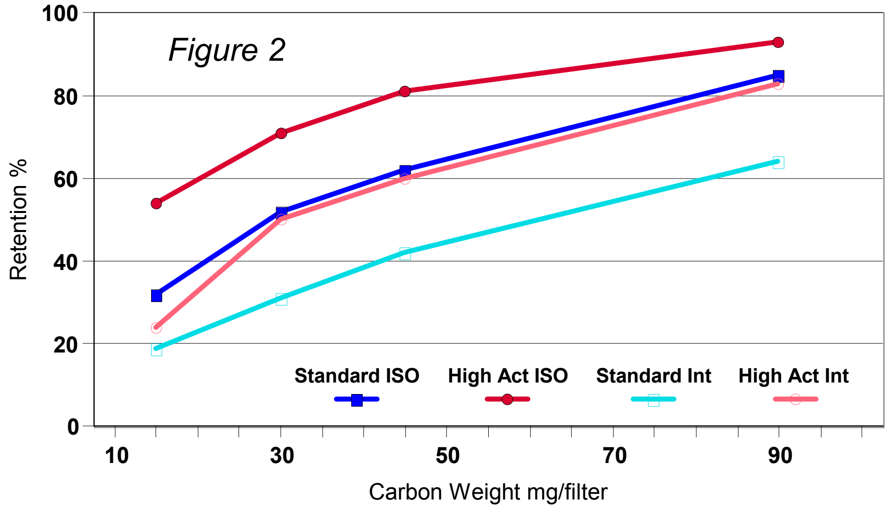
$$\% \text{ Retention} = \left(\frac{\text{Control Peak Area} - \text{Test Peak Area}}{\text{Control Peak Area}} \right) \text{X100}$$

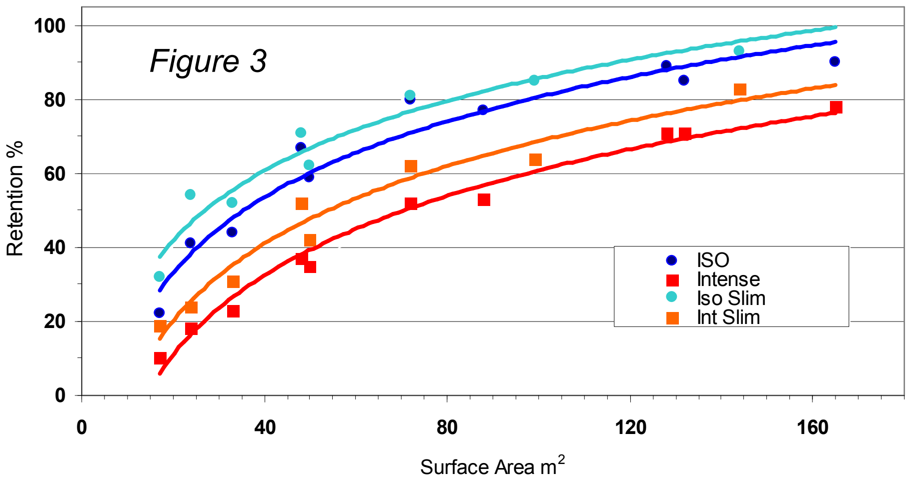
Calculation used for percentage vapour phase retention

The cigarettes used were nonventilated, Amercian blend products, circumference 16.7 mm, with yields of 13 mg tar, 0.6 mg nicotine and 9 mg carbon monoxide and about 1.3 mg of the selected vapour phase compounds for ISO smoking. When tested using the Canadian intense regime the yields increased to 26 mg tar, 1.2 mg nicotine, 17 mg carbon monoxide and 2.4 mg of vapour phase compounds. During the intense regime the carbon is exposed to approximately twice the amount of smoke passing through the filter at twice the velocity. That is, approximately 140 cm/sec for intense smoking compared to approximately 70 cm/sec for ISO smoking. This contrasts to similar standard circumference products (24.5 mm) where the yields were of the order 13 mg tar, 1 mg nicotine, 13 mg carbon monoxide and 2 mg of the selected vapour phase compounds for ISO smoking increasing to 26 mg tar, 1.8 mg nicotine, 23 mg carbon monoxide and 4.2 mg of vapour phase compounds for intense smoking. The smoke velocity in a standard circumference product is typically 35 cm/sec for ISO smoking increasing to 75 cm/sec for intense.

The measured particulate retentions follow the expected pattern for the larger circumference filters the retention falls by about 2% when comparing ISO to intense smoking. For the slimline filters the change is less only a fall of about 1 % in tar retention and 0.5 % in nicotine retention when comparing ISO to intense smoking.

For the retention of the twelve compounds the plots below figures 2 and 3, show the mean retention plotted against carbon weight (figure 2) and carbon surface area (figure 3). 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. In figure 3 the mean vapour phase retention is expressed as a function of carbon surface area in square meters. Figure 3 also contains data for standard circumference (24.5 mm) products for comparison. From the plot it can be seen that the retention values for the carbon in the slim filters is actually higher than that for standard circumference products for both ISO and intense smoking. In both cases the difference is about the same.





For the slimline products the amount of vapour phase compounds delivered to the filter is about half the amount for standard circumference products so although the actual retention is slightly higher the amount retained is actually less. However, the plot does suggest that smoke velocity is not a major factor in the retention of vapour phase compounds by carbon as the velocity for the slim products is approximately twice that for the standard circumference and the difference in retentions is much smaller.

Retention does vary with the properties of the individual compounds especially the boiling point and molecular weight. Unsaturated compounds are normally more strongly adsorbed than saturated compounds and cyclic compounds are more strongly adsorbed than linear 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 4 below shows the retention of four compounds for 45 mg of both activity carbons, both smoking regimes and filters of two circumferences.

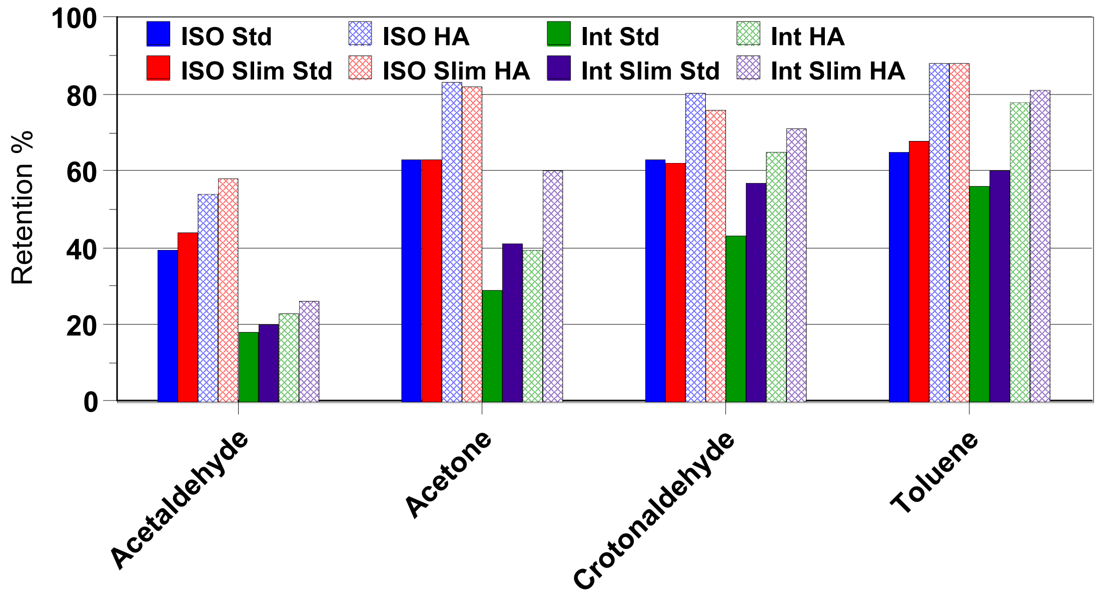


Figure 4 Effect of Activity and Circumference on Compound Retention

Most commercial slimline products would have carbon weights of less than 30 mg so 45 mg does represent a very high carbon loading for slimline products. However, the plot does show that the general trends observed for mean vapour phase retentions are applicable across compounds boiling point ranges from more volatile acetaldehyde, boiling point 21C, to less volatile toluene, boiling point 111C. The high activity carbon always has a higher retention than standard carbon and the retention found in slimline products is usually slightly higher than standard circumference products. Intense smoking gives lower retentions than ISO smoking with the difference normally more pronounced for the more volatile compounds.

While retention is useful in determining filter performance of more interest is the cigarette yields. The total yield of the twelve selected vapour phase compounds against filter carbon loading is plotted in figure 5 below. Over the range of typical carbon loading (10 to 30 mg) in a slimline filter increasing the weight of carbon gives a steady decrease in the yield of the selected compounds for both smoking regimes. To reduce the total yield of the twelve selected compounds to less than 0.5 mg requires about 30 mg of high activity carbon or 50 mg of standard carbon for ISO smoking. For intense smoking reduction to a total yield of less than 0.5 mg has not been reached in the weight range studied and it appears that it would take more than 100 mg of either activity carbon. If values for standard

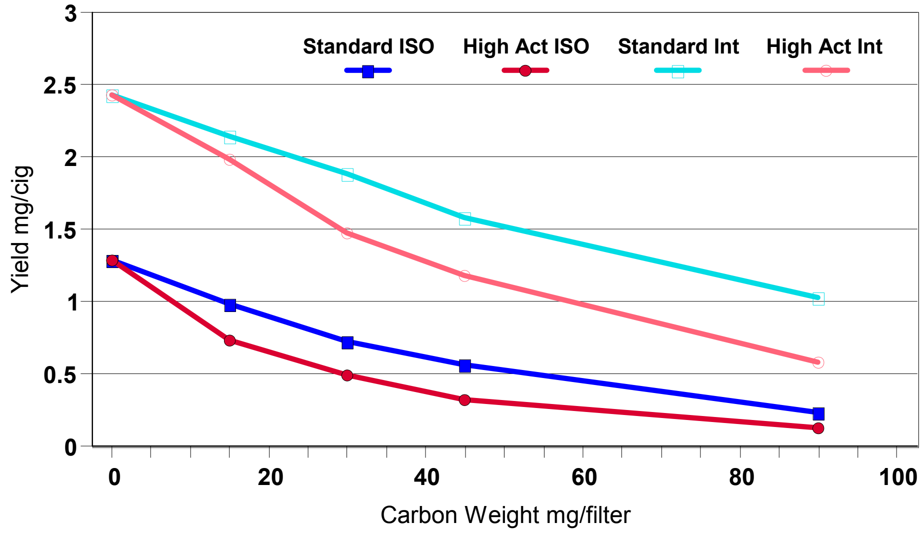


Figure 5 Effect of Carbon Weight on Yield Slimline Products

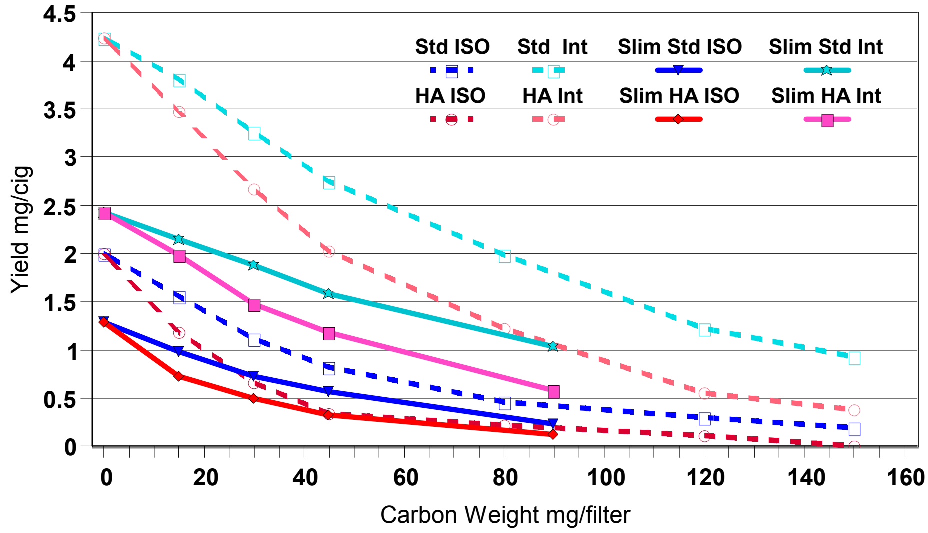


Figure 6 Effect of Carbon Weight on Yield All Circumferences

circumference products are also considered as shown in figure 6 below then it can be seen that for both smoking regimes the total yield of the selected compounds are much lower for the slimline products, shown as solid lines, than those of standard circumference products, shown as dotted lines. For ISO smoking at about 90 mg carbon loading the plots are converging but this is as the reductions exceed 80 to 90 % the concentration of the compounds remaining in the smoke is quite low and the carbon is less effective at lower contaminant concentrations. For the intense smoking this does not occur at 90 mg carbon loading due to the much higher levels of vapour phase compounds generated. From the plot it appears as though carbon loading in excess of 150 mg would be needed for the plots to converge.

The effect of carbon on the yields of individual compounds will to some extent depend upon the boiling point of the compound. For the twelve compounds considered the boiling points range from the very volatile, acetaldehyde boiling point 21 C, to the least volatile of the compounds considered, toluene boiling point 111C. Plotting the yields of these two compounds (µg/cig) against carbon weight for the slimline filters gives the plots shown in figures 7 and 8 below. The shape of the curves in the plots can be seen to be different. For acetaldehyde the reduction in yield with increasing carbon weight is essentially linear for both smoking regimes although it could be said that for the high activity carbon and ISO smoking the line shows some evidence of departure from linearity as the carbon weight approaches 90 mg.

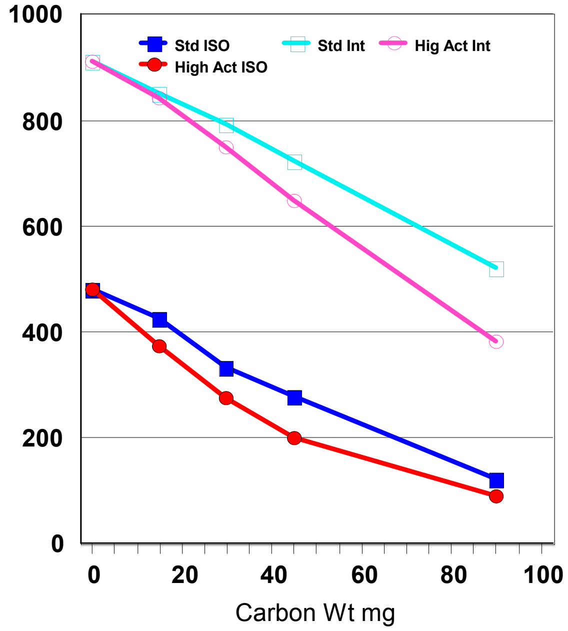


Figure 7 Acetaldehyde Yields

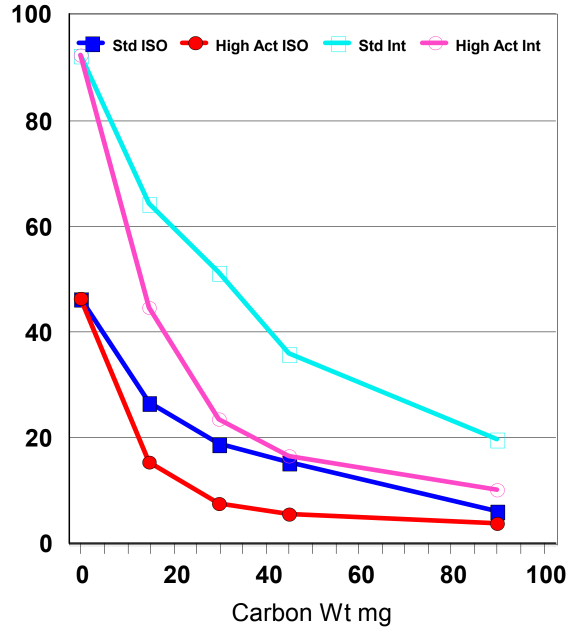
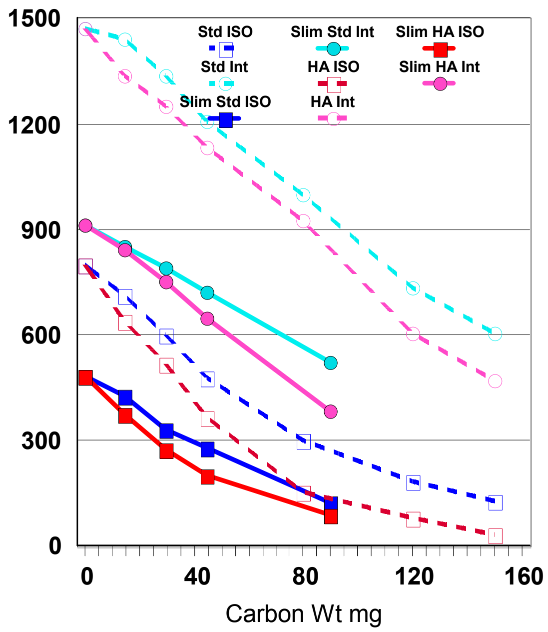


Figure 8 Toluene Yields

For toluene, however, the yields initially fall linearly with carbon weight but at carbon weights above 50 mg all the curves depart from linearity as toluene yields approach very low values perhaps demonstrating the stronger adsorption of toluene compared to acetaldehyde. The data for standard circumference products has been added to these plots as shown in figures 9 and 10 below.

Acetaldehyde



Toluene

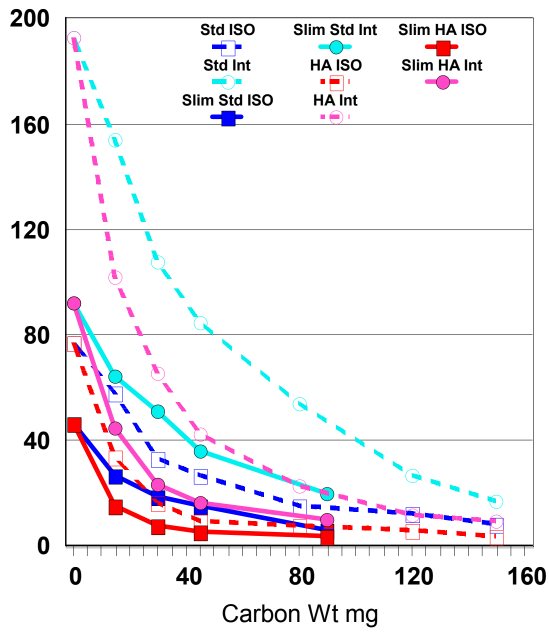


Fig 9 Acetaldehyde Yields all Circs

Fig 10 Toluene Yields all Circs

In general the only difference between the plots for the two circumferences is the much lower yields generated from the slimline products. The shapes of the curves are very similar suggesting that in the range studied the smoke velocity is not a significant factor governing the carbons ability to adsorb compounds from the vapour phase of smoke. The general effect of carbon in filters is to reduce harmful smoke compounds and carbon is still effective when tested using intense smoking regimes or in slimline products. Around twice as much carbon is needed to retain about 50 % of a particular compound when using intense smoking. However, the weight needed for a 50 % reduction is slightly less for a slimline product when compared to the equivalent standard circumference product. The minimum weight of carbon required to give 50% retention varies according to the compound considered, the circumference of the product and the smoking regime used. For example, for acetaldehyde the weight of standard activity carbon required in 24.5 mm circumference products for 50 % retention is 60 mg for ISO smoking which doubles to 120 mg for intense smoking. In 16.7 mm circumference products these weights reduce to 53 and 105 mg respectively. Whereas for toluene the weight for 50% retention in 24.5 mm circumference products is only 27 mg for ISO smoking and 38 mg for intense smoking. In 16.7 mm products the weights reduce to 22 mg and 34 mg respectively. 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. Carbon retains its ability to effectively adsorb smoke compounds over the range of smoke velocities encountered in cigarette filters at least up to the approximately 150 cm/sec velocities found when using slimline products and intense smoking regimes.

References

1) Tobacco production, chemistry and technology, Blackwell Science Ltd 1999. Chapter 11B, Norman A. Cigarette design and materials

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

3) Wieczorek R.; Roper W. CORESTA Congress Shanghai 2008. In vitro tests with fresh cigarette smoke – Effects of charcoal filters on whole smoke and vapour phase mutagenicity and genotoxicity.

4) Taylor M. CORESTA Congress Shanghai 2008. The effect of different smoking regimes on the performance of different weights and activities of carbon in cigarette filters.

5) Taylor M.; Walker J. CORESTA Study group Meeting Stratford-upon-Avon, 2005. The influence of age and storage conditions on the activity of carbon in cigarette filters