Filtrona Technology Centre

Mono-filter Solutions for Yield Reduction

For many years a global trend within the cigarette industry has been the reduction of tar and Nicotine yields of cigarettes. This has been brought about by consumer demand or the introduction of legislative maximum tar yields. Thus the cigarette designer has been challenged to produce cigarettes with ever lower tar yields while maintaining consumer satisfaction with the products they smoke. The success of this strategy can be shown by the general decrease in cigarette tar yields in most parts of the world. On a global basis the overall tar yields of cigarettes is steadily declining and this can be illustrated, **Slide 2**, by the fall in sales volume for cigarettes with yields over 10 mg. Cigarettes with yields between 6 and 10 mg have shown a significant increase over the same time period. In the plot the data for 2006 is estimated but considering a ten year period from 1997 to 2006 it can be seen that the annual sales of cigarettes with yields over 10 mg has fallen by around 735 billion cigarettes, whereas the annual sales of cigarettes with yields between 6 to 10 mg has risen by 522 billion in the same time period. Another change in the market over this time has been the increase in the use of special filters to help bring about these yield reductions. However, in many parts of the world tar yields are still relatively higher than 10 mg and in these markets while there is still a trend to lower tar cigarettes the growth in cigarettes with yields less than 10 mg is slower than the global trend. For example, **Slide 3**, in the Asia Pacific region the sales volume of cigarettes with yields above 10 mg has grown over the same 10 year period and seems to have reached a plateau from which they may now start to fall slightly. The 6 to 10 mg yield cigarettes have shown modest growth but not to the same extent as the global trend.

More recently the focus on cigarettes has expanded from the consideration of tar, Nicotine and Carbon Monoxide yields of cigarettes to consider the yields of many other compounds in smoke. These other compounds are now relatively well known and are some times considered to be the compounds most likely to cause health problems associated with smoking. So when considering a tar reduction program it is now more common to also consider the effect of different filter types on the yields of many compounds in smoke rather than only tar , Nicotine and Carbon Monoxide. Of course to understand the effect of different filter types on cigarette smoke it is essential to understand the form in which a particular compound passes through a filter. Considering the nature of cigarette smoke, **Slide 4**, the plot shown here gives the distribution of the compounds between the gas/vapour phase and the particulate of smoke. As might be expected the data generally shows the lower the boiling point the greater the portion in the vapour phase. The line in blue shows the expected distribution and as can be seen the majority of compounds follow the expected distribution. Notable exceptions are reactive or highly soluble compounds such as Ammonia, Formaldehyde and Hydrogen Cyanide, shown in red, where the amount in the gas/vapour phase is less than might be expected from a consideration of their boiling point alone. Generally this plot shows that the compounds of interest are found in all fractions of cigarette smoke and therefore no one simple filter solution will be available for removal of all compounds.

In general three major methods exist to reduce various compounds in smoke. These are the use of ventilation, filtration or adsorption by carbon. A summary, **Slide 5**, of the different methods of reducing various fractions of smoke is given in the table. From the table it can be seen that ventilation is the only method of reducing permanent gasses and that ventilation or carbon or a combination of both can reduce the organic volatiles. Filtration, ventilation or carbon can be used to reduce semi-volatiles and filtration and/or ventilation can reduce the non-volatile compounds. A more detailed, **Slide 6**, comparison of the three methods of yield reduction is given in the plot in this slide. As can be seen from the plot acetate filters are highly efficient for the removal of phenols and filter non-volatile compounds but have little effect on organic volatiles and no effect on gasses. Addition of carbon to a filter greatly increases the removal of organic volatiles and many semi-volatile compounds. Ventilation is the only current option for the removal of permanent gasses such as Carbon Monoxide.

The data in the plot refers to the retention of various compounds but of course retention information really depends on how much of a particular material there is in the smoke. Fifty percent retention of a compound present at the nanogram level represents a much lower weight of material removed when compared to 50 % retention of a compound present at the milligram level. So how much of these compounds are typically present in smoke. Apart from the major analytes, tar, Nicotine and Carbon Monoxide, **Slide 7**, the table gives typical levels of Hoffmann compounds in the smoke of an unventilated cigarette. From the table it can be seen that there is up to 0.6 mg of inorganic gasses in smoke the majority of which are Nitric Oxide and Hydrogen Cyanide. Organic volatiles can be present at up to 3 mg about half of which are volatile aldehydes. The semi-volatiles can amount to up to 0.5 mg the majority being phenolic compounds. Non-volatile Hoffmann materials are present at much lower levels typically less than 0.0005 mg per cigarette. But of course this is only referring to the amounts in smoke not their potential harmful effects.

A number of options do exist for the reduction of these compounds in smoke but many would rely on relatively complex multiple segment filters. To reduce these compounds but still use only mono-filters the number of options is less but some still exist. A filter that has been used successfully in tar and Nicotine reduction programs, **slide 8**, is the combined performance filter (CPF). This filter, **slide 9**, is now available as the CPF Advanced which is a recently improved version of the CPF filter. The latest feature is improved flute definition to enhance the visual appearance of the filter. The CPF Advanced filter can be processed on a cigarette maker in the same way as monoacetate so there is no need to adapt any existing production processes. CPF Advanced offers the same increase in tar and Nicotine retention as standard CPF but with the added benefits of the visual appearance offering instant anti-counterfeiting capability and clear product differentiation when compared to standard filters. This filter, **slide 10**, can be used in two orientations with the flutes to the tobacco rod end of the filter or the flutes to the mouth end of the filter. In both orientations the retention of the filter is the same but with flutes to tobacco the filter appears as a standard monoacetate. With the flutes to the mouth a strong visual difference is given that can also be a useful anti-counterfeiting tool, **Slide 11**. The main benefit of the filter is the higher tar and nicotine retention when compared to a monoacetate at the same filter pressure drop. The filter consists of cellulose acetate fibre surrounded with an embossed cellulose wrap. This wrap can be coloured to further increase the visual identity. As previously mentioned the filter can be configured with the flutes to the tobacco or the mouth end of the filter. It can be used on cigarettes of all tar levels and while time does not allow a description of all the options it can also be used as a segment in a variety of multiple segment filters.

The smoke flow, **slide 12**, in the CPF filter is split between the flutes and the main body of the filter with the majority of smoke passing through the main body. This smoke is filtered by the cellulose acetate fibres in the usual way. The smaller portion of the smoke that passes down the flutes actually passes through the cellulose innnerwrap at the point in the filter where the flutes end. This mechanism of filtration through the paper layer is very efficient and therefore the majority of smoke that passes into the flutes is retained by the filter. It is this mechanism that gives the filter its name, that is, the combined performance filter as it combines the filtration of cellulose acetate and cellulose in one filter. However, it is important to note that very little smoke filtered by the cellulose is delivered to the smoker as almost all is retained in the filter. The increase in retention, **slide 13**, varies with filter design but is generally around 6 % for tar and slightly higher for Nicotine. It is maintained across the full range of filter pressure drops normally found for monoacetate filters. The effect this can have on smoke deliveries will be illustrated with an example later. The flute definition of the CPF Advanced, **slide 14**, is shown here. The diagram in the slide shows the clearly defined flutes that are a feature of the advanced product. As previously mentioned. **Slide 15**, a coloured innerwrap can be used to increase the visual appearance of the filter. The example shown here is for a blue wrap but red and green have also proven popular. The filter can also be used as a flavour delivery system, **slide 16**, as shown here with a flavour thread added to the filter. The thread can be used as a method for the precise addition of a wide range of flavours to the filter.

The difference between the filtration mechanisms of fibres and carbon has been briefly described earlier. The main difference is that for some fractions of smoke such as the organic volatiles carbon can give much higher retentions than fibrous filters. A mono-carbon filter, **slide17**, has therefore been a long standing goal of the industry. This has now been realised by the Active Patch Filter or APF. The filter, **slide 18**, is available as a single patch or, **slide 19**, as a split patch. The split patch is to allow for filter ventilation in the gap between the two carbon patches. The active patch filter, **slide 20**, was designed to create an effective mono carbon product with the clean running production advantages of a mono-acetate filter. The filter consists of a patch of activated carbon printed onto the inner surface of the plugwrap. The patch position is flexible and ventilation can be achieved through either a single patch, or split patch configuration. The carbon loading can be up to 3 mg per mm of patch length and total loading is controlled by the length of the patch. The filter gives a similar removal of vapour phase and semi-volatile components as other carbon filters with the same carbon loading but has been accessed to have less carbon taste. For manufacturers that wish to take advantage of the filtration properties of carbon it is considered that this filter would a good first step to introduce carbon in to markets that are traditionally monoacetate or for use with blends such as Virginia that are some times considered not to be compatible with carbon. In production, **slide 21**, the filter would normally have a gap of around 5 m at the mouth end of the filter where no carbon is applied. Also a gap of around 2 mm is left at the tobacco rod end of the filter. This means that in cigarette construction the filter is only cut in area's free of carbon. Of course for maximum carbon loading the patch of carbon could be extended up to the tobacco rod end of the filter. In a ventilated cigarette a gap of around 4 mm, or larger if required, is left in the carbon patch for ventilation via on line laser or perforated tipping paper and porous plugwrap. Trials have also shown that it is perfectly possible to laser ventilate into a patch thus allowing further increases in the level of carbon loading.

Normally to evaluate the effectiveness of any filter it is compared against a standard filter which is usually monoacetate. However, for carbon filters the standard is usually considered to be an active acetate dual filter. A comparison of the filtration, **slide 22**, of various fractions of smoke for monoacetate, APF and active acetate dual filters ADD is shown here. The major difference can be seen in the higher reduction given by the carbon filter for the volatile fractions of smoke such as Hydrogen Cyanide, volatile aldehydes, volatile ketones and volatile hydrocarbons. The carbon filters also tend to give higher removals of semi-volatile bases such as Pyridine. For most filters of similar tar retention the removal of non-volatile compounds tends to be the same. In general the AAD filter gives slightly higher reductions than the APF filter for the same weight of carbon.

One aspect of the active patch filter is that while carbon loadings typical of most current commercial products are possible excessively high carbon loading is not possible. In order to increase the reduction of compounds by carbon various high activity carbons are available sometimes referred to as super carbons, **Slide 23**. The performance of filters can be enhanced by the use of these higher activity carbons. A recent version of these is a carbon that combines higher activity than standard coconut shell carbon with an impregnant that selectively reduces Hydrogen Cyanide in smoke. This particular carbon is also made from coconut shells but has a surface area of 1600 m^2/g compared to a surface area of 1100 m^2/g for the carbon most typically used in cigarette filters. These higher activity carbons are generally suitable for use in all filter manufacturing processes including the active patch filter. Impregnated carbons of this type have the advantage that the reduction of the compound that is selectively removed, Hydrogen Cyanide in this case, does not change with cigarette storage, **Slide 24**. The plot shown here gives a comparison of the performance of acetate, active acetate and active patch for the reduction of compounds in smoke, using the same weight of carbon, but now includes data for the patch filter with the high activity carbon. It can be seen that the high activity carbon increases the reduction of the more volatile compounds for the patch filter. The higher reduction is seen mainly for the volatile compounds and semi-volatile bases. Also, however, the reduction of Hydrogen Cyanide is greatly increased.

Although these filter types do show increased retentions of many compounds what does this mean in practise if the filter on a particular brand is changed. A typical cigarette from this region with a monoacetate filter has been tested for a range of compound yields and retested when assembled to different filter types. Not all Hoffmann compounds have been measured as in general filter types do not have a selective influence on non-volatile compounds as they tend to be proportional to the level of tar, the lower the tar the lower the level of non-volatile compounds. Because of this the only non-volatile compound that has been measured is Benzo [a] Pyrene.   The table, **slide 25,** shown here gives the yields of Hoffmann compounds for this brand which has a tar yield of just under 14 mg. The yield of volatile compounds is 2.21 mg and the yield of semi-volatile compounds, bases, phenols and cresols is considerably lower at 0.18 mg. The level of the non-volatile compound measured is very much lower at only 0.0087 µg which is only 0.0000087 mg. So it can be seen that for this cigarette apart from Carbon Monoxide the total yield of the measured Hoffmann compounds is about 2.39 mg the majority of which are the volatile cyanides, aldehydes, hydrocarbons and ketones. If the filter on this cigarette is changed what effect does it have on these compounds. If we consider first the CPF Advanced filter that is mainly used to reduce tar and Nicotine, **Slide 26**. The first point to note is that as expected the tar has been reduced and a corresponding reduction in Nicotine is also seen. As expected this filter has no effect on the level of Carbon Monoxide. A small reduction is also seen in volatile compounds from a total of 2.21 mg to 2.11 mg and in semi-volatile compounds from 0.18 to 0.16 mg. The expected small reduction in non-volatile compounds has also been found. Thus a relatively simple change in filter has given a cigarette with the same draw resistance and probably taste with a lower yield of tar and the majority of Hoffmann compounds.

A more significant change to cigarette design would be the introduction of carbon in to the filter and as we have seen this can now be achieved with a monofilter. Changing to an APF filter on this cigarette with about 60 mg of carbon on the filter, **Slide 27**, would change the yields of the cigarette as shown in this table. It is immediately obvious that this filter has had the same effect on tar and Nicotine as the original acetate filter and again as expected the Carbon Monoxide yield remains about the same. The largest impact is in the increased reduction of the volatile compounds and semi-volatile bases given by the APF filter. For the volatile compounds the overall yield has reduced from the original 2.21 mg to 1.55 mg a reduction of about 30%. The yields of the semi-volatile bases are reduced by over 50%. As expected the yield of the phenolic compounds remains relatively unchanged. However, it can be seen that a change in filter can reduce the yields of the Hoffmann compounds considered here from 2.39 mg to 1.72 mg which would constitute a significant reduction.

As mentioned earlier higher activity carbons can be used in filters to increase the reduction of volatile compounds and when they can be added on an equal weight basis the increased reductions are quite high. However, for a filter such as the Active Patch an area of patch is coated with carbon so a particular volume of carbon is added rather than a weight of carbon. The higher activity carbons have lower densities and so the same volume is a lower weight. Using an APF filter with 48 mg of high activity carbon on the same cigarette would change the measured yields as shown in the table, **Slide 28**. In general it can be seen that, due to the lower weight, the reductions given by the high activity carbon are about the same as those for the higher weight of standard carbon. However, the reduction in volatile cyanides is larger than that for the standard carbon. This is due to the selectivity of the HCNR carbon towards Hydrogen Cyanide. Of course if a equal weight of the high activity carbon had been added much larger reductions would have been achieved with the high activity material

In conclusion, **Slide 29**, it can be seen that the global trend in the tobacco industry is a continuing reduction of the yields of all compounds in smoke. The filter used will continue to play a major part in this effort. Monofilter solutions do exist to allow reductions in cigarette yields and two examples have been discussed here. Much research effort is being concentrated on the development of more efficient monofilters and the additives that can be used in these filters. Future filters may well become more complex multi-segment devices but an effective monofilter will always have a role to play.

Dr M J Taylor
Scientific Services Manager
Filtrona technology Centre