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The Role of Filter Technology in Reduced Risk Cigarettes

By Dr M J Taylor
Director of Scientific Development
Filtrona Technology Centre

When considering the role of filter technology in reduced risk cigarettes the most fundamental question to be answered is what constitutes a reduced risk cigarette. No clear definition of what would be an acceptable reduced risk cigarette currently exists and as would be expected for such a complex subject, scientific opinion is somewhat divided. A review of current literature illustrates the different opinions. For example Green et al (1) stated, **fig 1**, that at our current state of scientific knowledge no one will ever be able to claim the development of a less hazardous cigarette based solely on the reduction of known toxic chemicals in mainstream smoke. He also said the approach of reducing tar yields appears to be the most practical way of producing a less hazardous cigarette as when tar is reduced both known and unknown toxicants are reduced. As an additional comment it was also stated it is well known that charcoal-containing filters have a high efficiency for removing carbonyl compounds from smoke. Development of more consumer acceptable products that reduce gas-phase toxicants appears to be another route to a less hazardous cigarette. The US Institute of Medicine (2) also expressed a number of views in their publication "Clearing the Smoke", **fig 2**. Among the principle conclusions expressed were 1) For many diseases attributable to tobacco use, reducing the risk of disease by reducing exposure to tobacco toxicants is feasible and 2) Potential Reduced Exposure Products (PREPs) have not yet been evaluated comprehensively enough (including for a sufficient time) to provide a scientific basis for concluding that they are associated with a reduced risk of disease compared to conventional tobacco use.

Other quite novel approaches have also been suggested, for example Dr Gori (3), **fig 3**, has stated that less hazardous cigarettes are eminently feasible and that a relative scale of inhaled doses of tar from different brands is given by the tar to nicotine ratios of the smoke from those brands. Because gas and tar yields generally correlate, then the tar/nicotine ratio would be a reasonable proxy for the ratio of the whole smoke and nicotine and would be a valid index of overall risk reduction. The lower the tar/nicotine ratio the lower the potential risk. If the ratio of tar to nicotine could be reduced by 50% an impressive risk reduction could result. That is, for the same level of nicotine intake the amount of tar and potentially other toxicants would be reduced by 50%.

It is the extreme complexity of cigarette smoke which makes it difficult to give an accurate risk evaluation for exposure to smoke. Classical toxicology considerations for exposure to individual compounds would give a dose response curve as shown in this plot, **fig 4**. The general principal shows that increasing the dose increases the potential risk. That is exposure below or near the threshold level is potentially a lot less harmful than exposure at levels where significant response is experienced. Therefore, although no clear definition of a reduced risk product exists there would appear to be some consensus in the view that reducing exposure to all toxic materials may give rise to products that could be considered reduced risk. However, many years of testing would be needed to confirm the validity of any reduced risk claim. If reduced dose does equate to reduced risk, it is in the field of reducing the dose of various smoke compounds that filter technology can make a contribution to potentially reduced risk cigarettes.

Filter technology can make a dual contribution for lower yield products which are acceptable to consumers in general. The first is the development of filter solutions using new materials and the second is the more effective, lower cost manufacture of filters containing granular additives.

If we consider new materials, the vast majority of cigarettes globally use cellulose acetate or a combination of cellulose acetate and carbon as the filter material. Approximately 10% of the current world cigarette market uses carbon filter products and it could be argued that as the carbon filters reduce the yields of many gas/vapour phase toxicants that these are the first step towards commercial reduced risk products. Development of a new more effective granular additive may therefore be a further potential step towards a reduced risk product. An extremely wide range of materials could be used as granular additives including alumina's, carbons, catalysts, molecular sieves, ion exchange resins, sepiolite, silica gels and zeolites. Considering that these materials are available in a wide range of particle sizes, surface area's, and pore sizes and for some, different chemical forms, it can be seen that a huge number of possibilities are available. Also carbon can be produced from any carbonaceous raw material such as coal, lignite, wood, peat, coconut shell, petroleum coke, bones and fruit nuts. In addition it can be seen that by using many of the above materials as supports for chemical reagents the variations become almost infinite.

To evaluate a wide range of these materials for activity towards cigarette smoke, a reproducible method is required to introduce a fixed weight of the material into a cigarette during smoking. A method that has been found to be reproducible in Filtrona laboratories is to use cigarettes made from a 27 mm filter. This filter consists of a 10 mm segment of acetate and a 17 mm length tube as shown here, **fig 5**. Cigarettes produced using these filters were then used for testing the granular additives. A fixed weight of granular material, 100 mg, was added to each cigarette and the cigarette completed by inserting an 8 mm length of non wrapped acetate. The non wrapped acetate material helps give an effective seal downstream of the granular material and was always inserted into the cigarette so that the granular material formed a full cavity in the filter even if this meant leaving a short recess at the mouth end of the filter. A control cigarette was made by using the same cigarette with an empty cavity. Thus the only difference between the two cigarettes was the bed of material produced by the granular additive as shown here, **fig 6**. To evaluate the effectiveness of the additives, the percentage retention of a compound of interest has been calculated as, **fig 7**, the yield of the control cigarette minus the yield of the test cigarette divided by the yield of the control cigarette multiplied by one hundred.

Using this rapid screening technique we have evaluated many granular additives including those currently and previously used in cigarette filters. Time will not allow a review of all materials tested but a description of the effectiveness of eleven granular materials will be discussed. These are, **fig 8**, carbon 1, a standard coconut shell based carbon; carbon 2, a high surface area coconut based carbon; carbon 3, a coal based carbon; carbon 4, a wood based carbon; HCNR carbon, which is a high surface area coconut shell carbon impregnated with a material to reduce Hydrogen Cyanide; a typical silica gel (60 Angstrom pore size); a higher surface area silica gel (40 Angstrom pore size); ion exchange resin 1, a weak base anion exchange resin; ion exchange resin 2, an alternative weak base anion exchange resin; ion exchange resin 3, a non-ionic polymeric adsorbent resin and sepiolite. Some of these materials are currently used in cigarette filters or have been used in the past. They cover a wide range of surface areas, **Fig 9**, from the lowest at just over 300 m^2/g to the highest at 1,600 m^2/g. The materials also have a wide range of surface chemistries from the relatively inert carbon, to a more polar surface such as silica gel, to a chemically modified carbon, to the ion exchange resin which will give some purely chemical effects. Activity measurements have also been carried out on these materials using Cyclohexane. This method measures the equilibrium weight increase given when the material is exposed to Cyclohexane vapour. In some cases this can give an indication of activity towards cigarette smoke but it is carried out over many hours so does not always reflect what happens for the very short contact times experienced during smoking nor allow for specific chemical effects.   It should of course be noted that the rapid screening technique only supplies information on the performance of the fresh material it does not give any indication on how the material will perform in an aged product. Active granular additives in general only affect compounds in smoke that pass through the filter in the gas or vapour form. However, it is well known that none of these additives will reduce Carbon Monoxide or Nitric Oxide in smoke, **fig 10**. Therefore, for this work we have looked at some of the Hoffmann compounds with boiling points in the range from about -20 to 250 C. These compounds include many of the well known toxicants such as volatile cyanides, various carbonyls, volatile hydrocarbons, semi-volatile bases and phenolic compounds.

If we recall the dose response curve shown earlier a zero dose equals a zero response so in the plots of retention that follow 100% retention is equivalent to a zero yield and therefore a zero response. Looking at the retention of the cyanide compounds first, **fig 11**, it can be seen that the various carbons give the largest removal and increasing the surface area from carbon 1 to carbon 2 increases the removal of these two compounds. The coal based carbon (carbon 3) and the wood based material (carbon 4) give lower retentions of these compounds, especially Hydrogen Cyanide, in the case of the wood based material. Two of the ion exchange resins give good retentions of Hydrogen Cyanide but, in general, the resins, silica gels and sepiolite give lower removals than the carbons. Impregnating the carbon with compounds to enhance the removal of Hydrogen Cyanide does increase the retention of this chemical but as for the resins it is a very selective effect as only the retention of Hydrogen Cyanide is increased. Other work has shown this reduction in Hydrogen Cyanide is not affected by cigarette age, so for an aged cigarette the reduction in Hydrogen Cyanide given by the impregnated carbon is significantly higher than many other materials. However, it is difficult to judge when the Hydrogen Cyanide is in a complex mixture such as cigarette smoke if retention of over 90% is sufficient to reduce the dose to below the threshold level but the general principle is the lower the dose or yield the better.

Turning now to carbonyls, **fig 12**, again it can be seen that carbon is generally the best adsorbent as it gives higher retentions of the compounds and in general retention increases with increasing surface area. Carbons produced from other raw materials such as coal and wood also give relatively high retention of carbonyls. For the carbonyls, the silica gels give higher retentions than those previously seen in the last plot for cyanides. This is probably due to the more polar nature of the silica gel giving a better adsorption of the polar carbonyls. However, a surface area effect is not immediately apparent as the two silica gels have similar overall retentions of the carbonyls. Ion exchange resins 1 and 2 also give some retention of the carbonyls. As for the previous plot ion exchange resin 3 and sepiolite gives the lowest removals. Considering now the more volatile of the hydrocarbons, 1, 3 Butadiene and Isoprene, fig **13**, it can again be seen that carbon gives by far the greatest removal and, increasing surface area increases the retention of the materials. Again the carbons from other raw materials give relatively good retentions. Ion exchange resins, silica gels and sepiolite give very low retentions of these two chemicals. Some less volatile hydrocarbons, Benzene and Styrene, are shown in the next plot, **fig 14**. Again, all the carbons give high retentions with the high surface area coconut carbons and the wood based material giving retentions over 80%. The retention given by the silica gels is low for Benzene but higher for Styrene. The difference between the more volatile hydrocarbons 1,3 Butadiene and Isoprene with boiling points of -4.5 and 34C respectively and the less volatile ones Benzene and Styrene boiling points 80 and 146 C respectively is due to the volatility of the materials. Lower volatility materials are much more difficult to adsorb and retain and so need granular materials with a high surface area and a high proportion of micropores. The polar nature of the silica gel does not aid the retention of hydrocarbons and both the silica gel and sepiolite are poor for removing these compounds from smoke. The ion exchange resins especially 1 and 2 give some reduction of the less volatile hydrocarbons but have little effect on the more volatile chemicals.

For semi-volatile bases, **fig15**, the level of removal can depend as much on the boiling point, or availability of the material as the adsorbent itself. For Pyridine which boils at 115 C a significant amount of vapour that readily condenses is available so that the majority of the Pyridine can be retained by most of the materials studied. Again, ion exchange resin 3 and sepiolite have quite low retentions for Pyridine. The polar nature of the Pyridine means that lower surface area silica gels can retain almost as much Pyridine as the higher surface area carbons and the two silica gels retain over 80% of the Pyridine. The silica gels remove more Pyridine than the lower surface area coconut carbon and the coal based carbon. The high surface area coconut carbons and the wood based carbon retain about 95% of the Pyridine. General reductions of Quinoline are much lower, probably because the boiling point is much higher and hence the amount of vapour available is much lower. The polar nature of Quinoline allows the silica gels to retain slightly more than the carbons

For compounds of lower volatility the retention of the various granular materials is dependant not only on the granular material but also the amount of vapour present. Considering, **fig 16**, the phenolic compounds, it can immediately be seen that the retentions are much lower than for the compounds previously considered. This is likely to be due to the lack of free vapour present for adsorption to occur. Also, it should be noted that cellulose acetate has a high selectivity towards phenolic compounds and that the smoke in the test system we have used passes through an acetate filter segment so that some of the available vapour has already been removed before the smoke reaches the granular materials. The work discussed here has only looked at a snapshot of 11 granular materials; many others are currently being studied. For example, as mentioned earlier, carbon can be produced from any carbonaceous raw material and much work is still ongoing in the evaluation of different carbons and including those with added impregnants. In terms of the potential for reduced risk, carbon is currently the best option and, as Green et al stated, some prominent scientists have hypothesised that a major factor

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influencing the differential lung cancer rate between Japanese and Western smokers is the greater popularity of charcoal filtered cigarettes in Japan. This appears to be a situation where the main stream smoke chemistry, biological assays and epidemiological studies are in agreement, that is, reducing main stream smoke vapour phase toxicants is beneficial (1). Therefore, development of more effective granular adsorbents that can be used alone or in conjunction with standard or new, more effective carbons may give a positive contribution to the potential of risk reduction.

Once the new materials have been identified they would have to be incorporated into filters. The most common current method for incorporating granular additives in filters is the active acetate dual filter often referred to as the Dalmatian filter, **Fig 17**. This is usually a two segment filter with an acetate mouth end segment and a segment with carbon on tow at the tobacco rod end of the filter. To make such a filter requires 3 processes, the production of the white base rod, the production of the base rod containing carbon and combination of the two rods into a dual filter. In recent years filter production technology has made great advances in the speeds (and hence costs) at which such filters can be produced. For both the base rod containing carbon and the dual rod, machine speeds have more than doubled and the current machines, **fig 18**, for producing dual rods are clean, self-contained high speed manufacturing units. Furthermore, higher weights of carbon can be incorporated using the triple granular filter, **fig 19**. Filtrona's unique Cavitec™ process allows up to two different materials to be placed in the cavity and ensures that the cavities are full. Again, the speed at which these types of filters can be produced has greatly increased over recent years. Other types of filters containing carbon are used and currently the use of carbon in filters is increasing.

To combine more than two granular additives in a filter more complex multi-segment filters may be required and such products, an example of which is shown here, **fig 20**, have been proposed in the past (4). Such a filter could contain up to three different fibrous filter materials and four different granular additives and development samples of this type have been produced at Filtrona. Also, commercial equipment is now available to produce filters with up to 5 solid segments. So, while there are many ways of incorporating carbon or other granular materials in filters, it is well understood that increased complexity in the filter will generally lead to added cost in the final product. Thus some extremely complex filters may give rise to potentially reduced risk products but their cost would probably mean they tend towards very low volume niche brands that would not make a major contribution to reduced risk for the majority of smokers.

The most recent advances in the use of granular materials in filters have attempted to address the complexity issue by the production of mono-carbon filters. That is a carbon filter made in one machine pass. The first of these filters is the Active Patch Filter™ or APF™. The APF™ filter, **fig 21**, is available as a single patch or, **fig 22**, 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™, **fig 23**, was designed to create an effective mono carbon product with the clean running, secondary 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, 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 assessed 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 into markets that are traditionally monoacetate or for use with blends such as Virginia which are sometimes considered to be less compatible with carbon. In production, **fig 24**, the filter would normally have a gap of around 5 mm 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 the greatest possibility of reduced risk, maximum carbon loading, **fig 25**, may be more important than clean running so 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, **fig 26**, of various fractions of smoke for monoacetate, APF™ and Active Acetate Dual filters (AAD) 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, especially 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. If filters continue to follow the current trend and get longer, the maximum loading of carbon or other granular materials that can be included in the APF™ filter will increase. It is also worth noting that such a filter can often give higher carbon loading for a slim line cigarette product than the traditional active acetate dual. It can be seen that for either of the carbon filters, the dose of a number of toxicants is reduced compared to the monoacetate filter. Indeed Laugesen and Fowles have speculated that due to the known reductions of many smoke toxicants given by carbon, regulation to require effective charcoal filters is now long overdue (5). Should such requirements become fact, effective mono-carbon filters could be the answer.

In conclusion, **fig 27**, it can be seen that the road to a potentially reduced risk cigarettes could follow many routes. Until the exact nature of a reduced risk product is defined, the final goal will always be difficult. At the moment carbon is still the most effective granular filter additive available. It is expected that the global trend in the tobacco industry will be a continuing reduction of the yields of all compounds in smoke. The filter used will continue to play a major part in this effort and will continue to get longer and probably lower in circumference. It could be that this will involve the more complex filters with one; two or more granular additives used on premium brands as potential reduced risk products. Perhaps mono-filter solutions, which allow reductions in a range of toxicants that may be more readily available and acceptable to a wider range of smokers, may be the way to go. If the use of carbon, **fig 28**, does reduce risk, would changing every brand to a carbon filter bring about a reduction in risk for all smokers? Much research effort is being concentrated on the development of more efficient filters and additives which can be used in them. Future filters may well become more complex, multi-segment devices but an effective monofilter will always have a role to play. As always in the cigarette industry the next few years will bring some very interesting developments.

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