



Filtrona Technology Centre

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The Changing Concerns of Filtration Efficiency

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The role of the filter as a tool for cigarette design is now well established. However, over the last fifty years or so cigarette filters have evolved significantly from the first products used mainly to keep loose tobacco out of smoker's mouths. During this presentation we will look at how filters have evolved and give some predictions on how they may continue to change in the future. The major topics to be covered, as shown in slide 2, are, a reminder on the filtration of tobacco smoke, filter development, legislation and its impact, new cigarette product developments, emerging filter products, future outlook and conclusions. The physical properties of cigarette smoke are now well known but are shown in slide 3. Generally the particle concentration is considered to be between 10^8 and 10^{10} particles per millilitre. The particle size is between 0.1 to 1 micrometer and the particles pass through a filter with a linear velocity of between 35 to 50 cm/sec. Average particle weight is around 4 femtograms (10^{-15}) and the residence time in the filter is between 0.04 to 0.06 seconds. The temperature of the smoke by the time it reaches the filter is between 30 to 90 C. As the smoke passes through the filter, slide 4, its concentration is reduced by a number of mechanisms including particle impaction, adsorption, absorption, chemical effects and condensation. The filter essentially reduces the yields of a wide range of compounds reaching the smoker. Slide 5 shows a photograph of a filter before and after it has been exposed to cigarette smoke. This particular example is a filter containing carbon. As the photograph shows the white fibres of the filter become coated with tar during the retention process. Retention is usually defined as the ratio expressed as a percentage by mass of the particular material retained by the filter to those entering the filter. Traditionally filter retention's have been concerned only with tar and Nicotine but as we will see the retention of

the filter to a wide range of other smoke compounds is becoming increasingly important.

Cigarette smoke actually consists mainly of gases as shown in slide 6. Over 90% of the mass of mainstream smoke are gaseous. It is usually considered to be divided into two phases the vapour phase and the particulate phase. Each of these phases can be further subdivided, the vapour phase into permanent gasses and vapours and the particulate phase into semi-volatiles and non-volatiles. If we consider the filtration of the particulate phase, the major mechanism of reduction of smoke particles is by impaction as shown in slide 7. Generally this mechanism of reduction requires the smoke particles to strike a filter fibre and be retained. Three main types of impaction are thought to occur. These are direct interception, inertial impaction and diffusional deposition. Other effects such as electrical effects or gravitational settling are thought to be negligible. As seen in, slide 8, the filtration of smoke by impaction is the major mechanism for tar and Nicotine reduction. But impaction only removes smoke particles and hence has very little effect on gas or vapour phase compounds such as volatile aldehydes, volatile hydrocarbons and volatile ketones. However, other commonly used filter materials such as carbon work by adsorption. This is a different mechanism to that shown by fibrous filter elements and does allow the removal of vapour phase compounds. Under high magnification the pore development of carbon is clearly visible appearing like a porous sponge, slide 9. This high concentration of pores in a small physical volume produces a material with a high internal surface area. This large surface area gives carbon its unique ability to adsorb compounds from the smoke. Generally the compound to be adsorbed contacts the carbon and diffuses into the internal pore structure, slide 10. The internal surface area of the carbon exhibits weak forces, which lock the compound in to the pore structure. Thus carbon adsorbs the compound. In practise in a filter the different mechanisms of removal means that carbon and cellulose acetate gives different filtration properties when different fractions of smoke are considered. Slide 11, shows a comparison of the retention of a number of vapour phase compounds for both carbon and a monoacetate filter. The difference is obvious with the carbon retaining much higher amounts of the example vapour phase compounds shown. The carbon would also retain much more of a range of other vapour phase compounds in smoke. If however, compounds from the semi-volatile fraction of the smoke are considered, slide 12, the difference between the two is much smaller. The

main effect of adding carbon to a cigarette filter is to increase the retention of a wide range of vapour phase and semi-volatile materials.

Following filter development over the last fifty years or so we would see, slide 13 that early filters were mainly used to keep loose tobacco out of smoker's mouths. As the role of the filter developed it became a tool for adjusting the tar and nicotine yields of the cigarette by using higher or lower retention efficiency. As cigarette tar yields fell higher retention efficiencies were required and more complex filters with higher retention capabilities were used. Filters with granular additives especially carbon, initially used in Japan, became more common. Filters have also been used as flavour carriers. A long-standing goal of the industry to be able to combine filters containing flavours with activated carbon may soon be realised. If we look at the progression of filter development chronologically but not necessarily in exact order from about 1950 we can see, as shown in slide 14, that initially monofilters only were used. These monofilters were either paper or acetate although acetate quickly became established as the major filter material. The first commercial brand to use a monoacetate filter was launched in 1952. One of the first innovations was the use of dual filters allowing two different materials to be used in series in the same filter. Of course once dual filters were developed, the use of carbon was possible, as carbon needed to be placed in a filter away from the mouth end of the product. Triple filters allowing carbon to be placed in a cavity between two filter segments quickly followed. Probably at this time ventilation started to emerge as a method of yield reduction and offered an alternative to filtration only as a method of reducing cigarette yields. As markets became more sophisticated shaped filters were used. These were initially for product differentiation but are often currently used for their anti-counterfeit properties. As cigarette yields continued to fall, higher retention filters at acceptable pressure drops were required and monofilters with higher levels of retention at the same pressure drop as a monoacetate filter became available. One such example which is still going strong today is the Filtrona combined performance filter (CPF) introduced in the late seventies which gives up to 10% extra tar and Nicotine retention when compared to a monoacetate filter at the same pressure drop. Filters also began to be used as flavour carriers for mainly mentholated products. Further developments have seen the introduction of recess filters, which have proved particularly successful in Eastern Europe. More complex filter constructions also became available with the introduction of dual filters with the two-filtration media in

parallel rather than series. Recent developments have by and large concentrated on reduced exposure products and have, as we will see later, seen the introduction of more selective filtration products such as Ion Exchange Resins in new cigarette launches. Other newer filter developments will be discussed later.

Of course the development of new products can be driven by consumer preference or by legislation and legislation has changed significantly over the last few years. Early legislation, slide 15, was usually confined to maximum tar yields. In some countries a requirement would exist to print tar and Nicotine yields on the packets. But it was very rare for legislation to be concerned with other smoke analytes and even then only Carbon Monoxide was considered with the requirement to print values on the packets. Taking Europe as an example, slide 16, the maximum tar yield permitted has fallen from 15 mg in 1993 to 12 mg in 1998. New regulations in 2004 will reduce the maximum tar yield to 10 mg. But for the first time Nicotine and Carbon Monoxide will be covered by the regulations with maximum levels of 1.0 and 10 mg respectively. Further regulations are possible in the future but the current regulations include advertising bans. Also as shown in slide 17, the regulations will prevent the use of descriptors such as light and mild. The current regulations would also allow member states to require in addition to the basic testing of tar, Nicotine and Carbon Monoxide that manufacturers or importers test the yields of other substances produced by their tobacco product. In addition the directive also requires manufacturers to supply the government annually with a list of all ingredients used in the manufacture of their products by brand name.

In other parts of the world regulations sometimes still only cover the maximum cigarette yields. For example, in other parts of Europe the maximum permitted yields are Poland tar 12 mg, Nicotine 1.2mg, Russia tar 14 mg Nicotine 1.2 mg for filtered cigarettes. Many other European countries also have regulations on maximum tar and Nicotine yields. For the America's, slide 18, only Brazil has regulations covering maximum yields with the values of 10, 1.0, 10 for tar, Nicotine and Carbon Monoxide respectively being introduced earlier this year. Neither the USA nor Canada has regulations covering maximum yields but as we will see later, Canada has regulations covering the measurement and reporting of many compounds in smoke. In the Asia region tar yields tend to be slightly higher, slide 19, the maximum permitted tar values for Malaysia and Hong Kong being 20 mg and 17 mg respectively. Many Asian countries do not have legislative limits such as India,

Japan and Korea. China the biggest cigarette market in the world is only covered by a voluntary agreement with the current maximum tar value being 15 mg. Again a reduction program is in place with a target to reduce tar to 12 mg by 2005. Other countries like Australia and the Gulf states have regulations covering all three of the major analytes, that is tar, Nicotine and Carbon Monoxide in smoke the values being 14, 1.4 and 18 for Australia and 10, 0.6 and 12 for the Gulf States. For the countries that have these types of regulations the trend seems to be to reduce maximum yields to between 10 to 12 mg for tar and 1.0 to 1.2 mg for Nicotine.

As mentioned earlier regulations also exist in some countries covering the requirement to measure and report a wide range of compounds in smoke on an annual basis. This is mainly, as shown in slide 20, in Canada and Brazil where the requirement is to measure and report around 40 to 44 compounds in mainstream and sidestream smoke on an annual basis. The Canadian regulations also require this testing to be carried out using two smoking regimes and to print on the packet values for tar, Nicotine, Carbon Monoxide, Hydrogen Cyanide, Formaldehyde and Benzene measured using two smoking regimes. The compounds covered by the Canadian and Brazilian regulations are often referred to as the Hoffmann list of compounds and cover a wide range of materials in smoke from gas/vapour phase compounds through semi-volatiles to non-volatiles. Many of these compounds are irritant, harmful, toxic or potentially carcinogenic.

Time does not allow a full discussion of all of the compounds on this list but some of the major ones are shown in slide 21. These are permanent gasses such as Carbon Monoxide, Hydrogen Cyanide and Nitric Oxide. Organic volatiles consisting of Aldehydes: - Formaldehyde, Acetaldehyde, Acrolein, Propionaldehyde, Crotonaldehyde and Butyraldehyde, Hydrocarbons: - Isoprene, 1,3 Butadiene, Benzene and Toluene, Ketones: - Acetone and Methyl Ethyl Ketone. Semi-Volatile Bases, Pyridine and Quinoline. Phenolic compounds: - Phenol, Cresols, Hydroquinone, Resorcinol and Catechol. Non-Volatile compounds include the Tobacco Specific Nitrosamines: - NNN N-nitrosornicotine, NNK 4-(N-nitrosomethylamino)-1-(3-pyridyl)-1-butanone, NAT N-nitrosoanatabine and NAB N-nitrosoanabasine. The Aromatic Amines: - 1 and 2 Aminonaphthalene and 3 and 4 Aminobiphenyl. Benzo[a]Pyrene is also among the compounds listed. The Hoffmann list has focused attention on these compounds and lead to a drive to reduce these compounds in smoke, slide 22. Often cigarettes with reduced yields of these

compounds are referred to as reduced exposure products. With this type of product the aim is to reduce the yield of all of the compounds on the list when compared to standard products. Of course this is an extremely difficult task as the compounds are widely different in physical and chemical properties and range from an inert gas like Carbon Monoxide to reactive vapour phase compounds like Formaldehyde through to inert non-volatile compounds such as Benzo[a]Pyrene. Therefore, it is extremely unlikely that a single filtration medium will be effective for all of the compounds listed. Many of the semi-volatile and non-volatile chemicals are part of tar and removed by standard filter components such as acetate and as we have seen earlier the addition of carbon can increase the range of products removed. A very large amount of research work has been carried out on the selective reduction of these compounds in smoke. One consequence of the drive to remove these compounds has been a large increase in interest in the use of carbon in filters often in markets not traditionally associated with the use of carbon.

A number of reduced exposure cigarettes have already been launched, slide 23, and these have used either carbon or carbon in combination with other granular filter additives. Slide 24, shows two examples, the Omni brand, which uses a triple cavity filter using carbon and the Advance brand. The Advance brand employs a triple solid filter and is the first to use an Ion Exchange Resin. The smoke as it elutes from the tobacco column passes first through the segment containing the ion exchange resin, then through a segment containing carbon and finally through an acetate mouth piece. The Advance brand has a pack insert that compares the yield of many compounds on the Hoffmann list with those for other leading brands at similar tar yields.

Of course as well as the brands already launched much work on new filter types is being carried out, Slide 25, to help meet the future needs to reduce these compounds. Such filters include the Active Patch Filter (APF) the first commercial mono-carbon filter, the Hydrogen Cyanide reducing filter which is highly selective towards Hydrogen Cyanide and the COR filter that allows to use of ventilation to reduce permanent gasses, for example Carbon Monoxide, but still gives a cigarette with acceptable tar levels and draw resistance.

Looking at these products in more detail, a diagram of the active patch filter is shown in slide 26. As previously stated, slide 27 it is the first commercially available mono-carbon filter. Taste testing has produced some interesting results in that this filter

seems to give a taste more akin to monoacetate filters than to carbon filters. This makes it an ideal vehicle to introduce carbon into traditional monoacetate markets without the necessary adaptation to carbon taste. As shown in slide 28 the filter uses standard plugwrap on to which is printed a patch of carbon. As standard plugwrap is used the cigarette would be non-ventilated but ventilation via an online laser is possible. With this process carbon loading of 2.9 mg per mm of patch length can be achieved. Adjusting the length of the patch varies the carbon loading. Normally a 5-mm carbon free zone is left at the mouth end of the filter and a 3-mm carbon free zone at the tobacco end. Therefore for a 25-mm length filter a carbon loading of 45 to 50 mg can be achieved. The main advantages of this filter, slide 29, are the reduction in vapour phase and semi-volatile yields when compared to an equivalent monoacetate filter. Also during cigarette manufacture this is a clean run filter, that is, no carbon segments need to be cut during secondary manufacture. Slide 30 shows a comparison of the yields of various groups of compounds for an active patch filter with about 50 mg carbon loading compared to an equivalent monoacetate filter. As probably expected from the presence of carbon the difference is mainly seen in the volatile and semi-volatile compounds. Thus the active patch filter will give lower levels of Hydrogen Cyanide and volatile Aldehydes, Hydrocarbons and Ketones. Smaller reductions are also seen in semi-volatile bases and phenols. Another approach to overall yield reduction is selective filtration. That is using a filter additive that selectively removes an individual compound or group of compounds that are known to be toxic. One such compound that has been targeted for removal is Hydrogen Cyanide. The HCN filter, slide 31 utilises a special impregnated carbon to increase its removal of Hydrogen Cyanide. This is the first commercially available filter that specifically targets the removal of a single toxic compound in smoke. The carbon is essentially the same as standard coconut shell carbon in physical properties and as such can be used in any current carbon filter. Two examples are shown in slide 32 the active acetate dual filter and the triple granular filter. In some ways this filter, slide 33, is not a truly selective filter as it retains carbon's normal ability to remove a wide range of compounds from smoke. In general the activity of this material to the majority of compounds in smoke is the same or slightly higher than standard coconut shell carbon apart from its greatly enhanced performance in reducing Hydrogen Cyanide. An added bonus to the properties of this material is that the activity of the filter towards Hydrogen Cyanide only changes slightly with storage

as a filter or cigarette. Slide, 34 shows a comparison of the removal of a range of vapour phase compounds for equal weights of standard coconut shell carbon and the new 'special carbon'. As can be seen from the plot the percentage retention's are quite similar except for Hydrogen Cyanide where the special carbon removes over 80% compared to around 30% for the standard material. The next slide 35 gives a plot of the ageing characteristics over a six-month period for the carbon. The overall vapour phase retention (average retention value for 12 main VP compounds) shows the normal reduction in activity with time found for carbon filters from about 50% retention initially, falling to around 30% retention after six months. But in the same period the retention of Hydrogen Cyanide only falls from just over 80% to approximately 76%.

To date we have only considered the use of fibrous or granular materials to reduce compounds in smoke. As shown in slide 36 fibrous materials are effective at reducing tar and nicotine and highly retentive filters can be produced. Carbon will reduce the majority of vapour phase materials but neither of these materials reduce permanent gasses such as Carbon Monoxide or Nitric Oxide. The only current way to reduce these gasses is via ventilation. As shown in slide 37 the problem is that high levels of ventilation with high pressure drop/high retention filters produces very low tar cigarettes. Whereas, the use of high levels of ventilation with lower pressure drop/lower retention filters may produce acceptable tar levels but this is usually at an unacceptably low cigarette draw resistance. The requirement is to produce a high pressure drop but low retention filter. This can then be used in a ventilated cigarette to give lower Carbon Monoxide yields at acceptable cigarette draw resistances. Such a product would also deliver reduced levels of Nitric Oxide and many other vapour phase compounds. A diagram of the filter is shown in slide 38. It has been designed as a triple filter with an acetate mouth end an empty cavity and a tobacco rod end segment of acetate slide 39. The tobacco rod acetate segment is low-pressure drop low retention but the mouth end segment is high-pressure drop, approximately 70 mm for an 8-mm length segment, low retention. Using this filter, slide 40, allows reduction of Carbon Monoxide relative to tar for a cigarette with an acceptable draw resistance even at high ventilation levels. Of course carbon could be added to the cavity to enhance further the reduction of vapour phase materials. A comparison of the yields of a number of gas/vapour phase compounds is given in slide 41. This comparison is for a cigarette with a draw resistance of 100 mm and a tar yield of 8

mg. The reduction in yield of the cigarette using the COR filter is expressed as a percentage of the yield of a cigarette with a standard design. From the plot it can be seen that significant reductions of a wide range of compounds are given.

At this point in time we can see that a wide range of filter products have been developed over the last 50 years or so but what of the future? As slide 42 shows the trend towards lower yield products now seems firmly established. Because of this the use of carbon will be expected to increase in the future. Other filtration medium such as ion exchange resins and selective carbons, for example, will become increasingly common in the future. Perhaps catalysts and other selective adsorbents will also have a role to play. Probably new products will combine these new materials with the traditional properties of carbon. Looking at the developments of the last few years an interesting time awaits us all in the future.

In conclusion slide 43 over the last 50 years we have seen the use of filters grow to over 95% of the current cigarette market. The early relatively simple monofilters are being increasingly replaced with more complex filters. Current filters are generally longer and have higher retention capabilities compared to those of 50 years ago. The complexity of filters is expected to increase and we may see filters in 50 years time that are multi-segment filters utilising many different filtration materials which are degradable.