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Filter Innovations for Lower Yield Cigarettes

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A major global trend throughout the cigarette industry is the drive for lower yield products. In some areas this is by consumer preference and in some the trend is driven by regulation. The role of filters in the reduction of cigarette yields has been recognised for many years and a wide range of filters has been developed to reduce the yields of cigarettes. The majority of filters such as monoacetate are mainly used to reduce the yields of tar and nicotine but other filter types such as those containing carbon are used to reduce the yields of other smoke components. Of course it is not simply a matter of using higher pressure drop/higher retention filters to reduce yields, the filter must maintain the balance between draw resistance, taste and impact. The filter must also be applicable to the blend of tobacco it is to be used with. Some filter types will produce a better-balanced cigarette when used with a particular tobacco blend than when used with other types of tobacco.

The requirements governing maximum yields can be divided into two major areas' those covered by voluntary agreement and those governed by regulation. **Figure 1** gives some examples of the voluntary agreements in place the most important being that in China the worlds biggest cigarette market. Regulations can be subdivided into three main areas those with maximum tar and/or nicotine yields, those with maximum yields for tar, nicotine and Carbon Monoxide and those requiring the measurement and reporting of a wide range of compounds in smoke. Countries with regulations covering tar and/or Nicotine are shown in **Figure 2** and these include, for

Country	Tar	Nicotine	CO
China	15	N/A	N/A
Indonesia (White Cigarettes)	25	2.2	N/A
Australia	14	1.4	20

N/A = No Agreement

Figure 1. Voluntary agreements

Country	Tar	Nicotine
Russia	14	1.2
Czech Republic	12	No
Poland	12	1.2
Switzerland	15	No
Hungary	15	1.8
Malaysia	20	1.5
Hong Kong	17	No
Vietnam	24	2.2

Figure 2. Tar and/or nicotine

example, Hong Kong with a maximum tar yield of 17mg and Malaysia with a maximum tar yield of 20 mg and maximum Nicotine yield of 1.5 mg. **Figure 3** shows countries with regulations covering tar, Nicotine and Carbon Monoxide. A number of countries such as the European Union, Norway (starting at the beginning of 2004) and Brazil have maximum yield limits of 10:1:10 for tar, Nicotine and Carbon Monoxide respectively. In other parts of the world regulations exist to measure and report a wide range of compounds in smoke, that are considered to be harmful, often referred to as the Hoffmann list, on an annual basis. These countries are shown in **Figure 4**.

Country	Tar	Nicotine	Carbon Monoxide
European Union	10	1.0	10
Norway	10	1.0	10
Brazil	10	1.0	10
Gulf States	12	0.6	10

Figure 3. Tar, nicotine and Carbon Monoxide

With this clear trend in product yield reduction of all smoke compounds the cigarette designer is faced with producing a cigarette that is acceptable to the consumer but with lower and lower yields while trying to maintain product taste and acceptability. Obviously the filter has an important role to play in the cigarette design. In general four methods of yield reduction are available. These, shown in **Figure 5**, are: - increasing filter retention to reduce tar and nicotine, using carbon to remove organic volatile materials by adsorption, using a selective agent to reduce a specific compound or group of compounds, or using ventilation to reduce all smoke components. Ventilation is the only current practical method to reduce Carbon

- **In Brazil and Canada need to measure and report on an annual basis**
 - **Tar, Nicotine, CO, Smoke pH and filter Nicotine retention**
 - **Inorganic gases - Ammonia, Hydrogen Cyanide and Nitric Oxide**
 - **Carbonyls e.g. Formaldehyde, Acetaldehyde etc**
 - **Miscellaneous Organics e.g. Benzene, Isoprene, Pyridine, Quinoline etc**
 - **Phenolic Compounds e.g. Phenol, Cresols etc**
 - **Tobacco Specific Nitrosamines**
 - **Aromatic Amines**
 - **Benzo [a] Pyrene**
 - **Metals (Canada only)**
- **In mainstream and sidestream smoke and using two smoking regimes (Canada only).**

Figure 4. Other regulations

- **Increase filter retention to reduce tar and nicotine**
- **Add carbon to reduce a wide range of compounds, mainly the organic volatiles**
- **Add a selective reagent for reduction of a specific compound or group of compounds**
- **Use ventilation to reduce all smoke components but especially permanent inert gases such as Carbon Monoxide**

Figure 5. Yield reduction methods

Monoxide yields in cigarettes. However, it is not simply a case of increasing filter retention – which normally increases cigarette draw resistance – to give the required tar and Nicotine yield; or of adding large amounts of carbon to reduce organic volatiles; or of increasing ventilation levels – which reduces cigarette draw resistance – to give the required carbon monoxide yield. The filter used must be compatible with the overall cigarette design and tobacco blend to give an acceptable final product. To give higher tar and Nicotine reductions than a standard filter at the same pressure drop some filter options do exist. A filter that is being used on many brands in China perhaps because of its compatibility with the tobacco blends used is the CPF filter.



Figure 6. The different orientations of the CPA filter with the flute at the mouth end (left) and at the tobacco end (right)

This filter is shown in **Figure 6** and consists of a cellulose acetate filter wrapped with a partially fluted special paper. The flutes can be orientated so they are at the tobacco end of the filter or to the mouth end of the filter, as shown in **Figure 6**. The main advantage of this filter is the crossflow filtration achieved by the special fluted paper that increases the retention of the filter when compared to a cellulose acetate filter at the same pressure drop, sees **Figure 7**. This increase in retention can be up to around 10% and a plot of a comparison of the retention of a CPF with that of a cellulose acetate filter is given in **Figure 8**. An example of how such a filter can be used in a tar reduction program while maintaining a relatively constant cigarette draw resistance is shown in **Figure 9**. For example, if the requirement were to reduce the tar yield of a 15 mg cigarette to around 12 mg without a significant increase in cigarette draw resistance, the best procedure would be to achieve the reduction in 3 or 4 steps.

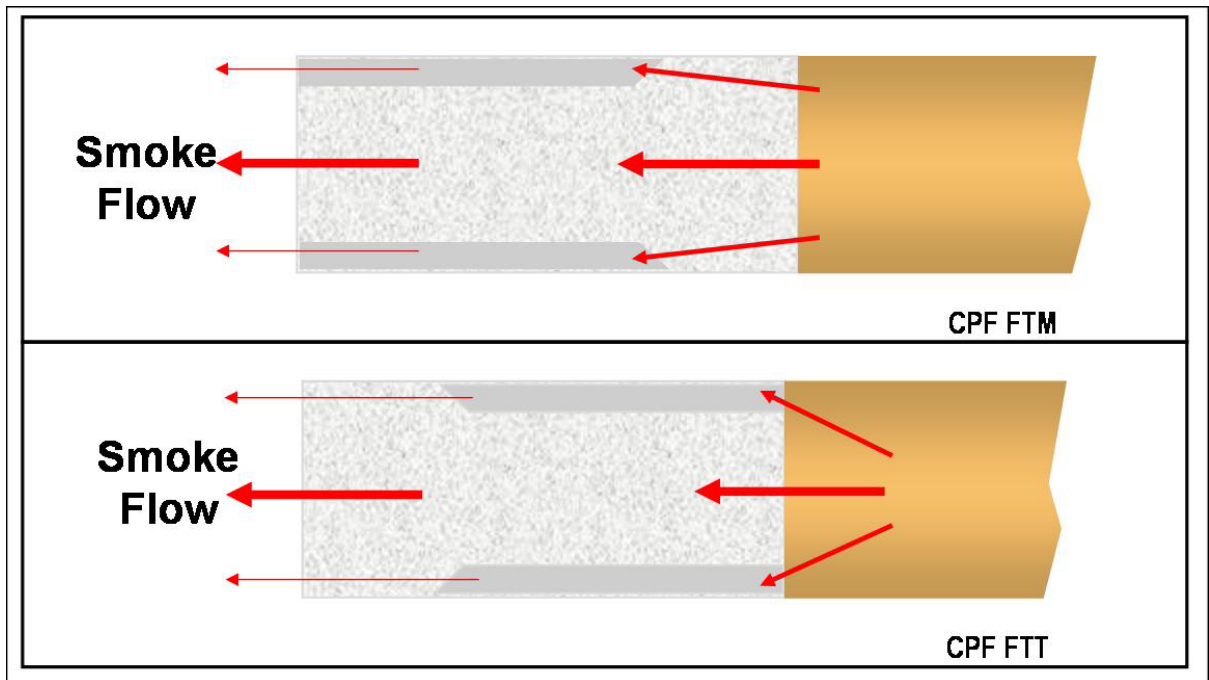


Figure 7. Combined Performance Advanced filter smoke flows

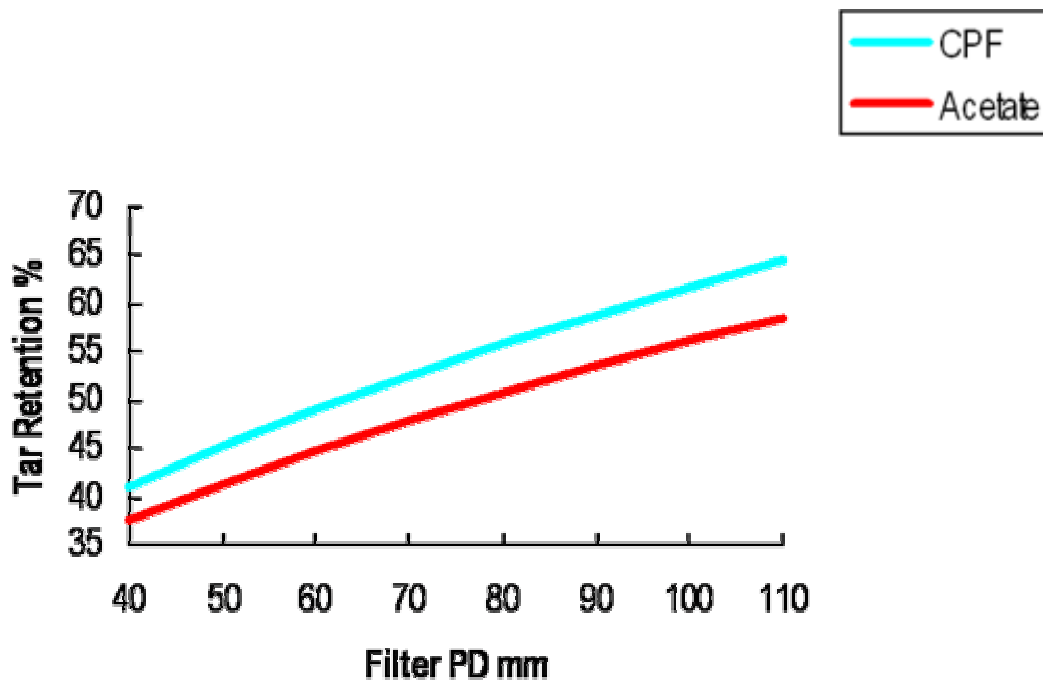


Figure 8. Tar retention of Combined Performance Advanced filter compared with MonoAcetate

Filter Type	Filter PD mm	Cigarette DR mm	Tar mg	Nicotine mg
Acetate Current	65	115	15.2	0.97
CPF 1	62	112	13.7	0.89
CPF 2	70	120	12	0.75
Acetate Equivalent	92	142	12.1	0.76

Figure 9. Combined Performance filters



Figure 10. Cigarettes with Combined Performance filters

The table in **Figure 9** shows two of the steps with the CPF filter finally achieving the 12 mg tar yield target at approximately the same cigarette draw resistance. It should be noted that to achieve the 12 mg target with a standard cellulose acetate filter would require an increase in cigarette draw resistance to a level that some consumers may find unacceptable.

Using the flutes to the mouth end of the cigarette to give a unique appearance has also been used with this type of filter to provide brand differentiation. This approach has also helped in anti-counterfeiting. A photograph of the end appearance of the cigarettes is given in **Figure 10**.



Figure 11. Combined Performance filters with coloured inner plugwrap

It could be claimed that the CPF filter is not a recent novel innovation as it has been successfully used on cigarettes for many years and has been especially successful on cigarettes using flue cured Virginia style tobacco blends. However recently much work has been carried out on this product which has led to new innovations, namely the third generation of CPF products. Among these has been the use of coloured innerwraps, which greatly enhances the novel appearance, and hence anti-counterfeiting benefits of this product. **Figure 11** shows some examples of the recent developments, which are still being developed, but are, hoped to be available shortly. The CPF filter has also recently been constructed with a flavour delivery system to allow the extra retention to be used in conjunction with flavour release. An example of this type of filter is shown in **Figure 12**. Another development of this filter has been its use as a segment in a dual filter product. This allows a combination with, for example, a traditional Active Acetate Dual filter to give a product a distinct appearance for brand differentiation while simultaneously utilising the properties of



Figure 12. Combined Performance Advanced filter with flavour thread



Figure 13. A Combined Performance segment combined with an Active Acetate segment

carbon and increased retention efficiency of the CPF filter. An example of such a filter is shown in **Figure 13**.

The use of carbon in cigarette filters is another area where much work on new filter types is being carried out. This is because of the ability of carbon to remove many compounds from smoke that are not affected by other filter materials. The complexity of smoke makes it difficult to describe the effect of carbon on smoke in a short period of time. However, if we consider a number of important compounds from smoke covering the full range of smoke components: - permanent gasses, organic volatiles, semi-volatiles and non-volatiles it is possible to compare the filtration by carbon with that of cellulose acetate. **Figure 14** shows the compounds selected from each of the fractions of smoke to illustrate the comparative performance of the different types of filtration and filter medium. These are permanent gasses Carbon Monoxide and Hydrogen Cyanide. Organic Volatiles such as Aldehydes, Hydrocarbons and Ketones. Semi-Volatiles such as Bases and Phenols and non-volatiles such as Tobacco Specific Nitrosamines, Aromatic Amines and Benzo[a]Pyrene.

- **Permanent Gasses - Carbon Monoxide and Hydrogen Cyanide**
- **Organic Volatiles - Aldehydes (Formaldehyde, Acetaldehyde, Acrolein, Propionaldehyde, Crotonaldehyde and Butyraldehyde), Hydrocarbons (Isoprene, 1,3 Butadiene, Toluene and Benzene), Ketones (Acetone and Methyl Ethyl Ketone).**
- **Semi-Volatiles - Bases (Pyridine and Quinoline) and Phenols (Phenol, o, m & p-Cresol, Hydroquinone, Resorcinol and Catechol)**
- **Non-Volatiles - Tobacco Specific Nitrosamines (NNN, NNK, NAT and NAB), Aromatic Amines (1&2 Aminonaphthalene, 3&4 Aminobiphenyl) and Benzo[a]Pyrene**

Figure 14. Important smoke compounds

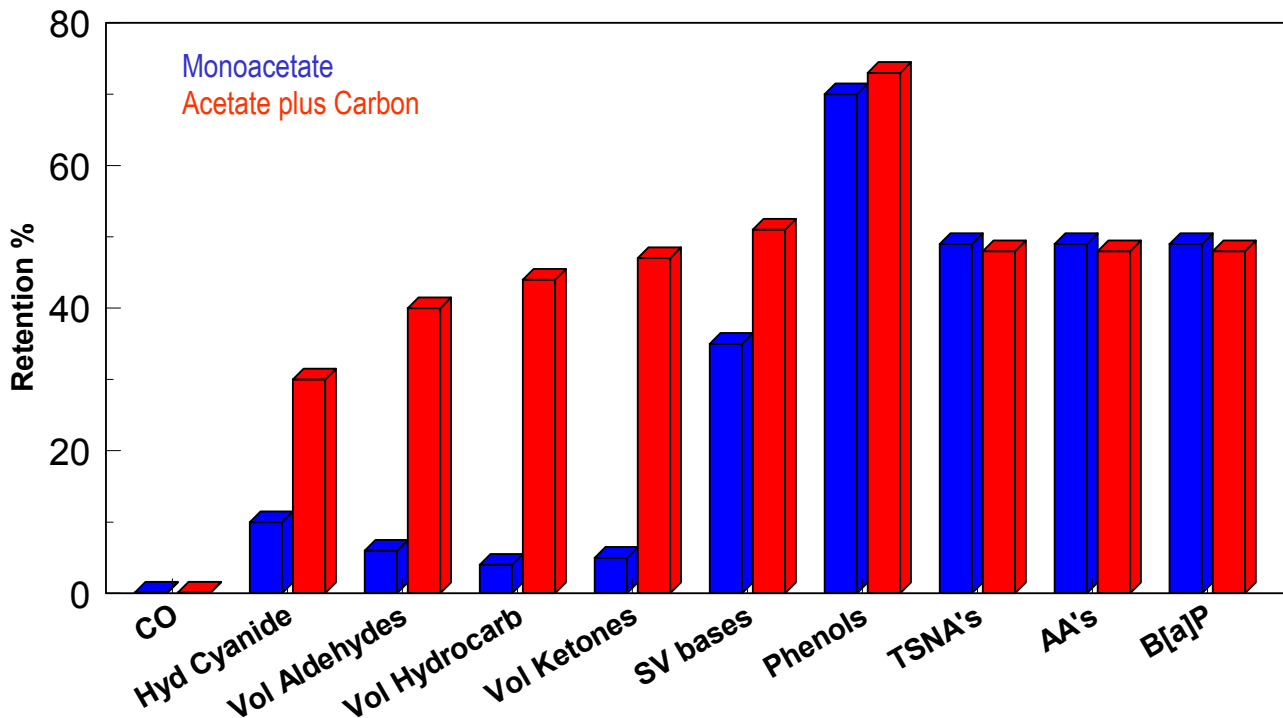


Figure 15. Retention MonoAcetate versus Acetate plus carbon

The plot in **Figure 15** gives such a comparison for a cellulose acetate filter with approximately 50% tar retention and a cellulose acetate plus carbon filter of the same tar retention with about 60 mg of carbon per filter. From the plot it can be seen that neither material has any effect on permanent gasses such as Carbon Monoxide but that carbon does give some retention for compounds such as Hydrogen Cyanide. Cellulose acetate has very little effect on volatile aldehydes (e.g. Acetaldehyde and Acrolein), volatile ketones (e.g. Acetone and Methyl Ethyl Ketone) or volatile hydrocarbons (e.g. Benzene and Toluene). Carbon on the other hand gives a significant reduction in these types of compounds, many of which are on the Hoffmann list of chemicals in smoke. For semi-volatile bases (e.g. Pyridine and Quinoline) it can be seen that although cellulose acetate gives some retention of these compounds the removal by carbon is much higher. As the boiling point of the compounds under consideration increases, the removal by cellulose acetate increases. Thus it can be seen that for phenols the removal by cellulose acetate is now higher than the overall tar retention of the filter. Again the use of carbon helps to increase the retention but this increase is now much smaller than seen for the volatiles. Once non-volatile are considered (Tobacco Specific Nitrosamines, Aromatic Amines and Benzo[a]Pyrene) it can be seen that the retention of these

types of compounds is very near the overall tar retention. This is because non-volatile materials are filtered by mechanical impaction only and thus cannot be selectively removed from cigarette smoke. Much research work is currently on going on the selective removal of volatile compounds and filter innovations in the near future (2004) will include special filters for the removal of some of these compounds. Carbon has been used in cigarette filter for many years and its use is increasing worldwide.

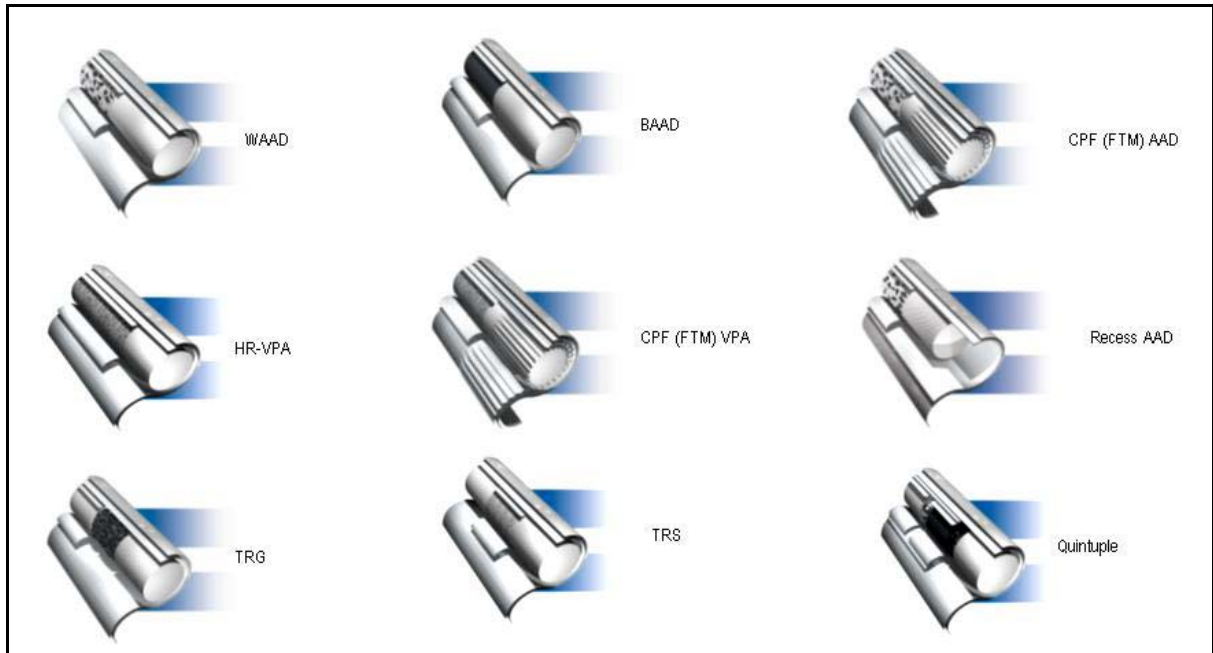


Figure 16. Filters with granular material

However, all current carbon filters use multiple filter segments with the carbon being held in the inner segments of the filter. **Figure 16** gives examples of some of the range of carbon filters currently available. Some examples are the traditional active acetate dual, the triple solid filter or the triple granular filter. A new type of carbon filter is available and will be the first mono carbon filter produced. This is the Active Patch Filter (APF) and consists of a patch of carbon printed on the inner surface of a standard plugwrap on a monoacetate filter. This is shown in **Figure 17**. The filter is a single segment filter wrapped in a plugwrap to which granular activated carbon has been applied. Other granular adsorbents can be added to the plugwrap such as silica gel or sepiolite or a selective filtration medium. **Figure 18** gives the main parameters of filter construction. The preferred additive would be an activated carbon on a standard plugwrap. The carbon loading is about 2.9 mg per mm of filter



Figure 17. The mono-carbon Active Patch™ filter

- **Standard plugwrap for non-ventilated cigarettes.**
- **Carbon Loading 2.9 mg per mm of filter length.**
- **Five mm carbon free zone at the filter mouth end**
- **Three mm carbon free zone at the filter tobacco rod end**
- **Carbon loading up to 50 mg per filter**

Figure 18. Active Patch™ filter parameters

- **Higher reductions of vapour phase and semi-volatiles when compared to monoacetate.**
- **Clean run filter - No cutting of carbon segments during cigarette manufacture or filter transport**
- **Can be used to introduce activated carbon into a traditionally monoacetate market without the necessary adaptation of carbon taste**

Figure 19. Active Patch™ filter features

length and carbon loading is controlled by patch length. Normally a carbon free 5 mm length on plugwrap is left at the mouth end of the filter and a 3 mm carbon free length is left at the tobacco rod end of the filter. Therefore, for a 25 mm length filter a carbon loading of up to 50 mg can be achieved with an unventilated cigarette. Future versions of this filter may allow for ventilated cigarettes. **Figure 19** gives the main features of this filter. These are higher reductions in vapour phase and semi-volatile components when compared to an equivalent monoacetate filter. The APF is also a clean run filter so that no carbon-bearing portions of the filter are cut through during cigarette manufacturing. A unique property of this filter is that it does not give the same taste usually associated with carbon filters. It has been said that the taste of this product is quite similar to monacetate filters. This makes the filter ideal to introduce activated carbon filters into a traditionally monacetate market without the necessary adaptation to carbon taste. But this filter may still give the benefits of carbon in that it can help the taste of certain grades of tobacco. The taste benefits of this filter may make it ideal for the introduction of carbon into markets using mainly Virginia flue cured tobacco.

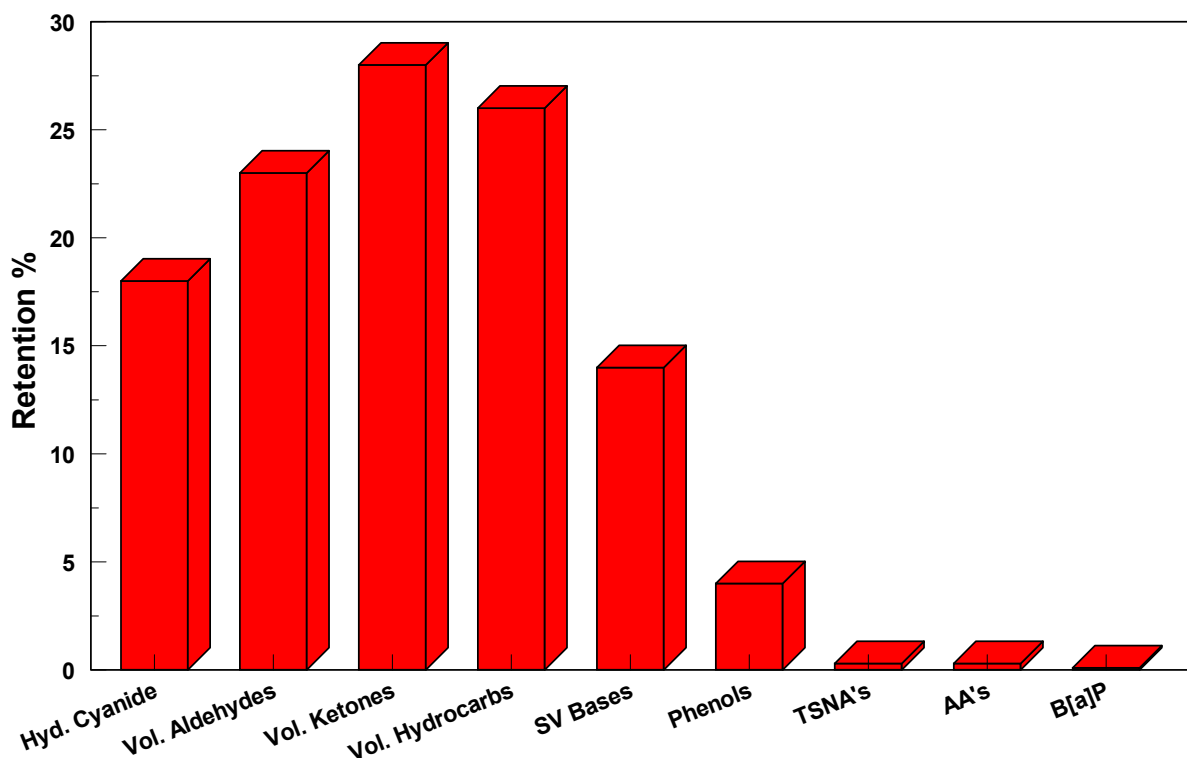


Figure 20. Increase in retention for Active Patch™ filter versus MonoAcetate

Figure 20 shows a comparison in performance between an active patch filter and a monoacetate filter. The main differences are seen as an increase in the retention of Hydrogen Cyanide, Volatile Aldehydes, Volatile Ketones, Volatile Hydrocarbons and Semi-Volatile Bases. The retention's of Tobacco Specific Nitrosamines, Aromatic Amines and Benzo[a]Pyrene are similar for both types of filter.

As we have seen earlier Carbon Monoxide is a compound that is increasingly being included in regulations governing the maximum yields of cigarettes. Also, carbon monoxide is not reduced by the use of standard filters or by carbon. In cigarette smoke Carbon Monoxide is formed by the thermal decomposition and incomplete combustion of many of the components of tobacco. Carbon Monoxide is an odourless colourless gas that is extremely toxic. The toxic effects of carbon monoxide are relatively well known the most important being its ability to combine with haemoglobin in blood to form carboxyhaemoglobin, more readily than Oxygen, to disrupt the normal oxygen supply to blood tissues. At this point, in time the only practical way of reducing carbon monoxide in smoke is by the use of filter ventilation. In general ventilation will reduce the cigarette draw resistance and the yields of all smoke components including tar and nicotine. Filtration for the majority of filters will reduce mainly tar and nicotine. To achieve a highly ventilated cigarette with an acceptable draw resistance a filter with a high-pressure drop is required. But if, for example, a cigarette with a high level of ventilation is combined with high-pressure drop/high retention filter the result will be a very low tar yield and low taste cigarette. If it were possible to use only ventilation to reduce (for example an empty tube with 50% ventilation) cigarette yields a cigarette with 50 % ventilation but no filtration would probably have a reduction profile as shown in **Figure 21**. The major difference for this plot with those shown earlier is the much larger Carbon Monoxide reduction than previously shown. If this data is combined with that for different filter types it is possible to compare the removal achieved by 50% ventilation with that for 50 % tar retention and for 50% tar retention combined with carbon. This is shown in **Figure 22**. As previously stated the plot clearly demonstrates that ventilation is the only current practical method of reducing Carbon Monoxide. Ventilation also reduces other gas/vapour phase compounds much more effectively than cellulose acetate filters and for the levels of ventilation and carbon considered here more effectively than carbon. Of course if lower levels of ventilation and higher carbon loading were

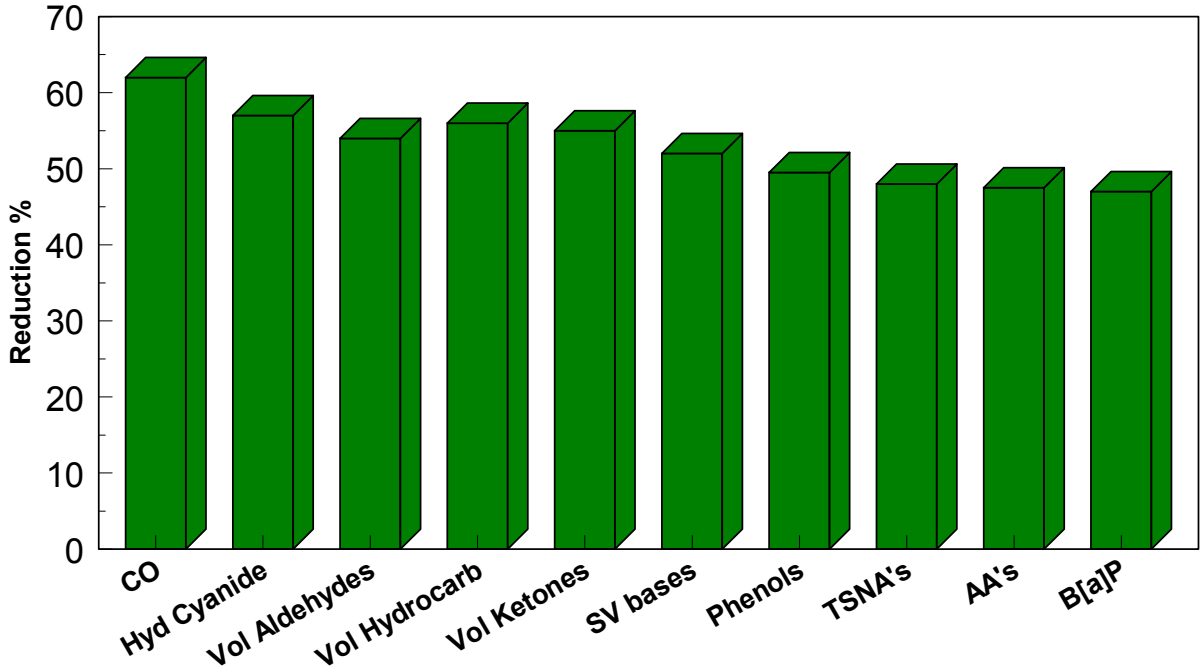


Figure 21. Yield reduction for 50% ventilation

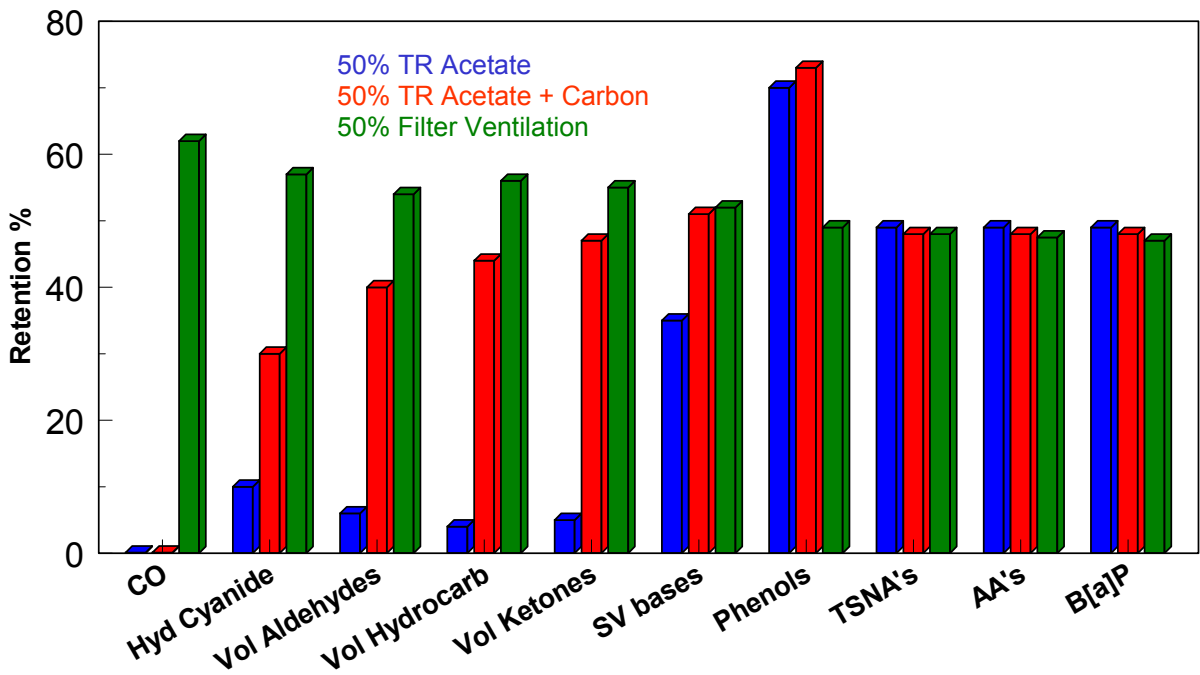


Figure 22. Comparison of yield reduction methods

considered carbon would be seen to be the most effective for removing volatile organic compounds. To utilise the effect of ventilation to reduce carbon monoxide but to produce a cigarette with an acceptable draw resistance and tar yield a filter with a high-pressure drop but low tar and Nicotine retention is required. **Figure 23** shows how filter tar/Nicotine retention can be reduced. The methods of reducing retention for a filter of a particular pressure drop include reducing filter length, increasing filament denier, and reducing filter circumference or the use of novel materials with high-pressure drop and low retention. A number of new novel filter constructions that meet the high-pressure drop low retention criteria are now available.

- **The requirement is for a High PD / Low Retention Filter**
- **Retention for a specified PD can be reduced by:**
 - **Reduced Filter Length**
 - **Increased Filament Denier**
 - **Reduced Filter Circumference**
 - **Novel materials with High PD / Low Retention properties**

Figure 23. Carbon Monoxide reduction

To illustrate the effect of the filter on the overall cigarette yields and especially the ratio of tar to carbon monoxide let us consider designing a possible 10 mg tar yield cigarette, as shown in **Figure 24**, from a 63 mm tobacco column yielding 25 mg tar and 13.5 mg Carbon Monoxide with a cigarette draw resistance around 115 mm Water Gauge (WG). The overall length of the cigarette is 84 mm and thus a 21 mm length filter is required. One possible solution would be to use a filter with a pressure drop (PD) around 80 mm WG and tar retention about 50 %. This would require a filter ventilation of about 20 % to give the tar target and as shown in **Figure 25** the Carbon Monoxide yield would be just over 10 mg. An alternative solution as shown in **Figure 26** would be to minimise retention and maximise ventilation. A filter with a PD of around 30 mm WG with a tar retention of 30 % could be used with 43 % filter ventilation. This would give a 10 mg tar yield with a much lower carbon monoxide yield of around 7 mg but at a much too low cigarette draw resistance, just over 50 mm WG. Such a product would be unacceptable to smokers. However, if a high PD

Cigarette	Target Value
Overall Length mm	84
Tobacco Rod length mm	63
Filter length mm	21
Cigarette DR mm	115
Tar Yield mg/cig.	10
Tobacco Rod	Value
Draw resistance mm	50
Tar Yield mg	25
CO Yield mg	13.5

Figure 24. Cigarette Design

Parameter	Tobacco Rod	Commercial Cigarette
Filter % TR	N/A	50
Filter Ventilation	N/A	20
Cigarette DR mm	50	114
Tar Yield mg/cig.	25	10
CO Yield mg/cig.	13.5	10.3

Figure 25. Carbon Monoxide reduction

Parameter	Tobacco Rod	Commercial Cigarette	Cellulose Acetate
Filter % TR	N/A	50	30
Filter Ventilation	N/A	20	43
Cigarette DR mm	50	114	53
Tar Yield mg/cig.	25	10	10
CO Yield mg/cig.	13.5	10.3	6.9

Figure 26. Carbon Monoxide reduction

Parameter	Tobacco Rod	Commercial Cigarette	Cellulose Acetate	CO Reduction
Filter % TR	N/A	50	30	30
Filter Ventilation	N/A	20	43	43
Cigarette DR mm	50	114	53	110
Tar Yield mg/cig.	25	10	10	10
CO Yield mg/cig.	13.5	10.3	6.9	6.9

Figure 27. Carbon Monoxide reduction

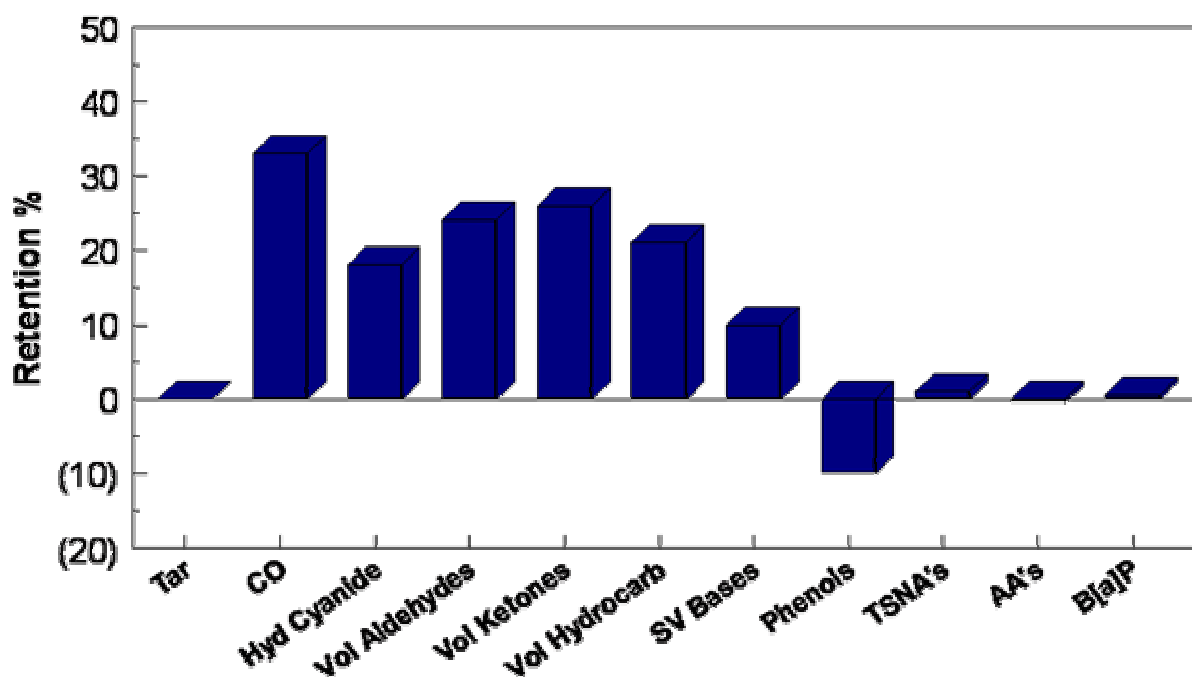


Figure 28. Compound reduction

low retention filter was used with a PD of 90 mm and a tar retention of 30 % the same tar and carbon monoxide yields could be achieved with a much more acceptable cigarette draw resistance. **Figure 27** shows the same table with the data for this type of filter added. The higher cigarette draw resistance is partially caused by the balance of PD within the filter being different to a standard product. As shown earlier of course ventilation reduces other volatile compounds in smoke. A comparison of a standard 10 mg tar yielding product and a 10 mg tar product made with a carbon monoxide reducing filter is shown in **Figure 28**. From the data it can be seen that the high PD low retention filter gives lower amounts of all the volatile compounds in smoke – Carbon Monoxide, Hydrogen Cyanide, Volatile Aldehydes, Volatile Hydrocarbons, Volatile Ketones and many others. Of course the use of carbon would allow reduction of many of the compounds reduced by ventilation to a similar or greater extent except Carbon Monoxide.

In conclusion, we have seen that a wide range of filter options are available to reduce various compounds in smoke. Consumer and legislative requirements are leading to the production of lower yielding cigarettes. This has led to an increase in the use of special filters especially those containing carbon. In future we can expect to see the use of more and more special filters in the global cigarette market. Much research work is being carried on selective filtration media and we can expect to see filters with selective filtration properties being used commercially in the near future.

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