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The Evolution of a Filter Family †

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Abstract

This paper describes the evolution of a filter-family from the early 90's into the new Millennium. Evolution instead of development was chosen, because the process to create a filter-family is like an evolution where the most fitted will survive. In this paper basic information about the filters is presented - the dimensions of the filters and their properties for gas and particle filtration. Also comparisons to older filters and filters of other producers are made and the results are discussed. In house test results as well as results from independent test laboratories are presented.

Introduction

In the beginning of the 90's, in Kemira Safety, we realized that our filters were old and old-fashioned. They were big and bulky, had gas capacities far over the minimum requirements of the new EN standards and had relatively high breathing resistance. However the filters were selling better than ever before, a steady growth of 2-3% per year. So it was not an easy decision, to go for a new filter generation. In the laboratory we started in 1991 to look at suitable filtration media, different types of activated carbon and fibreglass media, canister-materials and production technologies, to see what kind of goal we could set up for our new filter series. In 1992, Kemira Safety was awarded the contract for developing and producing a new NBC-filter for the Finnish military. By combining resources we now had the splendid opportunity to also develop a new filter for the industrial market. In this paper I will discuss the reasons for making the choices we did, with respect to filter dimensions, materials and technologies. The performances of the different end products are compared with older versions and products from other producers. Finally I will show that in a changing world, that development work will never end and the product developer will never come to the "final product!" The headline "evolution" (instead of development) is used because the process is more like an evolution. Because of standards requirements, customer needs, available materials, production technologies and market competition the products are "evolving" and only the most fitted will survive.

Product Family

The first approach was to make one canister for both military use and industrial use. EN standards minimum-requirement and the Finnish army performance specification did not fit together. From the laboratory work we did 1991 we had a pretty good knowledge of what would be achievable and what would not. It was evident that the carbon amount of the military filter had to be reduced to such a small amount, to meet the airflow resistance (30 l/min = 140 Pa and 95 l/min = 500 Pa) with the specified carbon type, that the filter size would not meet EN141 (1) class 2. The army specification specified

resistance to Mustard gas >24 h. That gave us limited choices for canister materials, only aluminum and nylon were realistic. The natural decision was to divide the product range into a military series with canister resistant to mustard gas and an industrial one made of cheaper material.

Filter Dimensions

The dimensions of the filter are of great importance both for the filtration performance and for wearer comfort. A lot of testing was done to get the dimensions right. When a standardized amount of air (30 or 95 l/min) shall pass through an area, the size of the area will affect the airflow resistance and the face velocity, which both are of great importance in a respirator. The phenomenon can be schematically shown as in picture 1. When the area gets bigger resistance and velocity are decreasing, first rapidly but then slower and slower. Finally you reach a level where a big enlargement of the area causes only a small decrease in resistance and velocity. Our measurements show that this point for respirators is in the range of 108-110 mm round filter diameter. Accordingly our filters are of that size.

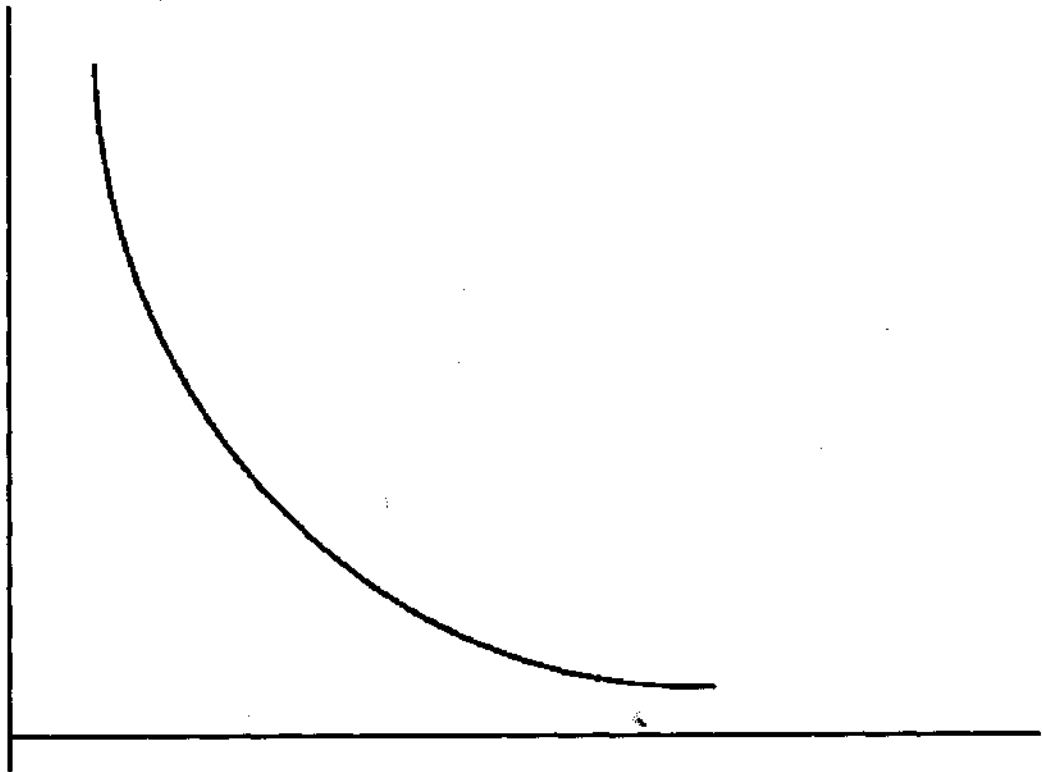


Figure 1. Schematic presentation of airflow resistance versus area.

The height of the filter comes from the space needed for internal parts, amount of carbon to meet specifications for gas and combined filters and particle filter element in particle and combined filters. Since the extremely low resistance requirement for the military filter that filter is the smallest combined filter. The filter thread is according to EN148-1 (2) and hence 18.6 mm high, the same for all the filters. Added to that is the canister, 71.90 mm, all in all 90.5 mm. For the industrial range we realized that it would not be possible to achieve EN class 2 for combinations of several gas types with 220 ml of carbon, but EN class 2-P3 is achievable for individual gas types as well as A2B2 -P3, with a safety margin of 15%. That gives a canister height of 75 mm plus the thread = 93.6. The combination A2B2E2K2-P3 and AX-P3 requires 320 ml of carbon giving a total canister height of 105 mm.

The separator between the carbon bed and the particle filter element is especially designed to be at the same time rigid but cause as little as possible resistance. Because of its low resistance, it is not possible to get readout for the resistance of the separator itself. The separator is fixed to the canister by ultrasonic welding.

As for the combined filters also for pure gas filters applies the same that two sizes is needed, 220 ml for individual gases and 320 ml for A2B2E2K2 and AX (EN371, ref.3). That gives as two new canisters 68 mm and 78 mm in height including thread.

The toplid is designed so that it both keeps the carbon in place and gives an esthetically acceptable product without an extra cosmetic cover. The lid is fixed to the canister by ultrasonic welding.

Finally we also need a canister for the particle filter. Since the height of the element is 20 mm the canister height needed is 56.5 mm including thread.

Particle Filter Performance

During the late 80's, Kemira Safety had developed its own pleating technology, with a pleat height of 19-20 mm. This technology gives many advantages compared with both our old collapsed cones and many other technologies.

In the most used pleating technologies some kind of distance element (a sticky yarn or a plastic web) is used to give space between the pleats. This technique gives rounded tops of the pleats and parallel pleats. In our technology we fix the pleats with strings of hot-melt glue when they are at suitable distance to each other. By this we get pleats with sharp edges and going zigzag at a small angle, not parallel.

The advantage of this is that the whole of the filter media surface is readily available and we get even

face velocity over the whole area. With the parallel pleats you get increased velocity when the air is entering the channels. There is a clear relationship between face velocity and filtration efficiency: the lower the face velocity the higher efficiency. Roughly, doubling the face velocity will decrease the filtration efficiency by a factor 10. Studies in the Kemira Safety laboratory has show that a filter tested at 47.5 l/min and getting 99.999% filtration efficiency, will when tested at 95 l/min get an efficiency of only 99.99%, with most penetrating particle size. It is not just a question of how much surface area you put into your canister. It is how well you make it available to your airflow, how low you get your face velocity. Decreased breathing resistance is another advantage you get at the same time.

The filter media is also one important factor. There are many suppliers of filter media as roll-material. We have tested most of the types available. The final choice was made on performance basis, the material that gave optimum performance with our pleating, cutting and gluing technologies. Out came a product, the PF10-P3 that according to our comparative test has an outstanding performance. In picture 2, in a diagram format, the PF10 is compared to 6 other remarkable brands on the market.

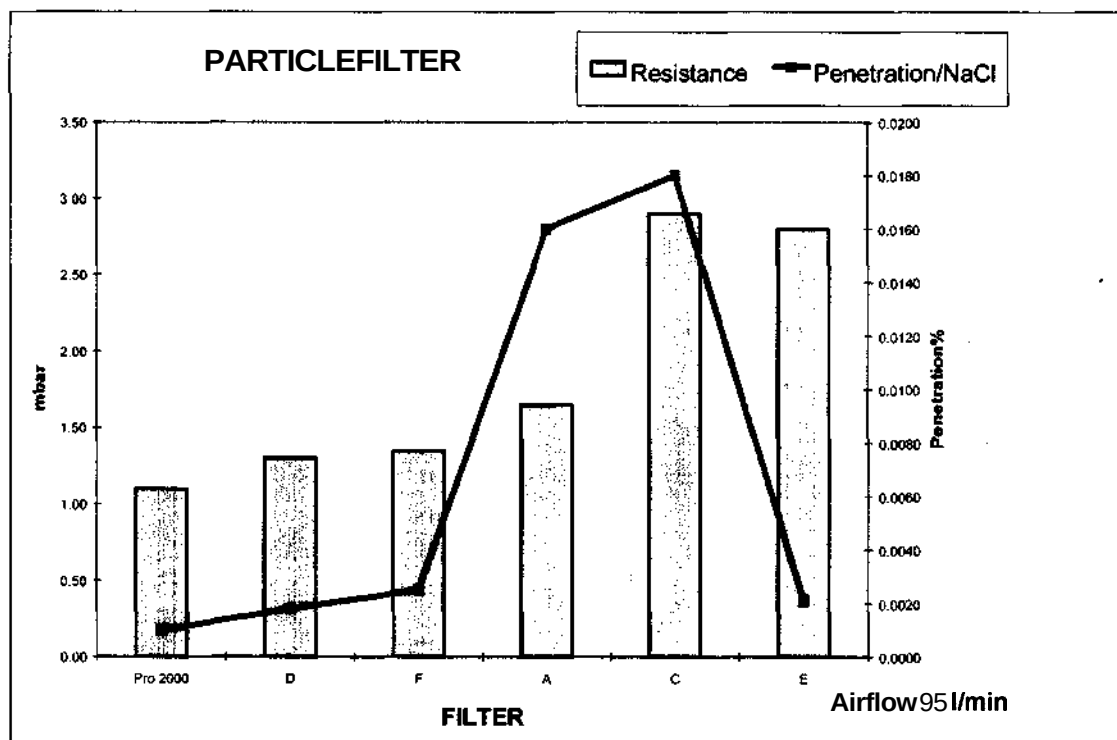


Figure 2. Pro2000 particle filter, PF10-P3 compared to filters from other producers.

A few independent test results also indicate a very high performance. The test results for EN143 (4) approvals and CE-marking were <0.001 for NaCl and <0.003 for paraffin oil and breathing resistance at 30 l/min 0.3 mbar and at 95 l/min 1.1 mbar. The breathing resistance is about $\frac{1}{4}$ of the maximum allowable and the penetration is between $\frac{1}{10}$ and $\frac{1}{15}$ of maximum allowable. The same filter element is used also in the industrial and military combined filters. A NATO-type military canister has been tested by TNO-PML in Holland (5). The penetration of the filter, tested with paraffin oil with a Lorentz AP2E Laserphotometer was 10^{-6} .

A clogging test is not needed for a P3 filter according to EN 143, but we wanted to do it anyway to see if a pre-filter for coarse dust is needed. We did a test for EN143 P2 clogging test with dolomite-dust and again we made a comparison to the most remarkable brands. The result is presented in picture 3. Again the open structure resulting from our pleating technology shows its advantages. The limit is 1.5 g before 500 Pa is reached so all the tested filters would have passed but there is a substantial difference between the products.

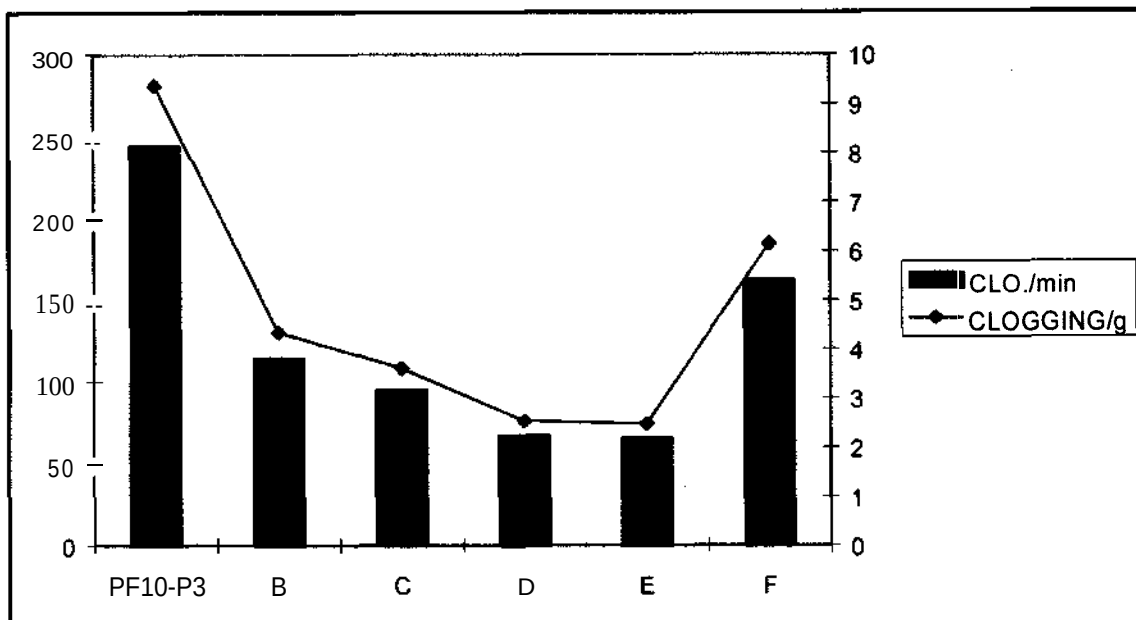


Figure 3. The bars indicate times in minutes when the filters is considered clogged according to EN143 P2 and the line indicates the amount of dust up taken at that point.

Gas Filter Performance

The design criterion for the gas filter was to achieve EN141 class 2 for individual gas- types with minimum breathing resistance. Since minimum resistance is not defined we had to invent a definition. Our definition: the lowest breathing resistance among class 2 filters on the market. In the approvals test for EN141 A2, the filter got the result 48 min tested with carbon tetrachloride and airflow resistance at 30 l/min 0.75 mbar and at 95 l/min 2.65 mbar. The resistance is about ½ of the maximum allowable according to EN141 gas filter class 2. In picture 4 is a comparison between the Pro2000 A2 filter and some remarkable brands. There is only one brand, F,

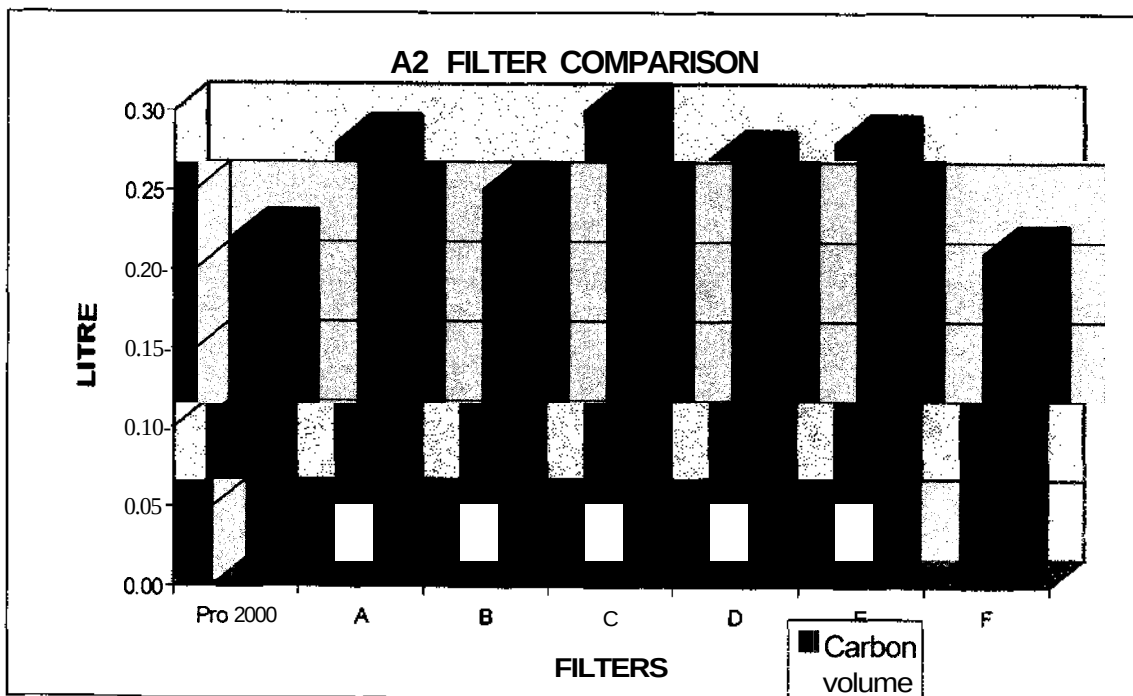


Figure 4. Carbon volume of the compared filters.

which uses less carbon than the GF22 A2 filter. In picture 5, showing the gas capacities of the same filter brands, it™s seen that F filter has a very borderline capacity. Picture 6 presents the breathing resistance of the same filters and it is evident that the Pro2000 filter has the lowest resistance. It is remarkable that there are big brands on the market, C with breathing resistance very close to the maximum limit. Finally picture 7 shows the gas-capacity versus carbon volume and gas-capacity versus breathing resistance. The bars tell how easy the user gets access to the gas capacity and the line shows how well the different brands utilizes the capacity of the carbon.

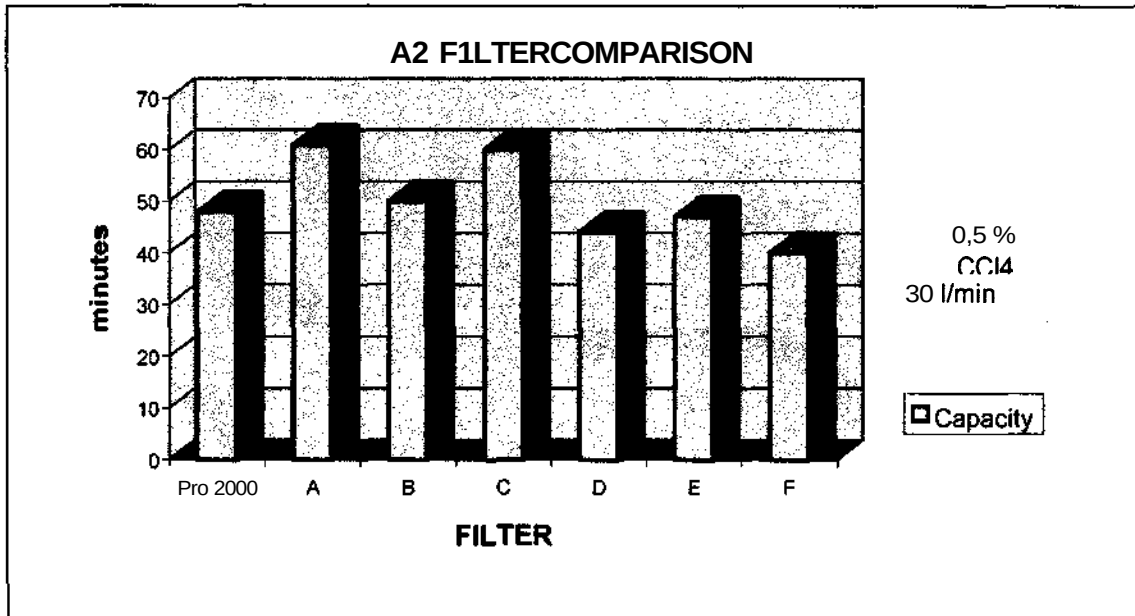


Figure 5. Gas capacities of the tested filters. 40 minutes is the limit for A2, CC14.

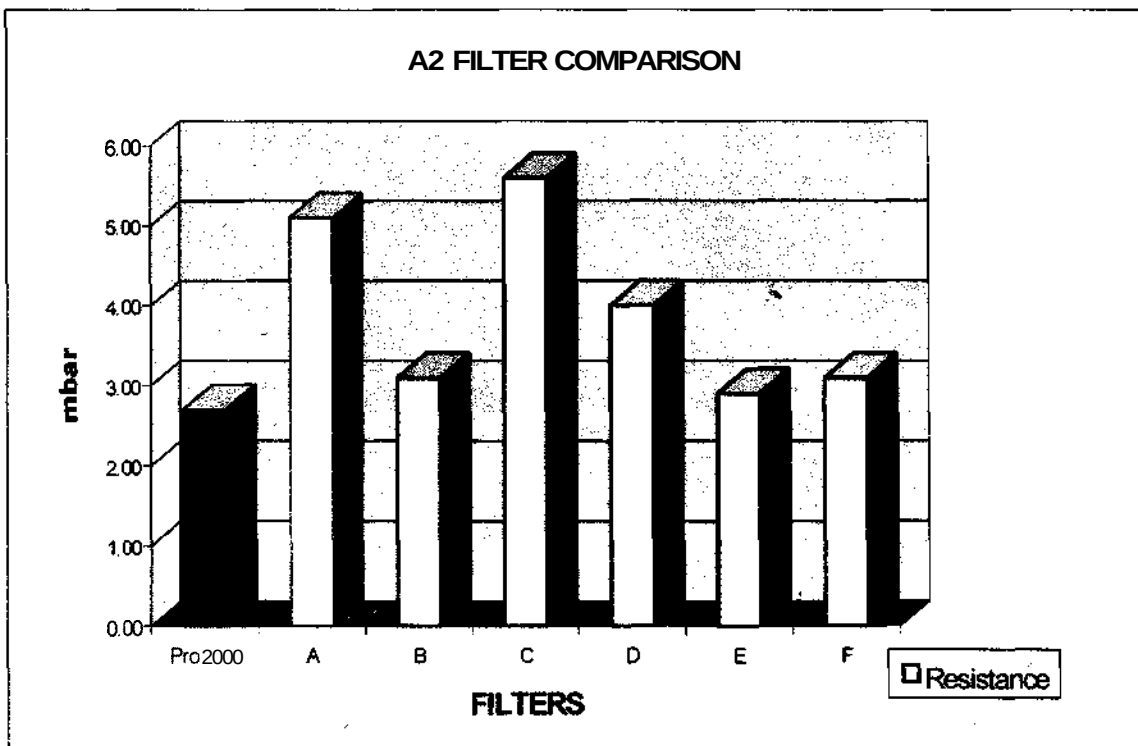


Figure 6. Breathing resistance of the compared filters.

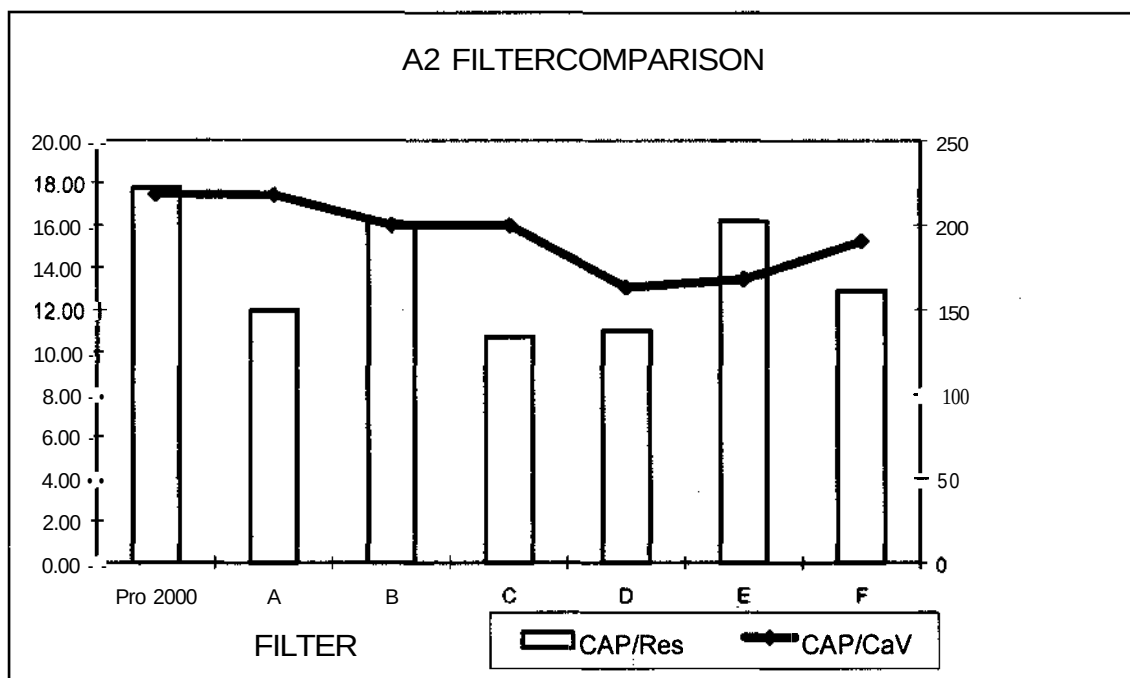


Figure 7. Gas capacity versus breathing resistance and gas capacity versus carbon volume for the compared filters.

Combined Filter Performance

In the combined filter we have combined the advantages of the gas-filter-design and the particle-filter-design into one canister, achieving the same gas-capacities with the small carbon volume and low airflow resistance due to both the small carbon volume and the particle filter design. The only filters I specifically want to mention is the CF32A2B2E2K2-P3 which achieves class 2 with only 320 ml carbon and airflow resistance of 5.7 mbar at 95 l/min and CF36A2B2E2K2Hg-P3 that achieves class 2 and Mercury with 360 ml carbon and resistance 6 mbar at 95 l/min.

Military Filter

The military filter M-95 was the first filter of the family to be ready, because of the demand of the Finnish military. Due to the cold winters in Finland the spec consisted of some special requirements. The most remarkable one is that the filter, after three drops at different angles, from one meter onto concrete floor at -40°C , shall be a working filter. Aluminum is not a suitable material, since it becomes dented. If the dent is at the particle filter, it will hurt the particle filter and it will no longer meet the spec of $>99.997\%$ efficiency. The normal industrial instruction "If the filter gets dented change to a new one" does not help much when you are in a war gas situation and have only one filter with you. An other requirement was, that the filter shall withstand Mustard gas penetration for more than 24h since the filter shall be used with gasmask M-95 which is a +24h mask.

The material that can meet these requirements is a special blend of glass fibre reinforced nylon, in combination with our production technology. This material combination meets also the EN141 rough handling test and the rough handling in the NATO specification.

When the first real filters came out of the production and went to approvals testing at the Finnish Defence Research Institute of Technology (FDRIT) they gave some remarkable results. With only 190 ml of the

standard military carbon and tested for 2g/m³ cyanogene chloride at 30 l/min the filter had a lifetime of 110 minutes when the old aluminum design —61 only had average lifetimes of 35 minutes.

Most of the filter performances were presented in reference 6, but some additional tests have been done. Because of the balance of the carbon used in the M-95 the filter passed only 80% of the EN141 class A2.

By choosing a carbon with the balance between physisorption and chemisorption more to the physisorption and filling the canisters to their maximum 210 ml, the filter type passed EN141 A2B2E1-P3. In this format the filter has been made available to Civil Defence in the EN-area where CE- marking is required. As earlier mention a version of the filter was produced for NATO-testing at TNO-PML. NATO requires the carbon ASC-TEDA although this carbon is forbidden in the USA. The test results by TNO-PML (5) are presented in table 1.

Table 1. Filter capacities obtained by TNO-PML

Gas-type	Capacity/minutes
Hydrogen cyanide before ageing	Av. 60
Hydrogen cyanide after ageing	Av. 46
Cyanogene chloride before ageing	Av. 76
Cyanogene chloride after ageing	Av. 62
Sarin after ageing	> 20, breakthrough < 3.1×10^{-6}
Sarin / Hydrogen cyanide	Av. 55 breakthrough < 1.1×10^{-6}
Sarin / cyanogene chloride	Av. 58 breakthrough < 1.1×10^{-6}
Chloropicrin	Av. 46

The NATO standard also requires a high level of hydrophobicity of the particle filter. This requirement was passed by choosing the maximum possible level of hydrophobicity without effecting the high efficiency and the low breathing resistance of the filter media.

Domestic Preparedness - First Responder Filter

Now we have passed the change of the Millennium, but the threats from chemical and biological attacks still remain. The Domestic Preparedness Program by the US Government requires a filter that takes out potential chemical and biological warfare agents as well as industrial chemicals that can be released due to terrorist attacks on chemical plants. Since the filter shall be used by civilians: fire fighters, rescuers, doctors, nurses and many more, it has to be approved by NIOSH. To make a combination of these requirements is a challenge to any filter producer.

In the filter family so far presented there is no filter that will meet this combination. The M-95 that has the military performance does not meet NIOSH gas capacity requirements and neither does the CF22 canister size. The CF32A2B2E2K2-P3 that has the gas capacity has a breathing resistance too high for NIOSH. A new filter has to be designed. Since the +24h Mustard gas penetration resistance would be an advantage the special Nylon blend was chosen. It also gives a very rugged canister for the possibly tough environments where it shall be used. With a canister that allows the use of in average 245 ml of carbon, the NIOSH requirement for Multi Purpose Cartridge, P-100 and HEPA, as well as the tear-gases CS and CN for Riot control is met for both negative pressure and PAPR. The test results from Miller-Nelson Research (MNR) are presented in the Appendix table 2, 3 and 4.

For cyanogene chloride, Chloropicrin (military test gases) and hydrogen cyanide (test gas for EN141 type B) FDRIT has also tested the filter. The test results are presented in the Appendix in table 3.

The test results from FDRIT show that the filter will filter the traditional inorganic war gases. The Organic Vapor results from MNR show that the Organophosphorous compounds are well filtered. The hydrogen

cyanide test from FDRIT shows that the filter meets that class 2 requirement for EN141 type B. The test results from MNR for carbon tetrachloride, chlorine, hydrogen sulphide, sulphur dioxide and ammonia show that the filter meets at least EN141 ABEK class 1, although the filter type has not yet been tested specifically for EN by an Accredited test laboratory.

Future Trends

The human being is very innovative and will continue to develop new threats with new chemicals. At the time, when this text is written the number of registered chemicals by CAS is over 23 million. It is evident that among these chemicals, and the future ones, there will be substances that will not be filtered with today's equipment. The future work of the filter developer will be to first find specific methods to filter these substances and then transplant this technique into the Multi Purpose filters.

This filter family has predominantly been developed for negative pressure respirators. The adaptation to PAPR has happened by chance. EN12491 and 12492 (the EN standards for PAPR) are having much lower gas life requirements than EN141 so adaptation has not been any problem. NIOSH PAPR requirement is very similar to the negative pressure requirement, so an adaptation there has not been a problem either. Still I believe that tailoring of filters both for PAPR and for specific customer needs, will be the future. Examples of that are a REACTOR-P3 filter with a special carbon, especially efficient in removing radioactive Methyl iodine, and a female thread on the inlet side of the filter so the filter can be used for instance in an airline system. Since the flow-rates are much higher in the PAPR and airline systems than at negative pressure test conditions the design criteria and filter dimensions can differ a lot from the presented family.

References

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2. European standard EN148-1, 1987. Respiratory protective devices - Threads for facepieces - Part 1: Standard thread connection. Respiratory protective devices
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Appendix

Table 2. Test results obtained by Miller-Nelson Research for negative pressure, tested As Received at 64 LPM and Equilibrated 25% and 85% at 32 LPM

Gas-type	Condition	NIOSH req.	Capacity/minutes
CCL4	AR	25	>65
CCL4	EQ25	25	134
CCL4	EQ85	25	27
SO2	AR	15	89
SO2	EQ25	15	> 40 (Test Stopped)
SO2	EQ85	15	> 40 (TS)
NH3	AR	25	> 55
NH3	EQ25	25	> 50 (TS)
NH3	EQ85	25	> 50 (TS)
Methylamine	AR	12.5	> 80 (TS)
Methylamine	EQ25	12.5	> 40 (TS)
Methylamine	EQ85	12.5	> 40 (TS)
CL2	AR	17.5	> 35 (TS)
CL2	EQ25	17.5	> 35 (TS)
CL2	EQ85	17.5	> 35 (TS)
HCL	AR	25	> 35 (TS)
HCL	EQ25	25	> 35 (TS)
HCL	EQ85	25	> 35 (TS)
H2S	AR	30	> 60 (TS)
H2S	EQ25	30	> 60 (TS)
H2S	EQ85	30	> 60 (TS)

Table 3. Test results obtained by Miller-Nelson Research, tested As Received as well as Equilibrated 25% and 85% at 64 LPM. Valid for both PAPR and negative pressure.

Gas-type	Condition	NIOSH req.	Capacity/minutes
CLO ₂	AR	30	> 60 (TS)
CLO ₂	EQ25	30	> 60 (TS)
CLO ₂	EQ85	30	> 60 (TS)
HF	AR	30	> 60 (TS)
HF	EQ25	30	> 60 (TS)
HF	EQ85	30	> 60 (TS)
Formaldehyde	AR	50	> 100 (TS)
Formaldehyde	EQ25	50	> 100 (TS)
Formaldehyde	EQ85	50	> 100 (TS)
CS	AR	480	> 480 (TS)
CS	EQ25	480	> 480 (TS)
CS	EQ85	480	> 480 (TS)
CN	AR	480	> 480 (TS)
CN	EQ25	480	> 480 (TS)
CN	EQ85	480	> 480 (TS)

Table 4. Test results obtained by Miller-Nelson Research, equilibrated and tested As Received as well as Equilibrated 25% and 85% at 57 LPM. (Continued on following page)

Gas-type	Condition	NIOSH req.	Capacity/ minutes
CCL ₄	AR	25	> 91
CCL ₄	EQ25	12.5	> 25 (TS)
CCL ₄	EQ85	12.5	> 12.5
SO ₂	AR	15	> 30 (TS)
SO ₂	EQ25	7.5	> 15 (TS)
SO ₂	EQ85	7.5	> 20 (TS)
NH ₃	AR	25	> 68
NH ₃	EQ25	12.5	> 35 (TS)
NH ₃	EQ85	12.5	> 25 (TS)
Methylamine	AR	12.5	> 25 (TS)

Methylamine	EQ25	7	> 20 (TS)
Methylamine	EQ85	7	> 20 (TS)
CL2	AR	17.5	> 35 (TS)
CL2	EQ25	9	> 18 (TS)
CL2	EQ85	9	> 18 (TS)
HCL	AR	25	> 35 (TS)
HCL	EQ25	12.5	> 25 (TS)
HCL	EQ85	12.5	> 25 (TS)

Table 5. Test results obtained by FDRIT.

Gas-type	Condition	Concentration	Capacity/minutes
Cyanogene chloride	AR	4 + -0.2 g/m ³	33 + -3
Chloropicrin	AR	15 + -0.5 g/m ³	72 + -2
Hydrogen cyanide	Rough-handled	5.6 + -0.5 g/m ³	45 + -2