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DESIGN CRITERIA FOR AIR FILTRATION IN GENERAL INDUSTRIAL VENTILATION

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ABSTRACT

There has been lack of fact-based knowledge for design and operation of supply-air filters for general industrial ventilation. A multi-company project within the Industrial Ventilation (INVENT) technology programme was started in 1994 to tackle this problem area which is assumed to be the most problematic one, according to the feedback from end-users in several industries, who also made the initiative to this project.

The main objectives of the project were to clarify a methodology for control of particulate contaminants in industrial premises, and to define the basic criteria for design and optimal selection of supply and recirculation air filters. This methodology will take into account outdoor air quality, desired indoor air quality, emissions from the processes and cleaning of ductwork and equipment.

The first stage of the project, finalized in the end of 1995, included state-of-art surveys, preliminary case studies and a preliminary proposal for the filter performance classification. The second stage, currently ongoing, will include validation of the existing knowledge by laboratory and field tests, development of an expert system for filter selection, and draft contributions to the international Design Guide Book for Industrial Ventilation (DGB).

DESIGN CRITERIA AND FILTER SELECTION

The detailed design of air cleaning systems should be based on the well defined target levels of airborne contaminants and it should result in a guaranteed performance. To achieve this goal and to define the requirements for the filter performance, it is also essential to know the particle concentration and the size distribution in the air to be filtered.

However, it is reasonable to assume that in most cases the design of the air filtration system does not require detailed information about the particle concentrations and particle size distributions. The design in these cases can be based on the assumption that the air to be filtered does not contain any especially hazardous contaminants and the total concentrations are well below occupational exposure limits. Also it can be assumed that a minor inaccuracy, when selecting the minimum efficiency of the filter, does not lead to serious contaminant problems.

The suggested design approach is based on the definition of target levels for filter performance in a such way that they are easy to understand by all parties including end-users. Also it is required that there is a simple physical explanation which clarifies the result which can be achieved, when a certain target level is applied, i.e. the end-user must be able to easily understand the advantages and disadvantages of different target levels. Furthermore, the target levels are defined in a such way that the fulfillment of the designed values as guarantee values can be checked using relatively simple measurement techniques.

Target levels for filter performance

The present work introduces a new style of filter performance classification which aims to avoid the vagueness of the present classification styles. It suggests a three-level classification which can be used when making rough estimates about the proper level of air filtration in different types of buildings and environments.

The conventional filter classifications (e.g. EUROVENT 4/5, or the G-and F-classes according to EN 779) provides only part of all essential information about the filter performance. In fact these classifications have been developed for rating in test conditions only, and with only a vague connection to filter performance in the real world.

The basic idea of the new approach is to define target levels with the aid of an expression which include exact information about the required filter performance and the particle size at which the required performance must be fulfilled in all conditions of operation throughout the lifetime of the filter. This approach is assumed to encourage all parties to use well defined data when describing the performance of filters.

The suggested basic target levels for filter performance which should be fulfilled troughout the filter life-time have been expressed in the form of cleanliness classes as follows:

T5/10	The maximum allowable penetration for 5μm particles is 10 %. This filter is assumed to effectively capture large particles, which may cause dust accumulation e.g. in ventilation ducts (settling dust)
T1/10	The maximum allowable penetration for 1μm particles is 10 % (minimum efficiency 90 %). This filter is assumed to cause significant decrease in the concentration of those particles which effectively deposit in the human respiratory system.
T0,5/10	The maximum allowable penetration of 0,5μm particles is 10 %. This filter is assumed to be effective even for fine particles, i.e. the particles which orginate from combustion processes (traffic and energy production) and atmospheric gas to particle conversion, and also a considerable part of staining particles.

The advantage of this type of classification is that filter performance is unambiguously specified in terms of maximum penetration at a certain particle size value.

Industrial environment categories

The premises in industrial environment can be characterized in categories. For each category, it is possible to recommend one target level for filter performance, see Table 1.

TABLE 1. Recommended target levels for dust filters in different environmental categories.[1]

Environment category:	SUPPLY AIR	RECIRC. AIR [2]	EXHAUST AIR
1. Covered processes No stationary working places, occupation is only temporary. Main part of the particulates is process emissions and the process doesn't set any requirements for the cleanliness.	T5/10 [4]	T1/10	
2. Working environments in industry Spaces with stationary working places and continuous occupancy. Particulate levels may vary considerably between different spaces. Supply air is normally better ducted and distributed than on category 1.	T1/10 [5]	T1/10	-
3. Spaces with special cleanliness requirement (incl. clean rooms) Spaces that set special requirements for the air cleanliness. Typical in electrotechnical, pharmaceutical and foodprocessing industry. Also special rooms like electrical equipment, tele, automation, and computer rooms and rooms for personal protection. Special quidelines are to be followed when exists.	T0.5/10 [6]	T0.5/10 [6]	- [6]
4. Laboratories, kitchens, smoking rooms Rooms where possible exhaust air filtration and increased need for cleaning of exhaust ductwork has to also be taken into account.	T1/10 [5,7]		[6]
5. Offices, other official spaces and residential areas Ductworks and used components, such as VAV-regulators, humidity and air quality sensors, are usually more complicated in offices that in industrial premises. Among other things it makes ductwork cleaning more difficult and expensive.	T1/10 [5,7]	T1/10	-

1) Cleanliness class T5/10: The maximum penetration of particulates >5µ m(removal of settling dust) is 10 %.
   Cleanliness class T1/10: The maximum penetration of particulates >1µ m(coarse particles are removed) is 10 %.
   Cleanliness class T0.5/10: The maximum penetration of particulates >0.5µm is 10 %.
2) Particle size distribution of emission from indoor sources has to be taken into account, when selecting recirculation air filter. Usually recirculation air filter should be at least the same class as in supply air.
3) If supply air is ducted it is recommended to use T1/10.
4) In some cases supply air can leave without filtration. In such case ventilation system components (coils, blower, etc.) has to be chosen and located so that they don't collect dust and are easy to clean.
5) It is recommended to use at least cleanliness class T1/10 before heat-recovery unit. If it is difficult to clean the unit, it is recommended to use class T0.5/10.
6) Special guidelines is to be followed if exists.
7) T0.5/10 is recommended in areas, where there are high emissions from traffic and energy sources.

The proposed target levels in relation to present filter classes

The correlation between present filter classification tests and filter performance on the field is weak. This situation together with the lack of design criteria and too many filter classes has led to non-fact based selection of filter in most cases.

New test methods based on a filter's fractional efficiency make it possible to compare the performance of filters and filter media in practise. According to latest measurements and discussions in Finland it is also evident that presently used filter classification has too many classes in order to make difference between different classes (filters tested according to EUROVENT 4/5 /2/, 8 classes EU1-EU8 for normal ventilation purposes). Even more confusing is that test results of several manufacturers EU6-class filters shows a wide variation in filter performance, when new methods are used. Initial efficiency of some EU6-class filters was even poorer than that of EU5-class filters, which were measured in same tests. /1/

Based on the tests of several glass-fibre bag filters of different filter classes /1/ it is possible to define, which of the present filters fulfil the recommended cleanliness classes. (The fractional penetration (efficiency) of different classes represent the average values of all tested filters.) Glass fibre filters normally has highest penetration as clean, so the requirement has to be compared to the penetration curves of clean filter.

The relation between the filter classes and the cleanliness classes, based on the measurements /1/, is shown in table 2.

TABLE 2. Approximate relation between the target levels (cleanliness classes) of dust filters and lowest acceptable filter classes, when maximum allowed penetration of nominal particle size is 10% in each cleanliness class.

TARGET LEVEL	FILTER CLASS1)
T5/10	EU4
T1/10	EU7
T0,5/10	EU8

1) Filter classes according to EUROVENT 4/9, /3/. Corresponding classes according to EN779:1993 are G4, F7 and F8 /4/.

TECHNICAL - ECONOMICAL OPTIMIZATION

Basis and problems of optimization are discussed and written down in this project. The knowledge is still at too general level to be used in optimization. The aim is to develop an expert system for filter selection and optimization. The following is a short decription of the core of the expert system, still under development but already collecting the best available knowledge into a real pratical tool.

The most important technical figure in system optimization is maximum allowed final pressure drop of filter, that depends on the allowed air flow change during operation and fan performance. This figure should be calculated during design phase, corrected after installation, if e.g. fan parameters is changed, and must not be exceeded during operation. The properties of filter material and filter construction has to be taken on account as well.

The properties of filter material and construction has to be taken on account as well. Breakage of the material is not a problem in normal cases, but too high pressure drop can cause increased penetration of fine dust (coarse filters).

The filter selection always has to be started from the target level. After qualification of acceptable filtering methods is done, can acceptable methods be quantified economically in order to:

-compare the total economy of filter that fulfil minimum requirements to more effective solutions

-compare filters with equal class with respect to lifetime and initial and final pressure drop.

-define economical final pressure drop

-compare economy of different filter constructions (compact vs. bag filters etc.) or properties (e.g. bag length) with respect to dust holding capacity and lifetime.

Because the lack of knowledge of filter performance in real conditions and of the influences of filtering e.g. to dust growth of ductwork and ventilated spaces, many assumptions and simplifications has to be done during calculations. This fact causes that reliability of general calculations is questionable. Thus, economical optimization can be used in single cases effectively, especially during operation time, when more accurate information of local conditions is available than during design phase.

SECOND STAGE (1996-97), THE MAIN OBJECTIVES

The main objectives and tasks for the second stage of the INVENT project are:

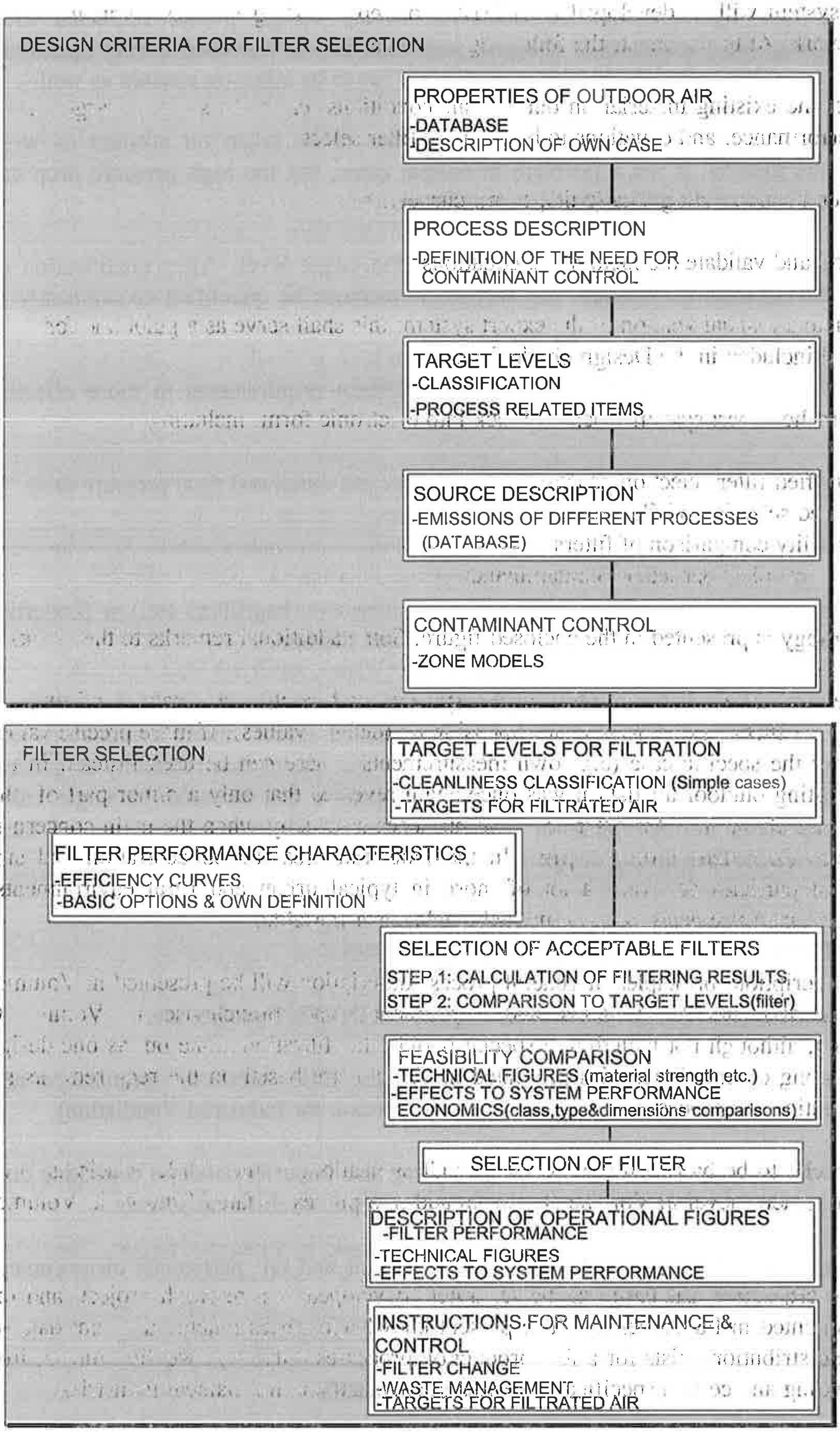
-write international guidelines for filtering fundamentals, filter selection, optimization and maintenance (start of contributions to the Design Guide Book for Industrial Ventilation),

-develop an expert system for filter selection, including also impurity database consisting data on consentrations and particle size distribution of emissions from different sources

-produce new data on filter performance in real conditions and on particulate measurement techniques by laboratory and field tests.

EXPERT SYSTEM - SOME PRELIMINARY FEATURES

In the following table, the framework and blocks of the planned expert system is described.


DESIGN CRITERIA FOR FILTER SELECTION
PROPERTIES OF OUTDOOR AIR
-DATABASE
-DESCRIPTION OF OWN CASE
PROCESS DESCRIPTION
-DEFINITION OF THE NEED FOR CONTAMINANT CONTROL
TARGET LEVELS
-CLASSIFICATION
-PROCESS RELATED ITEMS
SOURCE DESCRIPTION
-EMISSIONS OF DIFFERENT PROCESSES (DATABASE)
CONTAMINANT CONTROL
-ZONE MODELS
FILTER SELECTION
TARGET LEVELS FOR FILTRATION
-CLEANLINESS CLASSIFICATION (Simple cases)
-TARGETS FOR FILTRATED AIR
FILTER PERFORMANCE CHARACTERISTICS
-EFFICIENCY CURVES
-BASIC OPTIONS & OWN DEFINITION
SELECTION OF ACCEPTABLE FILTERS
STEP 1: CALCULATION OF FILTERING RESULTS
STEP 2: COMPARISON TO TARGET LEVELS(filter)
FEASIBILITY COMPARISON
-TECHNICAL FIGURES (material strength etc.)
-EFFECTS TO SYSTEM PERFORMANCE
ECONOMICS(class,type&dimensions comparisons)
SELECTION OF FILTER
DESCRIPTION OF OPERATIONAL FIGURES
-FILTER PERFORMANCE
-TECHNICAL FIGURES
-EFFECTS TO SYSTEM PERFORMANCE
INSTRUCTIONS FOR MAINTENANCE & CONTROL
-FILTER CHANGE
-WASTE MANAGEMENT
-TARGETS FOR FILTRATED AIR

The expert system will be developed in at least two steps, starting with the contents of the basic framework. At the moment, the following tasks are being planned:

1. To collect the existing material on outdoor air conditions, emission sources, target levels and filter performance, and equations to be used for filter selection.

2. To restructure the existing data (units, form, curves...)

3. To develop and validate the factors and equations

4. To complete a manual version of the expert system; this shall serve as a guideline for filter selection, and included in the Design Guide Book.

5. To convert the expert system block by block into electronic form, including

   -simplified filter selection process
   -detailed selection of filter
   -feasibility comparison of filters
   -total control of particulate contaminants

The methodology is presented in the enclosed figure. Some additional remarks to the blocks:

1. Properties of the outdoor air: the expert system shall contain a database of existing "typical" figures that can be selected for dimensioning (default values). If more precise values are known for the specific case (e.g. own measurements), these can be used instead. In the survey of existing outdoor air data it was once again revealed that only a minor part of the data can be directly applied for filter selection purposes especially when the main concern is small particles (less than 1 or 0,5 µm). In the industrial area the concentration and size distribution of particles cen vary a lot of those in typical urban and rural environments. Therefore local measurements are recommended whenever possible.

2. Process description: principles of general process description will be presented in Volumes A (Fundamentals) and B (Systems and Equipment), and branchwise in Volume C (Applications), although not including a special booklet for filtration alone but as one design parameter among others. Categories presented in Table 1 are based on the requirements set by work conditions or processes.

3. Target levels: to be based on the Cleanliness Classification. In the DGB, principles to be presented on general level in Volume A, and in addition process related features in Volumes B and C.

4. Source description: a database will be separately developed in a research project, and the results documented in Fundamentals. The present knowledge varies much; sufficient data on particle size distribution exists for a few production processes only: e.g. welding fumes, iron or brass grinding and certain specified processes in chemical and mechanical industries.

Blocks from the lower part (6...12) are planned to be included in the filtration blocks in Volume B.

FIELD AND LABORATORY TESTS, SOME PRELIMINARY RESULTS AND CONCLUSIONS

As a part of the second stage of the INVENT project, pilot field tests and one series of laboratory tests have been made to give a solid background to long-term field tests, which will continue to the end of year 1997 with selected filters.

The pilot field tests were made to test the measurement techniques and to produce some information about the filter behaviour in suburban environment. The laboratory tests were made for pre-selection of filters to the long-term field tests and to study the filter behaviour in different controlled loading conditions.

Laboratory tests were made by using material samples from twelve filters. Filter materials were exposed to a test aerosol which was a mixture of standard SEA Fine test dust and diesel fume. Air flow velocities were adjusted to correspond to the nominal flow rates of the filters. The pressure drop and penetration of the filter materials were measured as function of filter loading. Filter loading was given in terms of aerosol exposure, i.e. mass concentration x loading time. In this way, it is possible to give a rough estimate for the filter performance in true operation conditions in the time scale of one year (e.g. the exposure of 30 $\mu g/m^3$ year corresponds to a one year operation in the average concentration of 30 $\mu g/m^3$).

Figure 1 shows the relationship between filter material pressure drop and loading. This result indicates that there are big differences in the performance of the filters.

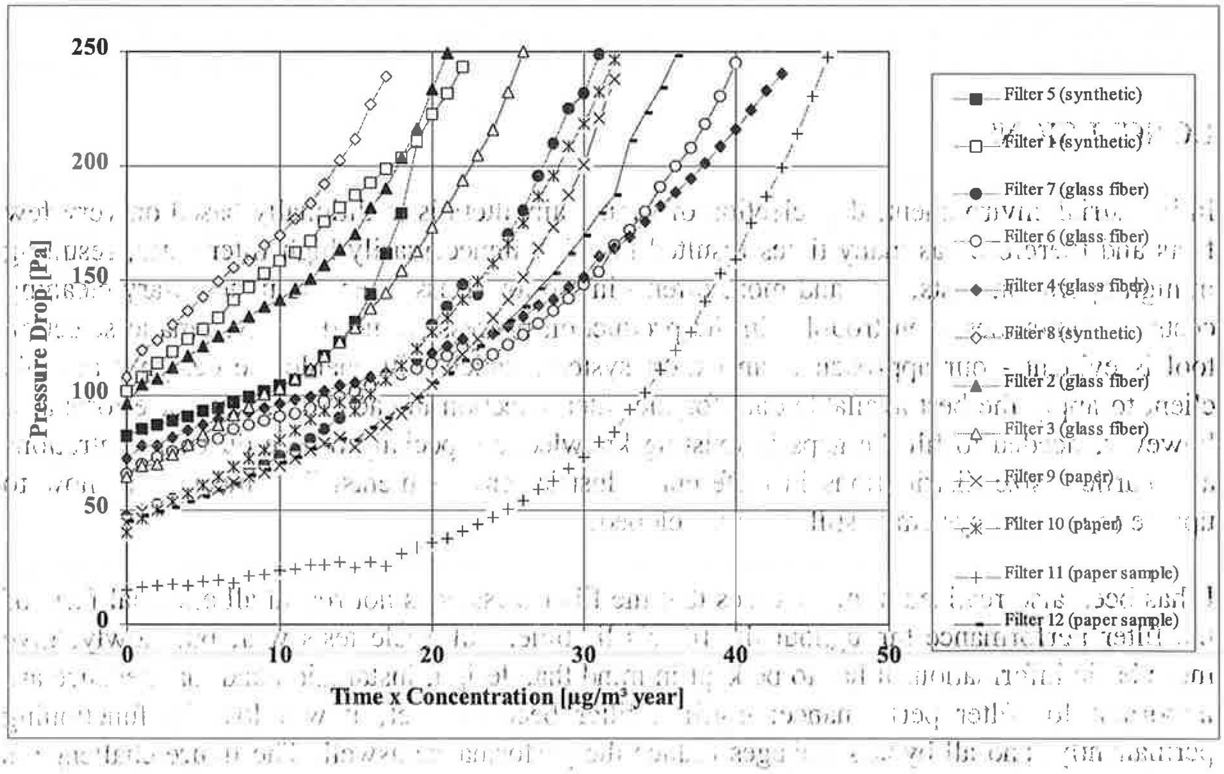


Figure 1: Filter material pressure drop as a function of filter loading.

Significant differences can also be observed in Figure 2 which illustrates the relationship between mass penetration and loading. Taking into account that all filters should be of the same filter class (F7), the variations were surprisingly high.

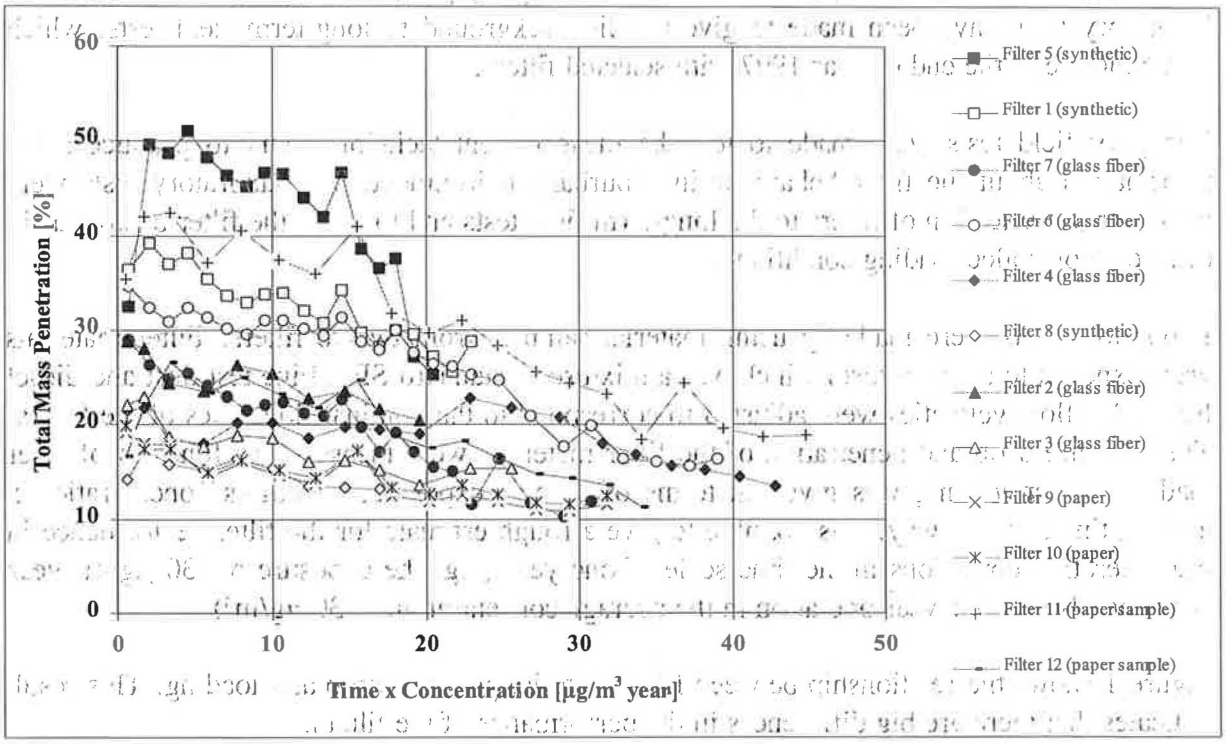


Figure 2. Mass penetration as a function of filter loading.

CONCLUSIONS

In industrial environment, the selection of supply air filters is traditionally based on very few facts and therefore has many times resulted in either unnecessarily high filter class, resulting in high operation costs, or - and more often - in too low-class filter and unnecessary cleaning costs or sometimes even troubles in the production process. A need for systematic selection tool is evident - our approach is an expert system, which will enable the designer and his client to apply the best available data for the filter selection in each case. Further efforts are, however, needed to fill the gaps in existing knowledge especially on the dust concentrations and particle size distributions in different industrial environments. The mechanism how to update the expert system is still to be developed.

It has been also realized in many cases that the filter class does not reveal all essential facts of the filter performance throughout the filter's lifetime. Full-scale tests will, but slowly, give more basic information. It has to be kept in mind that design, installation and maintenance are important for filter performance: e.g.if a filter becomes wet, it will lose its functioning permanently, and all bypass leakages reduce the performance aswell. The future challenge is to fill the gaps in existing knowledge about filter performance in real operating conditions.

REFERENCES

/1/ Holmberg R., Modern characteristics of filter performance for general air filters, INVENT-Report 31, 1993. (In Finnish)

/2/ EUROVENT 4/5, Method of testing air filters used in general ventilation

/3/ EUROVENT 4/9, Method of testing air filters used in general ventilation for determination of fractional efficiency.

/4/ EN 779:1993, Particulate air filters for general ventilation - Requirements, testing, marking.