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Chapter 4

Particulates are Killers

Peter MacDonald

INTRODUCTION

Much publicity has been given to the potential health risks posed by buildings, particularly those with mechanical ventilation or air conditioning. There have been concerns over the possible effects of the VOCs given off by the furnishings and finishes, of fungal spores shed from dirty ducting, of legionella distributed by wet cooling towers, of insufficient ventilation air, etc., etc. The list of concerns is a long one. But what about the effects on the building occupants of the air brought in from outside, the so-called 'fresh air'?

Compared with when domestic coal fires and 'smoke stack' industries were prevalent, present-day pollution levels are low. Despite this though, researchers recently have begun to find startling evidence that outdoor air can be positively harmful to health and that the biggest threat is the fine particles which are semi-permanently suspended in it. These don't just make people feel off-colour. They can kill.

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THE HARVARD STUDY

The most comprehensive study into the effect of air pollution on mortality has been that conducted by Dockery *et al* of the Harvard School of Public Health, which was published in 1993.

The research team took a random sample from six cities of 8111 white adults aged 25 through to 74 years and, over a 14-16 year period, compared their mortality rate with the pollution levels in their cities. All the subjects in the study had undergone lung function testing and had completed a standardised questionnaire which included questions about age, sex, weight, education level, complete smoking history, occupational exposures and medical history. So this allowed control for individual smoking status, sex, age, and other risk factors.

Concentrations of particulate matter, sulphur dioxide, ozone, suspended sulphates and hydrogen ions (for aerosol acidity) were monitored at a central location in each of the six cities. As well as measuring the total suspended particulate matter they measured the concentration of inhalable particles (aerodynamic

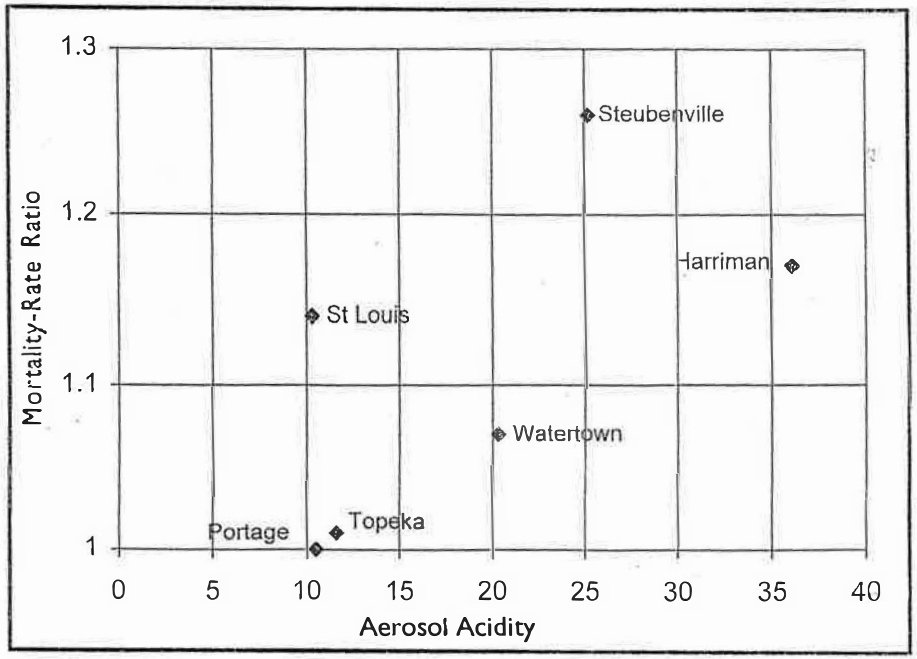

Figure 4.1 Relationship between Mortality-Rate Ratio and Annual Average Aerosol Acidity

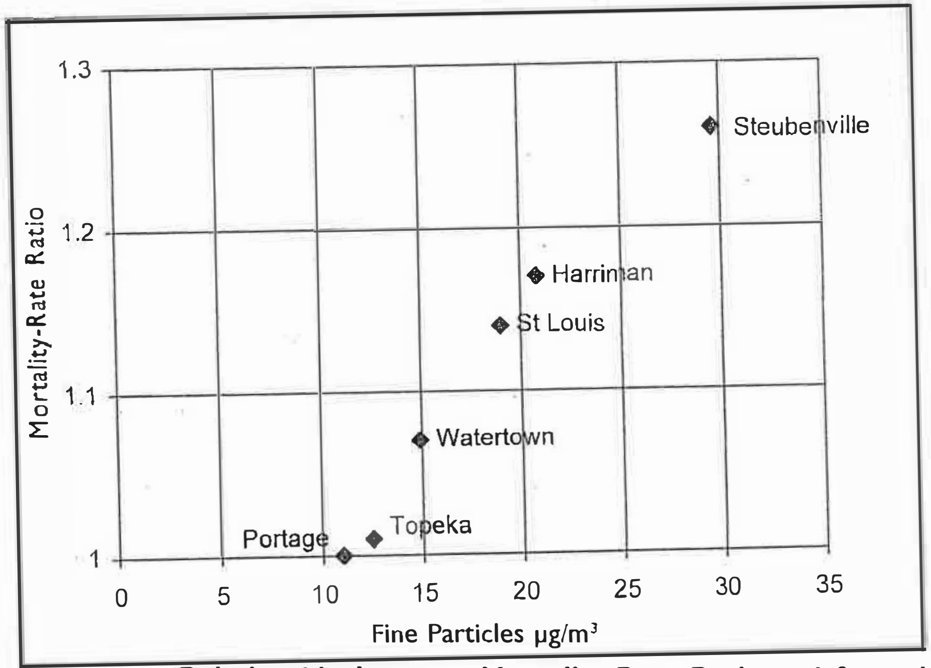

Figure 4.2 Relationship between Mortality-Rate Ratio and Annual Average Concentration of Fine ($PM_{2.5}$) Particles

diameter <10μm, commonly referred to as PM_{10} particles) and fine particles (aerodynamic diameter <2.5μm, referred to as $PM_{2.5}$ particles).

Mortality was most strongly associated with cigarette smoking and increased mortality was also associated with having less than a high-school education and with increased body-mass index. But after simultaneous adjustments for these risk factors, the differences in mortality among the six cities remained significant.

What was found was that city-specific mortality rates, adjusted for a variety of health risk factors, were associated with the annual average levels of air pollutants in the cities. Mortality was more strongly associated with the levels of inhalable, fine and sulphate particles than with the levels of total suspended particles, the sulphur dioxide levels, the nitrogen dioxide levels or the acidity of the aerosol. Figure 4.1 shows the scatter of the latter.

However, as Figure 4.2 indicates, there was found to be virtually a straight-line relationship between the levels of the fine $PM_{2.5}$ particles and the mortality rate.

The difference in mortality rate between the most and least polluted cities was an amazing 27%. But the most worrying aspect is that the increased risk of death occurred at concentrations well below those currently considered acceptable, as the annual average level of the inhalable, PM_{10} particulate was only 46.5μg/m³ in the most polluted city in the study.

OTHER STUDIES

This decade, following the revelations of the Dockery report, there has been a flurry of research activity into the harmful effects of air pollution. A recent UK study by Poloniecki *et al* has reported a statistically significant association between the daily incidence of myocardial infarction and daily concentrations of pollutants, especially particulate matter. The authors suggest that in the UK some 6,000 myocardial infarctions may each year be related to exposure to air pollutants.

This work on the immediate, short-term effects of pollution has been taken further. The Department of Health asked the Committee on the Medical Effects of Air Pollutants (COMEAP) to advise on the effects of air pollutants on health

Table 4.1 Effects of Each 10μg/m³ Increase in PM_{10} on Indicators of Ill-Health

	% change in health indicators
Increase in daily mortality	
Total deaths	1.0
Respiratory deaths	3.4
Cardiovascular deaths	1.4
Increase in hospital usage	
All respiratory admissions	0.8
Emergency department admissions	1.0
Exacerbation of asthma	
Asthmatic attacks	3.0
Bronchodilator use	2.9
Hospital admissions	1.9
Increase in respiratory symptoms reports	
Lower respiratory	3.0
Upper respiratory	0.7
Cough	1.2

in the UK, including an estimate of the numbers of people affected. Their report estimated that in the UK, 8,100 deaths of vulnerable people were brought forward by particulate air pollution. It was also associated with 10,500 hospital admissions, brought forward or additional, of vulnerable people suffering from respiratory problems.

For every 10μg/m³ increase in concentration of PM_{10} particles it has been estimated that there will be a 1% increase in the total death rate, a 3.4% increase in respiratory deaths and a 1.4% increase in cardiovascular deaths (see Table 4.1). Yes, particulates are killers.

WHY ARE PARTICULATES KILLERS?

It is not clear yet as to why fine particles are so dangerous, although a recent paper in the Lancet suggests that the immune system may be reacting to them as if they were invading organisms. This immune response causes inflammation of the tissues in a similar manner to the allergic reaction of a hay-fever sufferer, but with the ultra-fine particles the inflammation is deep in the lungs. The finer the particle size, the deeper it will penetrate. That is why many experts are calling for the monitoring and control of $PM_{2.5}$ particles (2.5μm diameter) instead of PM_{10} particles. It is even being suggested that ultrafine particles (< 0.05μm diameter) may play a role

WHERE DO THE PARTICLES COME FROM?

The primary sources of fine particles are old coal fired power stations, industry and especially road vehicles. By far the worse culprits are diesel engined vehicles – it is estimated that 90% of fine particles in the urban atmosphere are from this source.

Diesels use 20-25% less fuel than petrol engines, so have been trumpeted as being environmentally friendlier and have rapidly become popular. However, since combusting one litre of diesel oil produces about 15% more carbon dioxide than one litre of petrol, emissions of the 'greenhouse gas' carbon dioxide are only slightly less from diesel cars. Emissions from new diesel cars are estimated to be 3-4 times more carcinogenic than emissions from petrol cars. A modern diesel, even when it is correctly set up, emits 10–15 times more particles than a modern petrol engined car. Worse still, the particle sizes emitted by a diesel are considerable finer, more damaging to health.

Unless there are technological advances which will enable the cleaning up of diesel exhausts, or the Government takes steps to curb the growth in sales of diesel engined vehicles, the concentration of fine particles in the atmosphere, especially in our cities, will not decrease. It will probably increase.

IS THERE A SOLUTION?

Whilst the wearing of personal face masks, as favoured by some of our Japanese cousins, may provide a degree of apparent protection in the street, our buildings can be made relatively safe havens from the scourge of particulate pollution. How? By making sure that the 'fresh air' from outdoors is admitted in a controlled fashion, via an air filtration system.

This effectively means that a mechanical ventilation or air conditioning system is needed. A naturally ventilated city building can seriously damage its occupants' health is the message!

AIR FILTRATION TECHNIQUES

Contrary to what many might believe, air filters in ventilation systems do not work by straining or sieving the particulate matter out of the air. Instead they

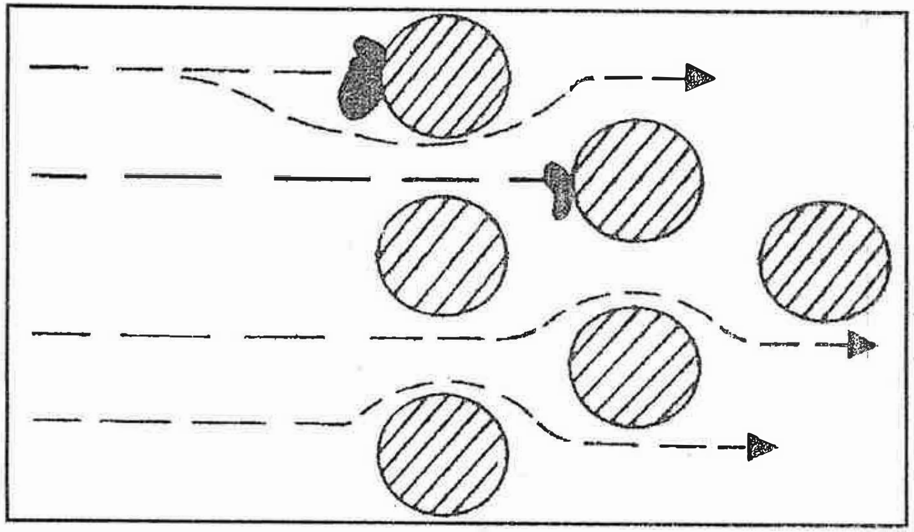

Figure 4.3 Inertial Impaction Principle

rely on three major collection mechanisms: inertial impaction, diffusion/interception and electrostatic precipitation. The last mechanism is not commonly employed, due to certain problems and drawbacks, not the least cost, so will not be covered in this Chapter.

INERTIAL IMPACTION

Particles in an airstream have mass and velocity, hence have a momentum associated with them. As the air and entrained particles pass through the filter medium the air takes the path of least resistance to flow and diverts round the fibres of the filter medium. The particles, because of their inertia, tend though to travel in a straight line and as a result, those particles located at or near the centre of the flow line impact on the fibre and are removed (see Figure 4.3)

Filters employing the inertial impaction mechanism are humble panel filters. These comprise a matt of fibres which is between 13 to 50mm thick, the thicker the better to provide as many obstacles (filter target fibres) as possible to produce sufficient deviations of the airstream. Typically the fibres are around 35µm in diameter and can be of graduated density so that the atmospheric contamination is collected throughout the depth of the matt, rather than just at the front.

The larger the particle and the faster the airstream the greater the particle's inertia, so the higher the likelihood of impaction taking place. However, if the velocity is too high, the particle can be blown off the fibre, so reducing the overall efficiency.

Filters relying on inertial impaction as a consequence start becoming ineffective at velocities through the filter medium above 3m/s. Below about 1.5m/s their efficiency drops off, due to the reduction in momentum. They are also only effective against the larger particle sizes, those above 5µm diameter, which, whilst accounting for just over half the total mass of typical atmospheric contamination, only account for a tiny percentage of the total number of particles present in the air.

This type of filter can typically remove 85% of 5µm particles from the airstream, but its efficiency drops to around only 15% for 1µm diameter particles. Put another way, 85% of the 1µm particles will pass through, will penetrate this type of filter.

DIFFUSION/ INTERCEPTION

Small, very light particles follow the airstream but are, under certain conditions, intercepted by molecular attraction forces between the particles and the filter fibres. This is called the interception principle.

Furthermore, all extremely small particles (<1 μm) are subject to erratic motion, termed Brownian motion, which is caused by colliding air molecules, so that they move in a random fashion around the fluid flowlines. It is possible to trap these small randomly moving particles by placing densely packed obstacles in their path. As the particles diffuse through the obstacles, hence diffusion principle, they are trapped. See Figure 4.4 for a depiction of the diffusion/interception principle.

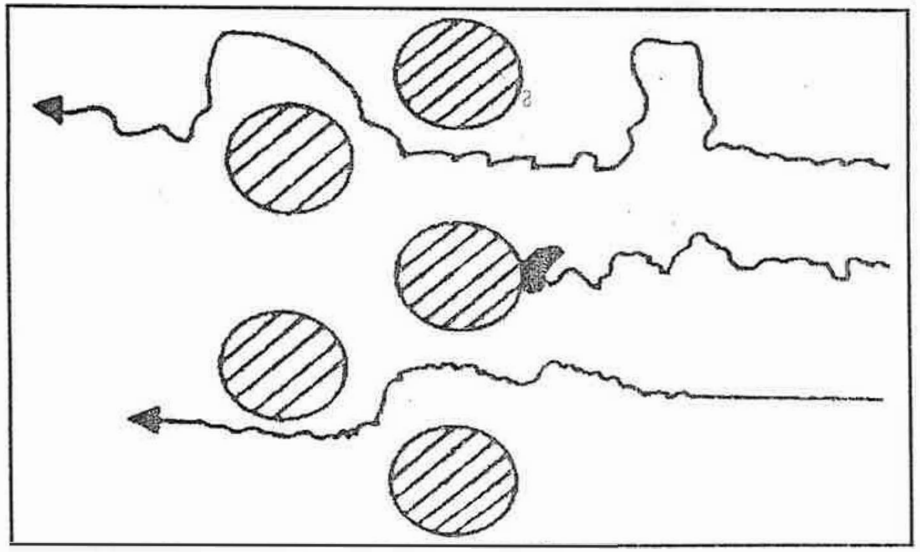

Figure 4.4 Interception/Diffusion Principle

All medium/high/ultra-high efficiency air filters, including bag, cartridge and HEPA (High Efficiency Particulate Air) filters employ the diffusion/interception principle. To help the process the air velocity through the filter is reduced to between 0.1m/s and 0.2m/s in the case of medium/high efficiency filters, either by fashioning the medium into the form of deep pockets (bag filters) or deep pleating it (cartridge filters). The velocity through the medium and the fibre diameter govern the filter efficiency - the lower the velocity and the finer the diameter the higher the efficiency, especially against the smaller particles. Typically the fibres used are

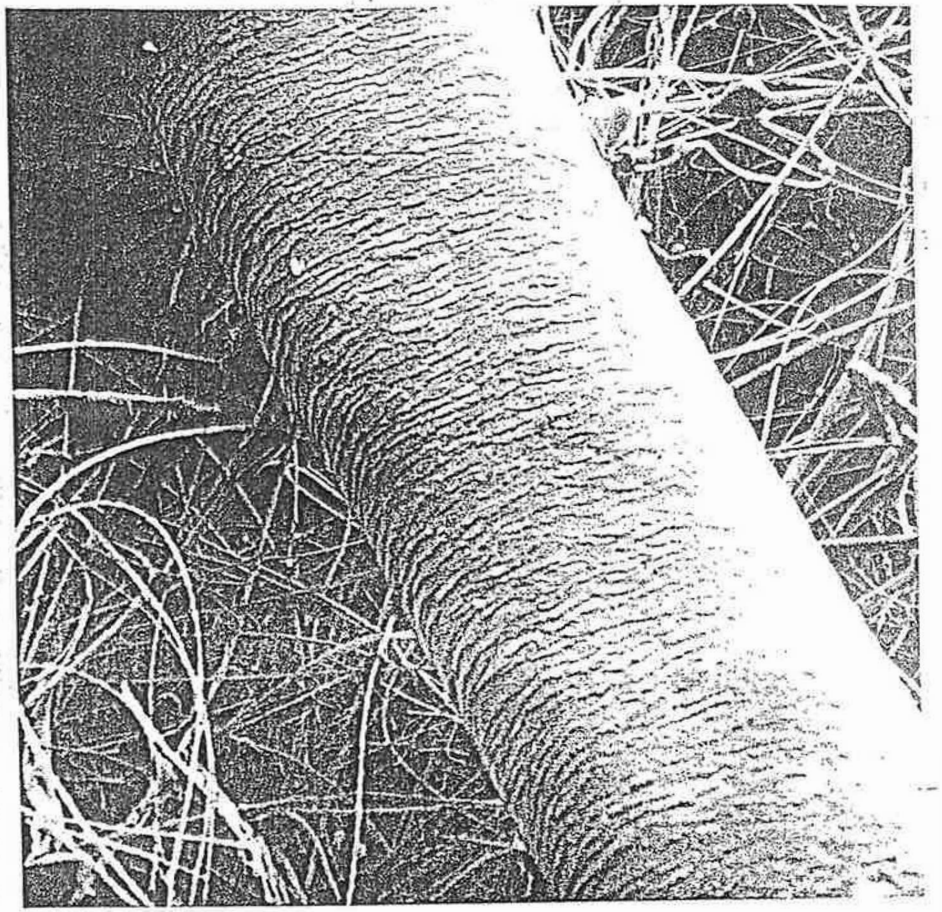

Figure 4.5 Human Hair Caught in Bag Filter Medium

less than 1μm diameter, as can be seen from Figure 4.5, a highly magnified electron microscope photograph of a human hair (35μm diameter) caught in a bag filter. Note that fibres, because of their relatively long length, are the exception as they are sieved out of the airstream by an air filter.

A high efficiency filter, class F8 to European filter standard EN 779, will remove 99.5% plus of 5μm particles from the airstream, and will only let 10% or so 0.5μm diameter particles penetrate. Figure 4.6 shows the comparative performance of three differing classes of filter against 0.5, 1 and 5μm particles.

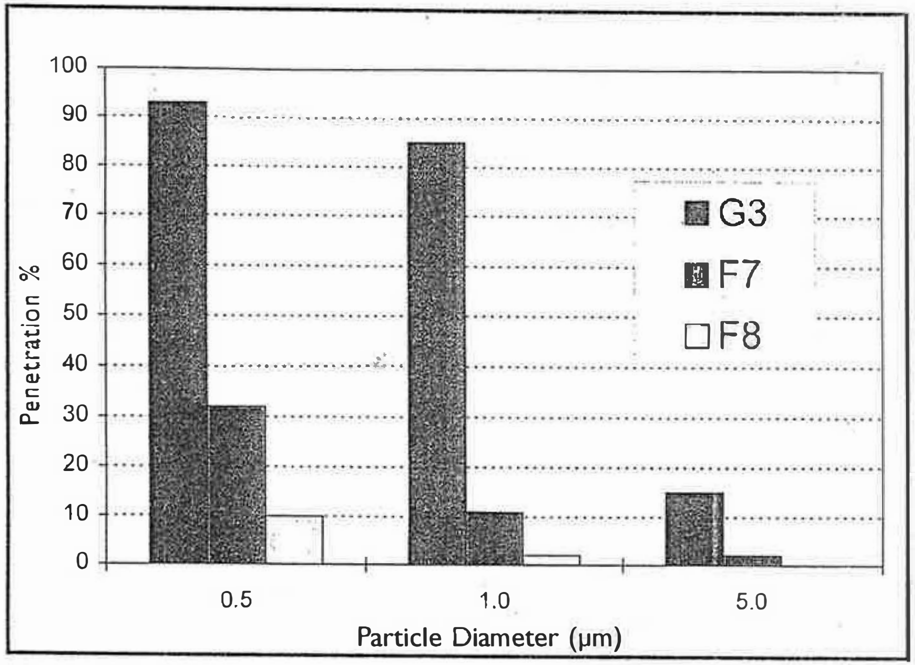

Figure 4.6 Penetration of a Filter as a Function of Particle Size and Filter Class

THE CORRECT FILTER TYPE

It is an unfortunate that with air filters it is almost axiomatic that as their efficiency increases, so does their cost and operating resistance. Possibly that is why so many installations have nothing better than panel filters, often poor ones at that, which as Figure 4.6 indicates, do virtually nothing to stop the dangerous, fine particles from entering the building. They are there to protect the items of plant such as heat exchangers from being affected by a build up of larger particles. They certainly are not there to protect the occupants.

At the other extreme, it would be completely unwarranted to install HEPA filters, which are capable of intercepting between 99.5 and 99.999995%, depending upon the filter grade, of even the most penetrating particles (these are approximately 0.2µm in size). Unwarranted unless there are special requirements, such as within a laboratory handling health-hazardous material. Using HEPA filters for general applications cannot be justified, due to their high cost and high pressure drop.

Most suitable are filter classes F7 or F8. Certainly an F7 filter is very effective against $PM_{2.5}$ particles, typically allowing only 5% or so to penetrate. But if the suspicion were substantiated that it is the ultra-fine particles that are the real health risk, then F8 filters would have to become the norm, as their performance when challenged by sub-micron particles is several orders better than that of the next grade lower filter.

CORRECT INSTALLATION

Air cannot be allowed to come through random holes in the building. The building must be slightly pressurised and airtight, the importance of which is beginning to be appreciated, so that air is only drawn in through the ventilation inlets, from where it is forced to pass through air filters.

Very obvious, but sometimes overlooked, is the siting of the inlets. These should be as high as possible, certainly away from street level and basement car parking, from where vehicle emissions can be directly drawn in.

Through-the-wall ventilation or air conditioning equipment rarely has other than a minimal panel filter, often so thin as to be of dubious efficiency, so is not recommended. All fresh air, even for decentralised systems, should be introduced into the building by air handling units, which can be fitted with effective filters of the required efficiency.

Finally, but not least, filters should be maintained and changed frequently. Seals need to be checked/replaced to prevent the by-pass of unfiltered air. After all, a filter is only as good as its seal. Also, there are now filters available which are treated with an antimicrobial. Filters can themselves become a potential hazard to IAQ if left too long between changes such that they can become a source of odours and growth of mould, mildew, fungi and bacteria. An antimicrobial can help combat this.

THE FUTURE

With the worldwide interest currently being shown in the harmful effects of particulate pollution we can expect to see research that more positively identifies and more precisely quantifies the problem. Meanwhile, the Government is trying to reduce the level of particulate pollution, but despite current efforts, has admitted that the UK will not reach its pollution target for particulates by 2005 as planned. Hence the need for effective filtration will definitely still be there.