# A New On-Site Performance Test for General Air Conditioning Filters

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## ABSTRACT AND INTRODUCTION:

The paper reports on development of cost effective on-site testing of air cleaning filters with regard to the size of particles which may cause health problems because they are respirable into the lungs.

The development is highly desirable to enable quality assurance to be determined at commissioning and during operation of equipment. It will also provide a reality check on the efficiency ratings of filters and assist in the study of health problems.

The test method is intended for general air conditioning filters such as those used in offices and shopping centres.

(The AS1324-1996[1] rating test reports are currently not reliable due to the substantial divergence of results being reported by the laboratories and the many defects which are inherent in the supply and installation of filters.)

AIRAH Victoria Division sponsored two Swinburne University students to research the test methodology which uses portable Laser Particle Counters (LPCs).

## Keywords:

Air filter testing, laser particle counter, AS1324, fractional efficiency.

## 1 BACKGROUND

The need for effective general office air filtration has become a greater issue in the last 10 years due to improving technology quantifying health risk from air-borne pollutants. Current Australian Standards for testing such air filters for capture efficiency of submicron particles are considered unsatisfactory and an improved and cost-effective laboratory test method is not yet available.

Presently no on-site filter testing methodology is known for determining fractional filtration efficiencies using LPCs. However, due to recent developments in LPC accuracy and robustness, it is opportune to develop a suitable test method.

This paper describes

1. A brief background to Australian filter testing
2. The research and test methodology findings
3. A proposed Australian test standard
4. Initial findings

## 2 A BRIEF BACKGROUND TO AUSTRALIAN FILTER TESTING

From 1973 when it was published, until 1996, AS1132[2] has been used for laboratory performance testing of filters for office air conditioning.

Results with No.4 dust were very similar to overseas results from testing to ANSI/ASHRAE 52.1-1992[3] composite dust. Results with No.1 dust were also similar to overseas results from Atmospheric Dust Spot efficiency testing to ANSI/ASHRAE 52.1-1992. For this period a typical air filter specification comfortably met was "average No.1 dust efficiency being not less than 15%".

When the NSW Health Department[4] and AS1668.2[5] introduced new regulations and incentives in 1991 for filters of higher efficiency (No.1 Dust 20% minimum), the industry found it challenging to provide low cost filters to this performance for the low design changeover resistance of filters common in Australia at that time (typically 125 to 150Pa).

The resulting increased testing to No.1 Dust revealed concerns about the accuracy and repeatability of the No.1 Dust test method.

Thus it is highly desirable to establish a supplemental test method for determining the efficiency of filters at capturing submicron particles to assure purchasers of the air cleaning ability of their installations and to assist in the assessment of the experimental error believed still to be exhibited by comparative test methods.

Opportunely, developments in Laser Particle Counters seemed to provide a solution. Prompted by research in the USA leading to the ASHRAE 52.2P[6] standard for laboratory testing air filters with LPCs, AIRAH Victoria division sponsored research by Swinburne University students into an on-site method of testing general air conditioning filters.

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A LPC test methodology was chosen in lieu of mass or stain measurement as LPCs enable determination of fractional efficiency and can be performed non-destructively on site using ambient dust.

## 3 FRACTIONAL EFFICIENCY TESTING WITH LPCS

The principle of the test method is to determine particle counts upstream and downstream of a working air filter, and determine the efficiency of the air filter calculated as:

Efficiency = 100%-(downstream count) / (upstream count) x 100.

As modern particle counters determine a spectral count showing counts for different particle size ranges, the efficiency can be determined for different particle size ranges. Thus the fractional efficiency may be determined.

However there are several sources for experimental error, hence research was needed, particularly in:

(a) Use of one or two particle counters
(b) Deposition in sampling tubing
(c) Isokinetic sampling
(d) Sampling time research and test methodology findings

The research encompassed the following areas:

(a) Study of available LPCs and selection of a suitable instrument.
(b) Investigation of testing method alternatives
(c) Defining the test methodology
(d) Testing, analysis of results and refinement of the methodology

### 3.1 Particle Counters

LPCs are laser optical devices which count individual particles in a small volume air flow. Over the years there has been great evolution in their design. Several of the latest LPCs are substantially superior to earlier models. It was important to research available LPCs to select an appropriate instrument for the intended function. A brief summary of findings follows.

Three counters were found to fulfil the initial parameters.

**1. TSI Abacus 301**

Sample size 0.3 - 10 micron

4 Channels 0.3 - 1.0, 1.0 - 2.5, 2.5 - 4.0 and 5.0 - 10 micron

Resolution: 0.3 micron at 50% counting efficiency

Overload …10,000,000 particles/ft$^3$

Software for PC

Weight 1 kg

Portable, easy to use, solid state reliability

Low maintenance (rechargeable batteries)

**2. Instrument B**

Minimum sample size 0.3 micron

Overload 100,000/ft$^3$

Weight 6.8 kg with batteries

5 channels variable

**3. Instrument C**

Sample size dependent upon model, from 0.1 micron and larger

Overload from 70,000 particles/ft$^3$ up to 640,000,000 particles/ft$^3$ (with 90% accuracy)

8 channels variable

Counting efficiency > 50% at 0.1micron

Weight 19 kg

### 3.2 Assessment of Particle Counters

Findings were:

**Instrument B:** not suitable for general air-conditioning on-site tests as it is easily overloaded.

**Instrument C:** Too heavy for multiple site, on-site testing.

At the time of the test, the **Abacus** was the obvious choice as it was relatively cheap, portable and able to cope with the high normal particle concentration levels present in an office air conditioning system.

### 3.3 Research

A standardised test dust may have some advantages. However, ultimately, it is the satisfactory performance in the field application that is required. Hence an on-site test method using ambient dust was chosen for the research.

The Test Methodology was developed through three phases:

(a) Familiarisation with instruments and office air particle counting.

(b) Design and experimentation with a single LPC using valve switching and multi inlet sampling manifold.

(c) Design and experimentation with a test method incorporating a pair of LPCs.

### 3.3.1 Familiarisation with Instruments

This initial phase involved using the Abacus in an office environment to understand instrument operation and to develop awareness of typical data. Aims included:

1. Investigate how concentrations vary with time, and
2. To estimate the minimum sampling time required to provide averages representative of long-term sampling.

### 3.3.2 Twin vs. Single Instruments

Two alternative test methods were considered:

(a) Use one LPC with an automatically controlled valve to repeatedly alternate between upstream sampling and downstream sampling.

(b) Use a pair of LPCs, one sampling upstream and one sampling downstream.

Using a pair of instruments has advantages:

- For both upstream and downstream sampling, the instruments can be adjacent sampling points hence inlets are at the same ambient air pressure as the instrument, reducing possible experimental error.
- Shorter tubing is also possible, again reducing experimental error.
- Instruments only have to purge their suction lines at the start, hence a greater proportion of suction pumping produces useful data.
- The pair of instruments with in-built clocks can be started at the same time, so data downloaded to a computer spreadsheet is easily synchronised, upstream with downstream.
- Most errors from a malfunctioning instrument can be quickly revealed by side-by-side comparisons before and after tests.

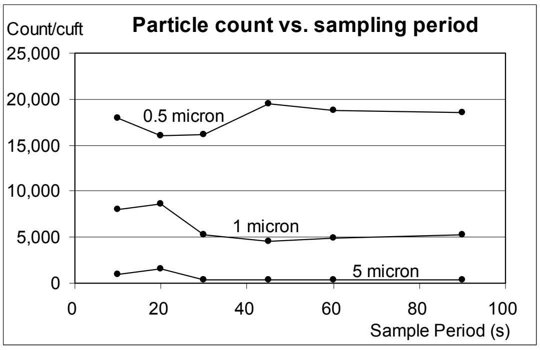
Method (a) using the one instrument to sample both upstream and downstream cancels some types of instrument error. However, alternation of upstream and downstream sampling extends test time.

Method (b) has the advantage that upstream and downstream sampling are concurrent, so on-site time is nearly halved for the same number of samples. Also possible errors from unmeasured deposition in the sample switching valve are eliminated with the removal of the valve. Synchronised dual instruments can also measure almost the same air sample, reducing errors from varying dust concentration.

Initially it appeared that the instrument capital cost would be a major burden for testing, and so Method (a) was thoroughly investigated. Eventually it was found many results were suspect and the test method was time consuming, hence subsequent tests used Method (b).

### 3.3.3 Sampling Time

To find the most appropriate sampling time, consecutive multiple samples were counted over various periods of time, sampled from upstream and downstream of the filter. The sample times tested were: 10, 15, 20, 30, 45, 60, 90, and 120 second samples. When grouped together on a single graph, the results showed particle concentrations determined for samples shorter than 45 seconds were not representative of long term average particle concentrations.



Most trials resulted in cyclic variations in downstream interval counts. It was thought this was due to periodic loading of filter media followed by periodic shedding of dust as air turbulence on media rearranged particles.

The ratio of downstream count over upstream count had similar cyclic variations supporting this explanation.

Occasionally, spurious variations in upstream count were also observed. These were largely unpredictable but may have been due to varying occupant movement stirring up dust from carpets, or the opening of doors, wind gusts, wind direction, nearby building works and truck movement, etc.

Thus in the proposed standard test method, it was decided to perform repeated sampling counts at 1 minute intervals to expose cyclic variation due to shedding, and to test for a minimum of half an hour to minimise influence of other time-varying influences. Also, where possible, outdoor air dampers should be shut during testing.

### 3.3.4 Sampling Manifold

The office air filter banks tested ranged from face dimensions of 1.2m x 1.2m up to 4m x 3m, and the filters were normally exposed to highly turbulent air. It was initially considered desirable to sample via a manifold arrangement with multiple sampling inlets over the whole filter bank face, and use one LPC with valve switching to alternate upstream and downstream sampling.

Studies of likely residence times of samples traversing tubing from intake points to the instrument revealed that tube lengths and inside diameter should be minimised for Method (a) alternated one minute sampling, however excessive air flow restriction could be imposed by small bore tubing.

The initial compromise was to use a 4-intake manifold covering a single 610x610mm air filter.

#### 3.3.4.1 Sampling Tubing

**a) Material**

Different tubes cause different levels of deposition, hence it was important to utilise appropriate tubing.

After consulting several authorities, Hytrel[7] was used for the sampling tubing as its very smooth bore was internally lined to counteract electrostatic deposition effects.

**b) Transport Tube Diameter**

**Isokinetic** sampling assumes that drawing air into the transport tube at the same velocity as the surrounding air flow velocity will create less flow disturbance and therefore present a representative sample for analysis by the particle counter. Therefore, tube diameters were calculated using the volume flow generated by the particle counter pump and measured air velocities in an air conditioning filter bank (typically 2.5m/s).

#### 3.3.4.2 Manifold Joints

For Method (a), two manifolds were required to transport the samples. A four-into-one manifold to connect the four inlets into a single transport tube, and a two-into-one manifold to connect the upstream/downstream sample tubes to the particle counter. The manifolds were commercially available units utilising 45 degree convergence angles. Ideally, manifolds using smaller angles would be superior but it was assumed that these would be adequate for initial testing purposes.

#### 3.3.4.3 Valves

To measure Method (a) samples with one instrument, a valve was required to rapidly alternate sampling from upstream and downstream tubes. This required a pair of solenoid valves chosen for low restriction and minimum deposition possibilities.

### 3.3.5 Purge Period

To ensure that the particle counter was presented with the uncontaminated sample air using Method (a), the tube residence time for sample particles was considered. The particle counter pump flow rate, sample tube diameters and lengths, and fitting volumes were used to find the minimum time required to purge before sampling alternation. In the purge period, an air sample is drawn but not used for counting.

### 3.3.6 Test Method For Single Particle Counter

The sampling sequence initially trialled [Method (a)] with the multi point inlet and tube system was:

- Draw sample from upstream of the filter (45s)
- purge from the upstream side (5s)
- operate the valve to cause sampling from the manifold on the downstream side of the filter
- purge from the downstream side (5s)
- sample from the downstream side (45s)
- purge from the downstream side (5s)
- change the sample to the upstream side
- purge from the upstream side (5s) then sample etc...

In this way, each sample was uncontaminated by air from the other side of the filter.

### 3.3.7 Testing Variations

Testing revealed promising arrestance figures close to what could be expected, but repeatability was poor. The changeover valves were suspected to be the cause as previous tests showed that the tubing had only a minor effect on data count. As a clean, reliable electromagnetic valve system could not be cheaply or quickly procured, and the losses due to the impediment to the airflow would remain questionable, it was decided to trial testing with two instruments with no manifold or tubing attached. This also provided isokinetic sampling for the air velocities present. We believe the more promising results of Method (b) were due to reduced deposition.

### 3.3.8 Problems Encountered and the Revised Test Method

With the single particle counter system, although manifold joints were designed to minimise deposition using careful selection of components, results still appeared inconsistent and deposition was considered the likely culprit, particularly in the switching valve. The switching valve was eliminated and all further tests utilised a pair of LPCs, one sampling upstream while the other sampled downstream. Immediately results were more consistent with less perturbations.

The flow restriction from sampling isokinetically through a manifold of small bore tubing was also thought perhaps excessive and to possibly cause deposition at tube joins. Trials were then done with a single isokinetic sampling tube with no joints and no sharp bends. Immediately results were again significantly improved in consistency with fewer perturbations. Of particular interest, when an upstream event caused particle counts to increase, a similar increase was usually noted downstream. Thus with the simplified test arrangement with two LPCs and simple tubing, the minute-by-minute fractional efficiency results varied considerably less than with earlier test equipment arrangements.

Some trials were made with samplers positioned in different regions of the filter bank without much variation in result. It would appear that for a bank of identical air filters exposed to similar turbulence, use of a manifold of sampling points may not be mandatory. But there are many installations where turbulence is not uniform across the filter face. Further research is warranted.

### 3.3.9 Test Method

The following describes Method (b) steps used for the results reported below:

- Choose positions for each instrument either side of the filter bank. Close outdoor dampers so only return air is sampled during the test.
- Program both instruments for approximately 90 sampling cycles of 45 second sampling period and 15 (or 5) second purge period. Place both instruments side by side upstream of the filter bank and start them at the same time.
- After 5 minutes, transfer one instrument into the downstream plenum to sample air there for 20 minutes.
- Then exchange instruments and continue sampling for another 20 minutes.
- Return downstream instrument to upstream, and again sample side by side for 5 minutes.
- During each test batch, record test times, mixed air temperature, humidity, wind strength and direction. Also record face velocity and proportion of outdoor air to return air if dampers were not kept closed.
- When testing is finished, retrieve each instrument, and download data immediately into a notebook computer. Import downloaded data into a suitable spreadsheet program template and analyse.
- Provided the side-by-side readings are in concurrence, calculate the average of the average fractional efficiencies determined for the two runs.
- The first 2-3 readings, the middle 3 readings (more if data shows this is necessary) and the last 2 readings should be discarded.

## 4 TEST RESULTS

The following is the result from testing a filter bank in a multi-storey office building in Melbourne with dampers set to 100% return air. The filters are rated F4 by AS1324.2-1996 tests. The results disagree with the filter's F4 rating (20 <= Em < 40).

| RATED 20% No.1 DUST EFFICIENCY FILTER | | | | | |
|---|---|---|---|---|---|
| No. | Date | Time | Count/cuft. | | 0.5-1μm |
| | | | Up | Down | Effi |
| 3 | 19/07/99 | 12:14:17 | 69150 | 61770 | 10.7% |
| 4 | 19/07/99 | 12:16:17 | 76420 | 65050 | 14.9% |
| 5 | 19/07/99 | 12:18:17 | 73300 | 65390 | 10.8% |
| 6 | 19/07/99 | 12:20:18 | 73760 | 65420 | 11.3% |
| 7 | 19/07/99 | 12:22:18 | 40690 | 37050 | 8.9% |
| 8 | 19/07/99 | 12:24:18 | 72090 | 62000 | 14.0% |
| 9 | 19/07/99 | 12:26:19 | 75330 | 68710 | 8.8% |
| 10 | 19/07/99 | 12:28:19 | 60950 | 54990 | 9.8% |
| 11 | 19/07/99 | 12:30:19 | 73500 | 67600 | 8.0% |
| 12 | 19/07/99 | 12:32:20 | 73150 | 66840 | 8.6% |
| 13 | 19/07/99 | 12:34:20 | 71670 | 65800 | 8.2% |
| 14 | 19/07/99 | 12:36:20 | 84650 | 77180 | 8.8% |
| 15 | 19/07/99 | 12:38:21 | 75870 | 69070 | 9.0% |
| 16 | 19/07/99 | 12:40:21 | 72200 | 66710 | 7.6% |
| 17 | 19/07/99 | 12:42:21 | 74600 | 68390 | 8.3% |
| 18 | 19/07/99 | 12:44:21 | 70870 | 59830 | 15.6% |
| **0.5-1μm EFFICIENCY RESULT:** | | | | | **10.2%** |

The following table shows the results from testing a portable fan filter unit having 3 filter stages. The filter unit was tested in a building undergoing fit-out. The results supported the visual observation that the final HEPA filter was damaged.

**RESULT FOR A COMPOSITE FILTER**

| | | | Count/cuft | | 0.5-1μm |
|---|---|---|---|---|---|
| No. | Date | Time | Up | Down | efficiency |
| | | | | | |
| 1* | 06/08/99 | 10:18:45 | 29910 | 33180 | -11% |
| 2* | 06/08/99 | 10:19:36 | 33015 | 33540 | -2% |
| 3 | 06/08/99 | 10:20:26 | 38220 | 7635 | 80% |
| 4 | 06/08/99 | 10:21:16 | 36765 | 9180 | 75% |
| 5 | 06/08/99 | 10:22:06 | 37020 | 6810 | 82% |
| 6 | 06/08/99 | 10:22:56 | 36750 | 9915 | 73% |
| 7 | 06/08/99 | 10:23:46 | 37515 | 8760 | 77% |
| 8 | 06/08/99 | 10:24:37 | 36495 | 9405 | 74% |
| 9 | 06/08/99 | 10:25:27 | 35205 | 10770 | 69% |
| 10 | 06/08/99 | 10:26:17 | 36120 | 6315 | 83% |
| 11 | 06/08/99 | 10:27:07 | 35250 | 7560 | 79% |
| 12 | 06/08/99 | 10:27:57 | 33510 | 6315 | 81% |
| 13 | 06/08/99 | 10:28:47 | 46530 | 6450 | 86% |
| 14 | 06/08/99 | 10:29:38 | 35070 | 8130 | 77% |
| 15 | 06/08/99 | 10:30:28 | 46380 | 8475 | 82% |
| *Results 1&2 discarded. | | | Mean: | | 78.2% |
| | | | StdDev: | | 4.6% |
| | | | 95% CL: | | 2.5% |
| L.P.Counter positions swapped | | | | | |
| 16 | 06/08/99 | 10:31:18 | 47640 | 6825 | 86% |
| 17 | 06/08/99 | 10:32:08 | 45480 | 6720 | 85% |
| 18 | 06/08/99 | 10:32:58 | 41205 | 5715 | 86% |
| 19 | 06/08/99 | 10:33:48 | 33810 | 7785 | 77% |
| 20 | 06/08/99 | 10:34:39 | 37350 | 7005 | 81% |
| 21 | 06/08/99 | 10:35:29 | 38865 | 8640 | 78% |
| 22 | 06/08/99 | 10:36:19 | 38250 | 5610 | 85% |
| 23 | 06/08/99 | 10:37:09 | 37260 | 7695 | 79% |
| 24 | 06/08/99 | 10:37:59 | 35430 | 7545 | 79% |
| 25 | 06/08/99 | 10:38:49 | 35985 | 4965 | 86% |
| 26 | 06/08/99 | 10:39:40 | 39945 | 6090 | 85% |
| 27 | 06/08/99 | 10:40:30 | 41835 | 6885 | 84% |
| 28 | 06/08/99 | 10:41:20 | 39315 | 7350 | 81% |
| 29 | 06/08/99 | 10:42:10 | 40035 | 7455 | 81% |
| | | | Mean: | | 82.4% |
| | | | StdDev: | | 3.3% |
| | | | 95% CL: | | 1.7% |
| **0.5-1μm EFFICIENCY RESULT:** | | | | | **80%** |

# 5 CONCLUSIONS

## 5.1 Pitfalls & Trouble spots

The research revealed a number of significant sources of error that the unwary could encounter inadvertently in on-site Fractional Efficiency testing with LPCs.

(a) *Variations with time* – sampling upstream and downstream must be concurrent through identical sampling tubes (and at the same air flow sampling rate) because in the field, particle count density varies significantly with time.

(b) *Sample for suitable duration* – preliminary findings are that results appear to become significant and representative only after taking repeated 45s samples over a minimum of 30 minutes test duration.

(c) *Isokinetic sampling* – although literature strongly recommends isokinetic sampling, some trials reveal its importance may be exaggerated, especially for submicron particles which are dominated by viscous effects.

(d) *Avoidance of Deposition* – sampling tubing must be of an appropriate selection and diameter, and have few bends and joins to minimise deposition.

(e) *Overloading* – LPCs are highly sensitive instruments, and even when properly used, require regular calibration. To minimise damage, LPCs should only be exposed to particle densities within their specification.

(f) *Cross Calibration* – although use of a pair of LPCs doubles testing rate and enables concurrent sampling, part of the testing methodology must include cross calibration (side-by-side sampling of air before and after each test) to reveal any instrument bias.

In particular, the research revealed that a five-minute fractional efficiency test using a single LPC cannot provide significant results that represent the average performance of the filter.

## 5.2 Proposed Australian Standard Test

The research has confirmed the viability of an Australian Standard On-Site Fractional Efficiency Test method using suitable modern portable Laser Particle Counters and appropriate test steps.

The authors were tempted to draft this method however we consider that further research is first warranted; in particular, more practice and experience are required with the final, twin instrument test method and potential experimental errors need further investigation.

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