Guidance On In-Situ Filter Efficiency Testing Within The UK For Nuclear Facilities – ISNATT Air Cleaning Technology Conference 2022

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G Hall, AWE Plc, Reading, UK

ABSTRACT

HEPA Filter efficiency testing has been conducted within the UK Nuclear industry since its inception in the 1950's. Changes in technology and standards have brought about many changes in techniques and installation philosophy.

This paper describes a brief history of filter efficiency testing along with current methods and details of possible measurement errors.

INTRODUCTION

From time to time there is a requirement to test the efficiency of ventilation High Efficiency Particulate Air, HEPA, filters whose role is to collect particulate dust from discharge airstreams. In the UK the current standard method is to perform an efficiency test with the filter in position, in-situ, using a Dispersed Oil Particulate, DOP, challenge.

The aim of the document is to give basic information for a beginner to this subject as well as more advanced information for designers and practitioners. It should also provide a basis for debate on the various topics.

This discussion document details:-

- The Standard Test Method
- A Brief History Of Filter Efficiency Testing And The UK Adopted Dispersed Oil Particulate Mixing Length Testing.
- Filter Testing Standards
- Injection And Sampling Point Details
- DOP Injection And Sampling Characterisation
- Measurement Accuracy
- Possible Filter Test Regime Errors
- Licence Site Test Parameters
- Mixing Devices
- Possible New Methods For Adoption

SCOPE

The scope of this document is to give a low and medium experience level guide to in-situ filter efficiency test methods used within the UK nuclear industry. The guide is based around the “ductwork mixing” method of measuring the efficiency of filter installations. Established methods used by UK manufacturers for checking the efficiency of high efficiency filter products are also listed.

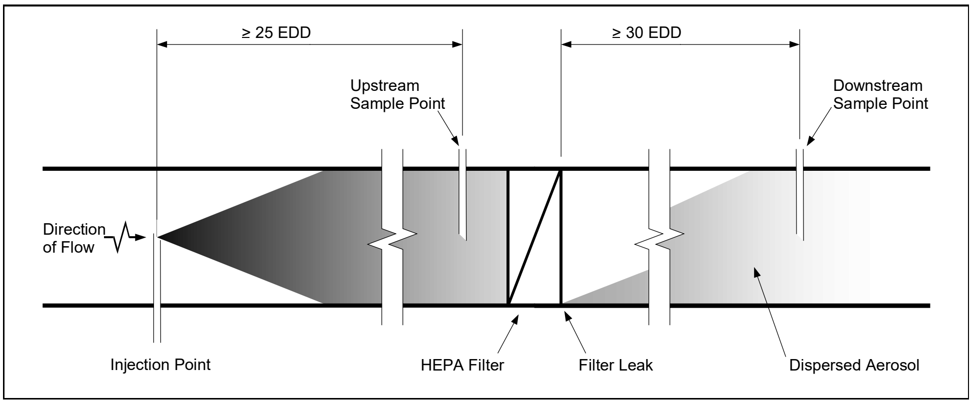
The document also describes measures to overcome practical problems encountered with in-situ testing.

GENERAL PRINCIPLES FOR DOP INSITU FILTER TESTING

Generally, the final stage filters, also called abatement filters, of a nuclear facility will have high efficiency filters. These filters will often require efficiency testing to demonstrate that they will meet the stated particulate capture claims within their safety cases.

As standard the UK use a “duct mixing” method where a particulate challenge is injected into the ductwork upstream of the tested filters, the particulate challenge mixes within the duct through diffusion and air turbulence, a sample of the air just before the filter is measured to determine the challenge concentration, any leakage of the test media through the filter is mixed in the airstream after the filters and a sample is removed and the particulate concentration measured. The filter efficiency is simply a ratio of the challenge upstream concentration to the downstream concentration. As can be seen the method is very simple and can normally be performed using portable equipment.

Fig 1. Typical filter test configuration.



The particulate challenge commonly used is a Dispersed Oil Particulate, most commonly known by its initials DOP. With DOP testing within the UK the particulate challenge is a light mineral oil which is thermally vaporised in the presence of CO_2 and condenses to form a uniform particulate challenge of oil droplets of around 0.3µm diameter. The abatement HEPA filters used in UK Nuclear Facilities normally have filter media manufactured from fibreglass bound together with fillers and processed into a sheet material. It's been known for some time that the most penetrating particle size, MPPS, for the fibreglass filter media is around 0.15µm *(note: This changes with velocity)*. Therefore although the challenge produced from using DOP is not at the MPPS for the filter paper, its ease of use and consistency of results has allowed its use to continue.

Within the general non-nuclear industry, the downstream challenge is commonly measured using a scanning method, where a probe is traversed over the back of the filter element to detect any challenge penetrating through the filtration media. However due to issues with trying to reliably access the rear face of a filter when in a nuclear facility and the lower efficiency levels often required, e.g. DF of >1000, the "mixing length" method where the test challenge is mixed within the downstream duct gives enough test accuracy to satisfy the measurement requirements.

Upstream and downstream particle measurements performed with photometers give a mass, as opposed to a particle count, measurement. This is ideal as in the nuclear industry we are looking to limit the mass of particulate discharges as opposed to the number of particles.

BRIEF HISTORY OF FILTER EFFICIENCY TESTING

In the 1950's the UK nuclear industry looked towards the method already developed by the Chemical Weapons Defence establishment at Porton Down. Porton had developed the Methylene Blue and Sodium flame filter efficiency test equipment in the late 1930's, ref 1. Within many nuclear sites the Methylene Blue laboratory particulate dye test was adopted and the British Standard detailing its methods followed in 1957 (BS 2831).

Fig 2. Methylene Blue Particulate Dye BS 2831 Test Rig (Copyright British Standards)

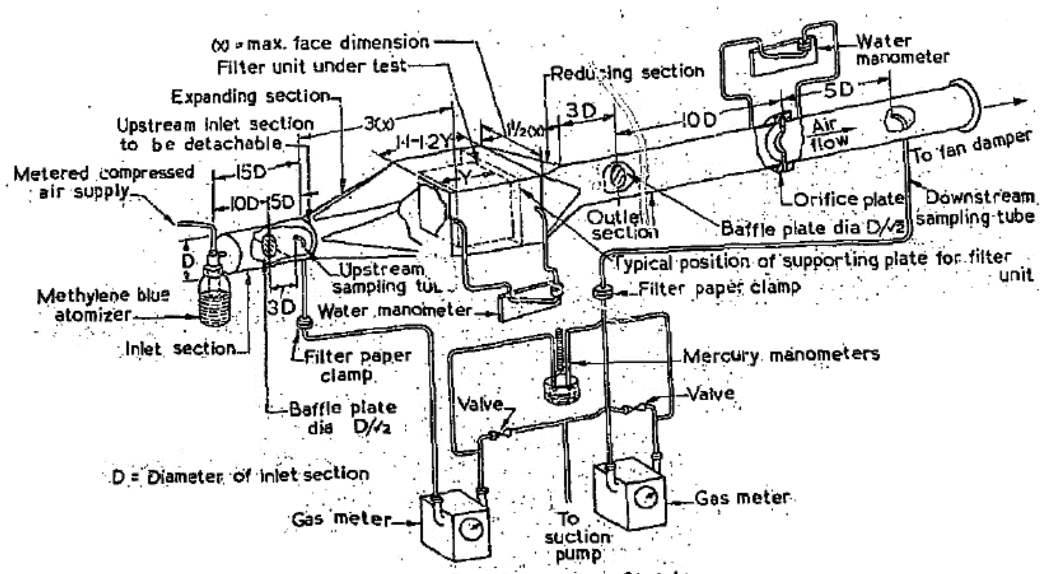


Fig. 9. General arrangement of test rig.

With the Methylene Blue laboratory testing the filter housings, complete with filters needed to be moved to a test rig and efficiency tested, before being installed in the facility. As such filtration systems were designed where the filters and housing together could be easily replaced. It is believed that the original design was to replace both the filters and housings, although it is understood that some lightly contaminated housings were de-contaminated and re-used. In practice most of these early filter housings had two HEPA filters in series. As the second filters saw very little dust loading the first filter was usually only changed leaving the housing and second filter in place. This situation gave rise for in-situ testing techniques to be developed and put into practice

These early types of housings have spigot features for easy canister removal and replacement. Because the filters were designed to be tested off line the ventilation systems were often designed with insufficient mixing lengths for subsequent conversion to fully compliant in-situ testing. For the actual filter testing in the laboratory the Methylene Blue Dye was dissolved in water and sprayed into the duct where the water evaporated leaving the dye particles of approximately 0.5µMMD. Samples before and after the filters were passed through filter papers. The amount of dye captured was measured allowing a determination of the filter efficiency. The test took about 1 hour per filter to complete. Of note the diagram in BS 2831 shows baffle plates to encourage **sample** mixing and the downstream sample point to be placed 18 duct diameters after the filter housing.

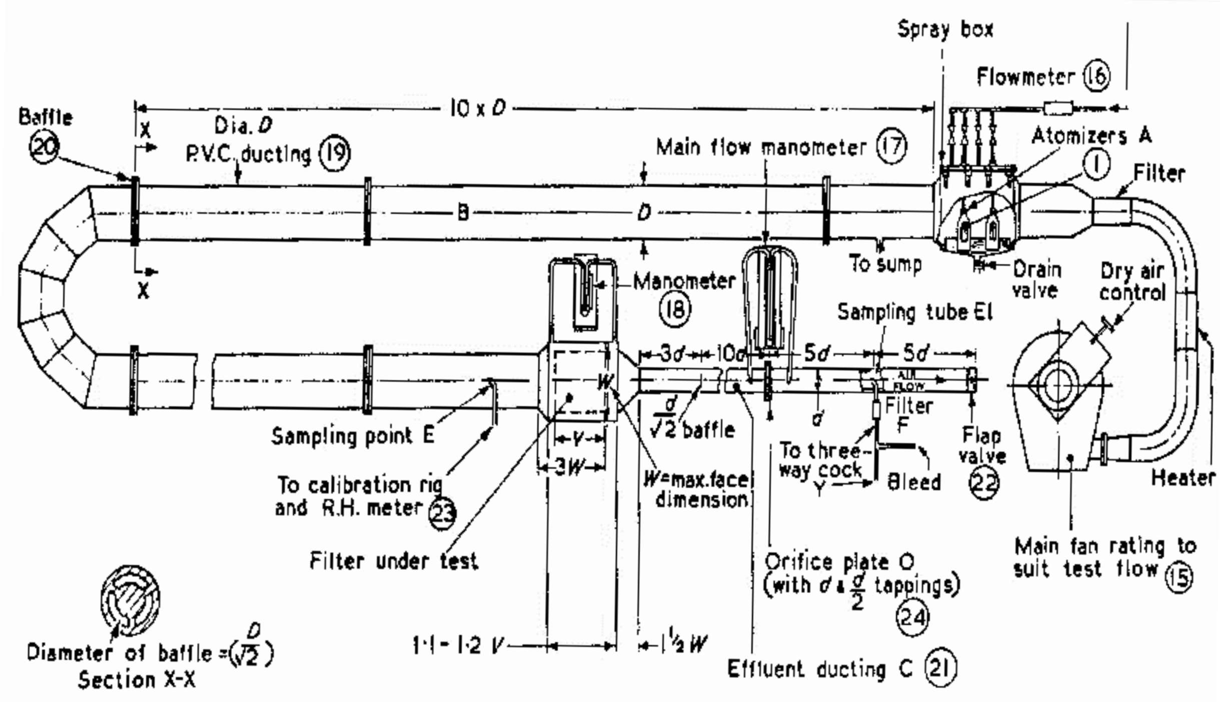
Fig 3. 1960's Filter Housings With Removable Filter Canister

The sodium flame test developed at Porton Down used the same Methylene Blue atomiser (subsequently also used for respirator testing's – BS 4400). After WWll R.G. Dorman working at Porton decided to use the sodium flame test on ventilation filters for protection against germs and particulate forms of poisonous agents. The atomiser was increased in size, the compressed air increased to 100psi and the salt concentration increased from 1% to 2%. The flame photometer was exactly the same as used for testing the respirator filters. Sodium flame testing became a British Standard in the early 1960's and was confirmed as such in the later still current version of this standard in1969.

While Porton Down were developing filter efficiency test methods Tom Hodge working at Harwell developed an alternative form of the Sodium Flame photometer. It burned methane, not hydrogen, and used a premixed flame, i.e. a gas/air mixture. The detector in the Harwell rig used a light sensitive resistor, rather than the photomultiplier used in the Porton rig. Tom convinced HEVAC and Eurovent that his apparatus had advantages over the British Standard equipment, and it was adopted in a Eurovent Standard. However, the later development of the CEN standard and its adoption of particle counting rather than mass concentration as the measure has overtaken both methods. (Particle counting is of course best for checking ultraclean environments as airborne cleanliness is measured in terms of particle numbers.) Most of the Nuclear filter manufacturers still use the sodium flame British standard for the very good reason that it measures mass concentration of salt rather than particle numbers; for radioactivity at least it is concentration of activity i.e. mass rather than particle numbers that interest the regulators.

In recent times the allowable manufactures filter test method has been increased to allow the efficiency to be measured with DOP, while leaving the pass mark the same.

Fig 4. BS 3928 Sodium Flame Test Rig (Copyright British Standards)



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The development of mobile photometers and particle counters has allowed a practical in-situ test. One of the early popular test methods used particulate thermally generated with Dioctylphalate, DOP. However, this was later believed to be carcinogenic and was later replaced in the UK with the Dispersed Oil test, which was also called DOP.

There are today many alternative test aerosol media generated either thermally, i.e. by vaporisation and condensation, or by pneumatic atomisation of liquids using Laskin or other pneumatic nozzles, or by ultrasonic dispersion, *e.g. Workers at AEE Winfrith developed a test method using nuclei [similar to atmospheric nuclei] as a challenge both for testing of filter units and for in-situ testing of installation. The detection device was a simplified Wilson cloud chamber. The whole arrangement was portable and convenient in use.*

Of interest the French developed their Uranine in-situ test where the test is in-situ performed as per the DOP test but using filter papers to collect the samples which are developed and counted within a laboratory normally external to the building under test – See ISO 16170. *(The filter papers used are membrane filters; they are washed with ultra pure distilled water and the solutions analysed fluorimetrically.)*

FILTER TEST STANDRDS

There have been many national and international standards. Each test is subtly different so although a comparison can be made between tests, this will not tell the whole truth.

The three main factors effecting the efficiency measurement are:-
A, Test challenge particle, shape, size and particle distribution.
B, The method of challenge measurements, mass or particle count.
C, The type of leak within the filtration medium, via the filter media of through seal leaks.

Different tests use different test particles. The technology of how to produce dust and particles is actually vast so can't be touched on in any great detail in this simplified text. The main parameters when looking at test particles are aerodynamic diameters, particle shape, and size distribution.

The following is a list of the old and current filter efficiency test standards.

Table 1. Past and present filter efficiency test standards. *(Used in the UK)*

Standard	Title/Commentary
BS 2831	Methods of test for air filters used in air conditioning and general ventilation – 1957 – Gives details of the Methylene Blue Filter test and Dust loading tests (Withdrawn)
BS 3928	Method for Sodium Flame Test for air filters – 1969 – Details the flame photometry method for filter efficiency testing using sodium chloride as a test dust. (Under review)
ISO 29463-1	High efficiency filters and filter media for removing particles in air – Part 1. Classification, performance testing and marking.
ISO 29463-2	High efficiency filters and filter media for removing particles in air – Part 2 : Aerosol production measuring equipment and particle counting statistics.
ISO 29463-3	High efficiency filters and filter media for removing particles in air – Part 3. Testing flat sheet filter media.

ISO 29463-4	High efficiency filters and filter media for removing particles in air – Part 4 : Test method for determining leakage of filter elements – scan method
ISO 29463-5	Test method for filter elements (testing at MPPS – inlet challenge concentration within 10% over the duct, isokinetic sampling)
ISO 16890-1	Air filters for general ventilation – Part 1: Technical specification requirements and classification of systems based upon particulate matter efficiency (ePM)
ISO 16890-2	Air filters for general ventilation – Part 2: Measurement of fractional efficiency and airflow resistance.
EN 779	Particulate air filters for general ventilation. Determination of the filtration performance. (withdrawn)
EN 1822	High efficiency air filters (EPA, HEPA and ULPA). Determine the efficiency of filter elements (Superseded by BS ISO 29463-5)
ISO 16170	In situ methods for high efficiency filter systems in industrial facilities. (Covers both DOP and Uranine)

With a Nuclear type ventilation system for high hazard airstreams it's standard to install multiple stages of HEPA filters. The actual safety claim at each stage is normally much lower than the HEPA filters measured performance, so normally a maximum decontamination factor of 1000, or less, is claimed per stage. With multiple filter stages the first stage will normally remove 99.9% or greater of particles in the air stream and the second stage 99.9% of the particles which are left. Although this is an over simplification as the particle challenge distribution will be modified as it passes through each filter stage, see ref 2. In this way two filters in series should have a DF of greater than 1,000,000. With most HEPA filters the measured DF values are normally greater than 10,000. Therefore, for a filter to be reduced to the DF of interest, 1000, it's normal that there has been a weakness in the filter, such as leakage at the seal or a tear in the media. With such a defect the "filtration" mechanism is vastly different to the air passing through the filter media, there being no real MPPS for a seal leak. Therefore, when comparing filter standards there is the choice to either compare the test results of filters with their maximum efficiencies, filters with efficiencies at the manufactures pass/fail level or filters at the licence sites pass/fail criteria, or perhaps at various efficiencies. However, this still won't uncover the true relationship between the various tests as the ratio of seal leakage to media penetration will still be an unknown variable. So, when comparing apples with apples it's very important to understand what attribute of the apples you should be looking for.

As can be seen there is only one national or international standard which covers DOP testing, ISO 16170. This document introduces the principle of "accountancy tests" and "integrity tests". The "accountancy test being required to make an accurate measurement of filter decontamination factor and the "integrity" test to confirm there are no significant leaks. This compromise was written into the standard to allow the French to continue to use the Uranine test media and the rest of the world to carry on with what they were using. If the UK were forced to adopt the Uranine off line test this would have caused a lot more work for very little return.

INJECTION AND PRE-FILTER SAMPLING POINTS.

For standard UK DOP the test challenge is generated by heating the particulate generators mantle to 500°C and carefully injecting the Shell Ondina oil in the presence of an inert gas, usually CO2. The generated test media challenge is then injected into the ductwork at a concentration of 40ug per litre of air duct flow. This type of particle generator is very simple with the calibration being a check to test the heater element actually is maintained at 500°C. The volume of DOP produced is relative to the amount of oil reaching the heater, which can be varied by adjusting the volume control. Standard portable DOP generators are available to give the required 40ug/l concentration into duct flows of 63 to 9015 l/sec (833 to 119,000 m3/hr).

Depending on the ductwork configuration single or multiple point injection probes are used. Traditionally the holes on UK nuclear injectors face downstream, where other industries have the holes facing upstream. The required standard distance from the upstream sample is shown in Table 2 for single and multiple point injection probes.

Table 2. Standard Mixing Lengths

Injection Holes	Distance To Upstream test Point	Upstream test Point To Filter	Filter To Downstream Test Point
1	25 Dia	3 Dia	30
4	12 Dia	3 Dia	15
16	6 Dia	3 Dia	7

Normally if the duct is under a negative pressure there is enough draw to pull sufficient test media into the duct. On occasions for large systems multiple smoke generators need to be used. Ultimately if the aim to achieve a test media concentration of 40 ug/l can't be met the test is performed at a lower concentration, which may require a small alteration to the standard test method calculations.

For room ventilation systems where sufficient mixing lengths have not been provided in the ducting an alternative can be to inject the DOP into a room extract grill.

Where inlet systems are to be tested a positive displacement pump will be required to push sufficient DOP challenge into the duct.

The test challenge should be distributed within the duct to within 10% of the average concentration at the upstream sampling point. The upstream sample point is always a single point device as the test challenge should be well dispersed at this point. This device normally samples from the middle of the duct.

Within the filter housing the test challenge should then meet the filter. Should the filter test flow rate be different from the normal flow rate, which is not often the case, then test inaccuracies may be introduced due to the change of the flow patterns and approach velocities.

Where there is a sudden divergence of the duct to accommodate a much larger filter housing area the flow at the filter edges may be a little smaller than the middle. How this effects the filter efficiency is normally determined by experiment. However, if the upstream challenge is well mixed before reaching the divergence any less flow through the filter edges should not be an issue provided the test flow rate is similar to the actual flow rate.

DOP POST FILTER SAMPLING

Post filter any test challenge passing through the filter will need to be mixed within the airstream, a sample of which is taken from the duct and the test concentration measured. The sample once measured is then returned to the duct or discharged to the laboratory via a HEPA filter. *(Sampling downstream of a fan would normally provide a well mixed sample)*

For a single point probe, 30 diameters mixing are recommended downstream of the filter for adequate mixing. This length can be shortened by using multiple orifice sampling probes at positions as per Table 2.

DOP INJECTION AND SAMPLING CHARACTERISATION

As detailed before the test challenge media is generated by heating the Shell Ondina Oil on a 500°C heated plate in the presence of a CO2 cover. The oil condenses to form a spherical particulate with an average particle size of around 0.3um.

On new systems it would be expected that the HEPA filter test points would be designed to give the recommended mixing lengths and that all sample points would be easily accessible.

The test challenge should be uniform within 10% of the average reading across the duct at the upstream test point. This can be measured by taking a traverse across the duct provided sufficient tapping points have been included in the ductwork.

Testing the downstream mixing lengths will require a similar process, with suitable tapping points available to make a downstream duct traverse and injection point just after the filter.

It is important that the test concentration is measured using the test media which is planned to be used for filter efficiency measurement and not a substitute gas with different diffusion properties, i.e. Helium is not to be used for filter test point substantiation as its diffusion properties are very much greater.

Ideally a test to show that with the filter removed and the differential pressure adjusted using the filter housing isolation valves the upstream and downstream readings should be within 5%. Obviously, removal of the HEPA filter could only be carried out on a clean non active system.

For characterisation of the downstream test points another method to determine the collection efficiency is to measure the particulate concentration through the normal sample position and then measure at a second point further downstream and compare the two. The second downstream point may have a smaller concentration due to air leaking into the ductwork but should in theory have a similar reading.

Where filter test point characterisation is required on an in-use contaminated system then filter test point characterisation will normally be limited to the measurement of mixing lengths.

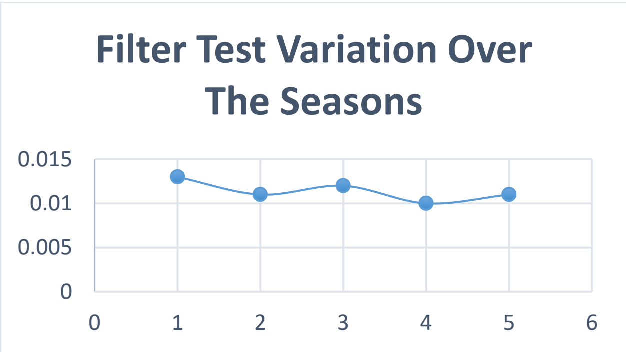
MEASUREMENT ACCURACY

There are many factors which can influence test accuracy. The main issues are:-

- Incorrect mixing lengths
- Dilution from duct leakage or branch flows
- Instrument accuracy
- Duct flow velocity
- Temperature
- Humidity

One indication of how accurate a test is judged to be is the repeatability of test result, either using the same or different test equipment. If testing 12 monthly the conditions with respect to duct flow velocities, temperature and humidity will likely be the same, giving a similar result. However, this is not necessarily an accurate result as the errors in the measurement will likely be the same. With six monthly testing seasonal variation can normally be seen in the test result, see fig 5. Having consistent results does not reflect that the test is accurate, but only the same measurement errors are being consistently repeated. The efficiency test in the UK is to determine if a filters efficiency has decreased since last tested with an acceptance that there will be an inaccuracy in the result. So, provided that all the errors in the previous test are still present any change in filter efficiency will be revealed by a measured change in test result. Therefore, the measured change from the last result is more important than the actual test value. This however will not be true if the sample points are positioned where they do not take representative samples.

Figure 5 - Typical 6 monthly filter test result.



To understand the fuller picture a fully analysis of filter efficiency test "accuracy" is detailed below by the various test parameters:-

Mixing Lengths – Under ideal conditions, good mixing on the upstream side of the filter (good being defined as +/- 10% of the mean test media concentration value at the upstream test point) and with representative sampling both upstream and downstream, the overall uncertainty of the measured penetration should be well within +/- 40% on a single measurement. Shorter mixing lengths will give decreasing accuracy in results. Where a single downstream test point is mounted less than 2 diameters from the filter no claim from the filter test measurement could be made.

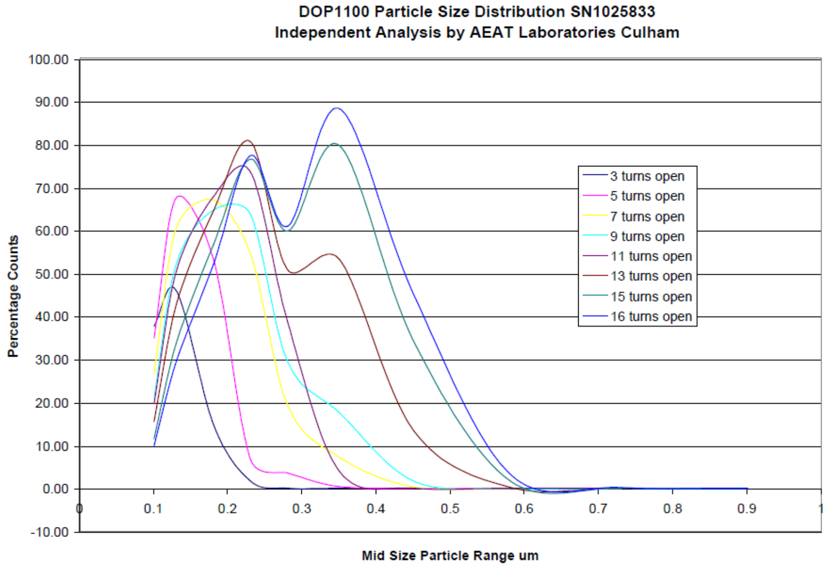
Dilution Issues – This is basically air leaking into the duct test section. Issues with dilution flows in the test ductwork are covered in more detail in the para on "Possible Filter Test Regime Errors". These can have a variable effect depending on the size of the dilution flows and duct flows. Correction factors may be able to be calculated and applied. The effect on the test result will very much depend on the dilution circumstances.

Test Instrument Accuracy - A typical photometer will measure DOP concentrations to a precision of about +/-10%. However as the test media concentration both upstream and downstream is measured by the same photometer some of the inaccuracies should be repeated and so cancel out. This accuracy will also depend on the sample concentration. The sampling hoses should be the same length and diameter. This is important if the length of the sampling hoses exceeds 10 meters. Note: The loss of DOP aerosol has been stated in a coiled 10m length of 10mm bore tube to be about 5% at the flow rate of 0.5 l/sec.

Duct flow – The amount of DOP needed to be thermally generated is dependent on the duct flow. The higher the duct flow the more DOP needs to be generated. Although a thermal DOP generator can vary its DOP output the physics of the generation causes larger particles to be generated with larger flows, see Fig 6. The larger the particle size the lower the measured penetration. So basically a filter in a low volume flow duct will have a measured penetration higher than when the same filter is inserted in a higher flow duct using the same measuring equipment. Moving from a mean particle diameter of 0.11 micron to 0.32 micron may double the filters measured capture efficiency.

Additionally at very low flows the DOP generators tend to present the oil onto the heating plates as large droplets, which gives a very uneven output.

Figure 6. Particle Size Distribution For The DOP 1100 Generator (Copyright ATI)



Temperature And Humidity – There is a direct correlation between temperature and humidity levels and test result. These are regarded as some of the smaller effects when compared with other factors at only around +/-5%. Interestingly other test aerosols such as Uranine do not suffer as greatly from temperature and humidity issues, but a +/-5% variation is small when compared against the overall accuracy. The test result variation in Fig 4 when measuring at six monthly intervals is likely due to changes in temperature and humidity levels.

The expected test accuracy from a well-designed system is within +/-40%. Poorly designed and retro fit systems should achieve a test accuracy of better than +/-60%. Very poor retrofit systems may give a test accuracy of +/-80% or worse. The required test accuracy needed will depend on the safety and reliability claim made. Actual real world tests with process particulate show that the first stage filters normally have a high capture efficiency due to the challenge having a wide particle size distribution. Subsequent filters have a lower efficiency as the challenge particulate is now nearer the Most Penetrating Particle Size, MPPS. Therefore, measuring filter efficiency with particulate near the MPPS will be conservative for the first stage filter and will be close to the actual efficiency for subsequent stage filters.

POSSIBLE FILTER TEST REGIME ERRORS

Filter test regime errors can broadly be divided into four categories, which are:-

A, Incorrect mixing lengths.
B, Dilution flows.
C, By-pass flows
D, Low system flows

Incorrect Mixing Lengths

The issues with incorrect mixing lengths are simply a matter that the test media does not have time to correctly mix by the time it reaches the sample point or filter, therefore giving an inaccurate filter test result. Sometimes an alteration to the injection/sampling points can be made by increasing the number of holes within the sample probes.

Where the ventilation system has been constructed in the 1970's or before, it is likely that the filter test regime consisted of removable filter housings which to change the filters the housings were removed, decontaminated and then moved to a station to be re-packed with filters and then Methylene Blue efficiency tested. The ducting was therefore in most cases not designed to give sufficient mixing lengths for DOP efficiency testing as there was no requirement to do so.

In most cases with these older systems the cost to install compliant mixing lengths would be excessive. The alternatives to modifying the ductwork is to install multiple probe systems, install mixing devices, inject into an upstream open grill (if possible) or accept that the accuracy of these system will be less than a modern purpose designed scheme. Having a lower accuracy the efficiency test may be unable to detect faults within the safety claim limits made for the system. A review of the process arising and abatement claims in the aerial effluent flow sheet would indicate if the safety claim, if there is indeed a claim, can be met.

Normally if the filter test media is passed through a fan this gives sufficient mixing to make up for any issues with the mixing length.

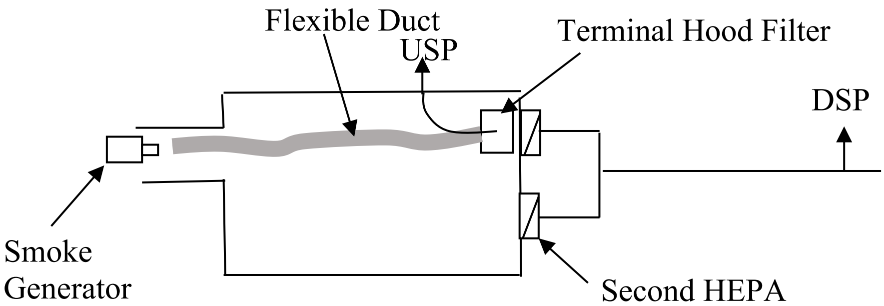
Dilution Flows.

Ideally there should be no joining ventilation branches within the filter test ductwork section, as this will obviously alter the test media concentration, possibly leading to an inaccurate test result.

However, during filter testing there are occasionally un-avoidable dilution flows which will dilute the up or down stream challenge. Where these situations occur, it may be permissible to calculate the dilution rates and modify the penetration calculated rates accordingly.

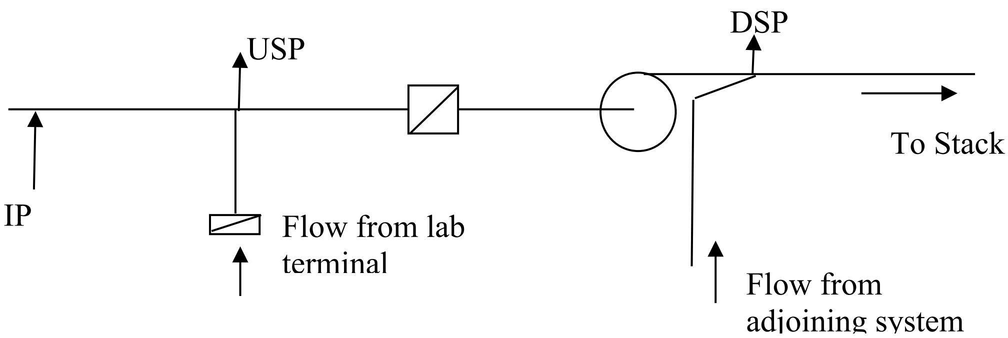
For example, Fig 6 shows a typical decommission containment extract with two terminal HEPA extracts. Using a suitable hood a smoke challenge can be introduced to each terminal filter at a time, however due to the ductwork configuration the second terminal filter will dilute any filter challenge before it reaches the downstream sample point. As the two terminal filters see a near identical particulate challenge the flows should be near identical. The measured penetration rate should be doubled to give the corrected penetration level.

Figure 7 Un-avoidable Dilution Issues Example 1



The second example at Fig 8 shows a branch joining the extract near the Upstream Sample Point and a branch joining the outlet to the stack near the Down Stream Sample Point. In these circumstances the effect on the filter test result will be very difficult to calculate as the flows will not have time to mix. As the plant may not have been designed to allow filter testing, i.e. we did not have in-situ filter testing in the 1960's, the retro fit test points can normally only be placed in poor positions. The only method to determine the effect these dilution flows will have is by experiment on the plant.

Figure 8 Un-avoidable Dilution Issues Example 2 – Dilution flows near to the sample points.



The third example will be on systems which have very low flows. With these types of systems the duct and filter housing leakage will have a bigger effect on the filter efficiency result than for systems with a more standard flow velocity of a few meters per second. One real plant example showed that the test smoke took 1.5 minutes to get from the injection point to the upstream sample point. The leakage could only be estimated to make a correction factor for the penetration. Additionally, the test time was increased to 7 minutes, keeping the smoke injection time at 2 minutes, to allow any penetrating smoke to get to the downstream test point.

By Pass Flows.

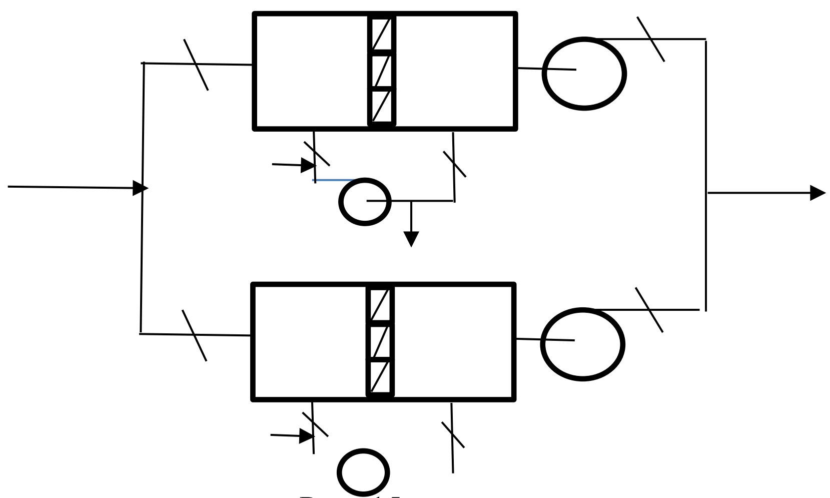
In its simplest form a bypass flow is where there is a shortcut around the filter. The filter test regime may or may not be able to pick up the bypass.

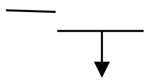
Where water filled manometers are installed over filter banks they can dry out if not maintained correctly and so a small percentage of the ventilation flow may simply take this route and bypass the filter. This type of issue should be identified during the filter test programme. Using modern diaphragm type pressure gauges will lessen the possibility of this issue arising although modern 5 port calibration valves can introduce their own bypass flow.

<u>Offline Systems.</u> During the 1980’s an “Off line” filter test method was developed and installed in a very small number of establishments. These systems used a separate fan to push the DOP through the filter system when isolated from the main extract. Ideally if a filter test could be conducted “Off line” and there was an issues with the new untested filter it would not be put “On line” before being corrected and so would not be called on to provide an abatement service.

Currently there are very few filter banks with an “Off line” filter test capability due to the inherent problems with such an arrangement. The only “off line” testable filter banks in the UK are a limited number of space extract ladder rack systems, see fig 9.

Fig 9. Typical Off Line Filter Test System.





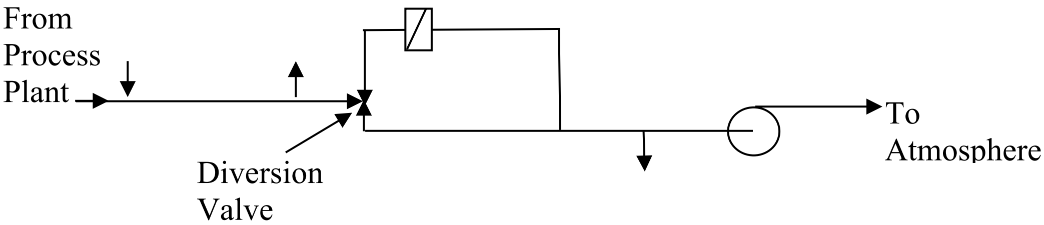
The main issues found from these “Off line” ladder rack systems are:-

- The main header isolation dampers are not fully leak tight, therefore a small dilution flow continuously passes through the ladder rack plenum. Before filter testing the air inlets and outlets need to be sealed up using plastic sheeting adding extra time and effort to the filter test programme.
- The off line DOP distribution fans only provide 10% of the normal flow. This effectively gives a different airflow pattern than at full flow and different pressures over any seal leaks. The MPPS would also be effected by the different air velocity. Experiments have shown that the same defect in a filter when moved lower or higher in the ladder rack gives a different reading in overall efficiency. To make an allowance for this possible inaccuracy the acceptable decontamination factor is altered to double the required level.
- The isolation dampers to shut off the filter test ductwork need to be very high integrity and need to be proved that they isolate fully after filter testing. If these valves remained open they could provide a massive unfiltered bypass route around the filters. This adds extra testing and components which could fail.

Diversion System Errors.

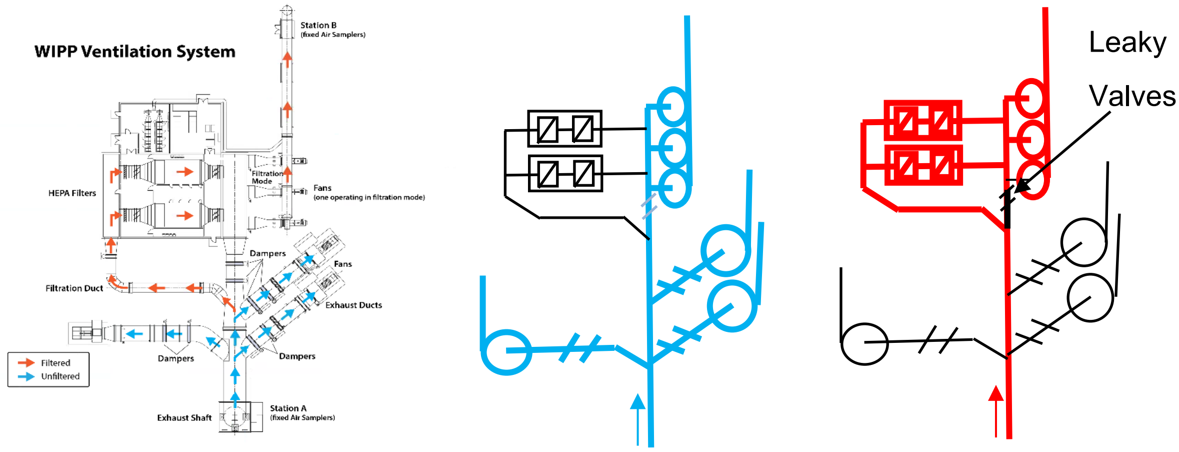
Diversion systems normally operate on unfiltered extracts and where there are any signs of contamination in the exhaust air this will cause the ventilation to be shut down or be diverted to a HEPA filtered route. Where a diversion valve is used the leak tightness of the diversion valve to isolate the flow to atmosphere needs to be proven to be able to be closed to an agreed leak-tightness specification. The penetration through the diversion valve and filtration system would normally be measured as a single unit, giving the overall DF as opposed to simply measuring the efficiency of the HEPA filter alone.

Fig 10. Diversion Valve For Part Time Filtered Systems.



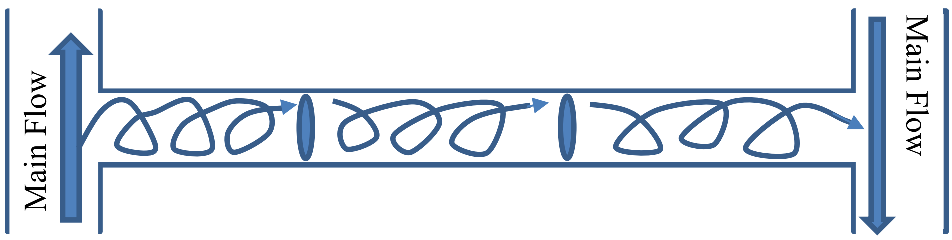
With the Waste Isolation Pilot Plant diversion filtered system, the normal designed extract flow is via the unfiltered system. Should airborne contamination be detected within the storage area the system automatically closes and opens valves to extract the discharge via HEPA filter. As can be seen from fig 11, the fans serving the HEPA filters are continually run, and a percentage of unfiltered air is run through them. When the diversion dampers close the full extract flow should be diverted through the HEPA filters. Unfortunately, as several of the dampers were a little leakier then realised, when a contamination release occurred in the storage area a percentage of the flow was discharged to atmosphere unfiltered which had leaked passed the now closed isolation dampers. Clearly this leakage failure mode had not been considered to be credible as two isolation dampers had been fitted in series.

Fig 11. WIPP Diversion Filtered Systems.



Where the is a reliance placed on isolation valves the obvious question is “how can they be adequately tested”. With the system shown with two valves the test particulate challenge needs to flow down the dead leg to the first valve, mix within the space between the valves, and then exit the second dead leg. The likely time to establish a full flow of the filter test particulate through the valves is going to be dependent on the valve leakage and the dead leg volumes. However if the filter test is only performed for 2 to 3 minutes, which is quite normal, then it’s unlikely the true leakage through the diversion valves will be measured. Ideally a different system of checking the diversion valves are closed, such as using butterfly valves with leak testable seals or pressurising the interspace between the valves and measuring the rise in pressure.

Fig 12. Diversion Valve Diffusing Particulate.



Systems With Low And Very Low Flows.

Systems with very low flows should be avoided if possible, where the filters need to be testable. If unavoidable extra air inlets may need to be designed into the system and opened up during filter testing. For the normal smoke generators used the minimum system flow is generally 63 litres per second. However, where the ductwork is very large giving a flow velocity of less than 0.5 m/sec this would also be designated as having a low flow and precautions taken appropriately. Systems with very low flows suffer from three main issues which are:-

- Leakage of air within the test section can cause dilution of the test smoke.
- An increased test time may be required to ensure a developed test smoke profile reaches the downstream test point.
- The minimum smoke generation may exceed the adjustment on the photometer to set correctly if the flow is less than 63 l/sec in the main duct.

Air leakage within the test section will proportionally cause a larger dilution as the duct flow rate decreases. It is unlikely the air leakage can actually be measured so an estimate may need to be made. This estimate could be based on measurable leakage rates from other parts of the system. Filter housings have more positions where they could possibly leak, so checks that leakage is minimised by having DP points capped etc. should be made.

The time taken for the smoke challenge to travel from the injection point to the upstream sample point can be relatively easily measured. This will then give the system flow rate, and so a calculation for the time the test media takes to reach the downstream sample point can be made. This will just be the time the photometer needs to be sampling and not the smoke injection time. The smoke injection time can still be the standard two minutes unless calculated otherwise.

Where the system flow is less than 63 l/sec only a percentage of the smoke generated will be needed to give the correct challenge concentration. Commercial units are available to reduce the smoke generated concentration by absorbing the unwanted percentage of the test media, normally by HEPA filtration. Where the system design has two stages of separately testable HEPA filters with low flow, the design of the smoke injection should be such that the two injection points can’t be accidentally cross connected, as this would provide a bypass to the first filter. To prevent this issue the absorption unit should be connected individually to each injection point via a flexible hose and not hard piped.

MIXING DEVICES.

As detailed earlier fans or long lengths of duct are one of the most effective mixing devices found so far. Where long mixing lengths or a fan are not available there are other established mixing designs available. However, with most of these mixing systems they cause losses within the ductwork causing inefficiencies and increased extract power consumption. Some devices such as Stairmand Discs can be rotated in the duct to reduce their profile and so reduce pressure losses, however the filter test team need to remember to move them back to their rest position after use and their “in use” position for filter testing. The most common mixing methods are:-

- Quickmix injectors.
- Discs
- Ring and donut mixers
- Komax mixers.
- Multiple Point Injection

The Quickmix device uses compressed air to deliver the filter test media into the duct at velocity and with some swirl. There is test data to show that 4 to 5 duct diameters are required for full mixing. Obviously, a pressurised air supply is required. One main advantage is that the Quickmix has a very small profile, and will therefore cause only a very small pressure loss. The current sole supplier of the Quickmix is Wozair.

The Stairmand disk is a plate which sits in the duct at half the duct area. The plate can be rotated to align with the flow during non-testing periods. However to get full mixing the filter test team would need to remember to turn the disk back to its filter test position, therefore placing a high reliance on this human interaction. Of interest both BS 2831 (Methylene Blue Test) and BS 2938 (Sodium Flame Test) show a disc type mixing plate. On the laboratory type configurations the rig will only operate part time so a loss of flow efficiency will not add greatly to the running costs and give the benefit of less pipework and a smaller rig footprint.

The ring and donut is similar to the Stairmand disk and causes mixing by generating a high amount of turbulence. Mixing lengths can be claimed as being reduced to 5.5 diameters, but at a cost of a pressure loss of 108 Pa or more depending on the flow rates.

The Komax Mixer is a commercially available mixing device which looks like an Archimedean screw approximately 3.5 duct diameters in length. This has a claim of reducing the required mixing length to 4.5 diameters, but at a pressure loss of about 245 Pa depending on flow conditions.

With multiple point injectors and samplers the idea is to inject or extract gas at an even flow rate among the multiple injection/sampling holes at positions of equal area so giving a representative sample without the full mixing. To draw an equal flow through the devices holes, the holes are designed relatively small when compared with the pipe size and normally ¼ or less of the pipe internal diameter. Details of multiple point injection and sample points can be found at Annex A.

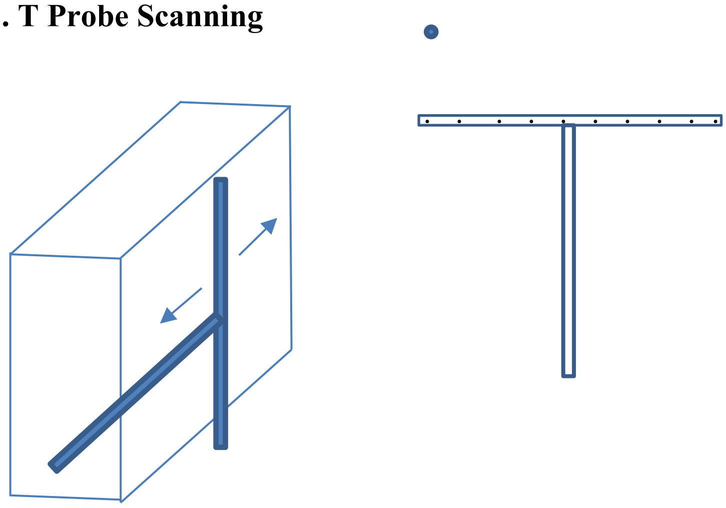
Possible New Methods For Adoption

<u>Filter Manufacturers Testing Procedure</u> - One issue of contention is that the factory efficiency test was until recently stated that only Sodium Flame testing could be used. Although the UK Nuclear Industry has had good past experience with using filters certified to this standard in some areas it is considered to be outdated. Approximately two years ago filter procurement standards for HEPA filters were changed to allow DOP efficiency testing to allow more competition in the filter manufacturing market.

<u>Filter Scanning T Poles</u> - Standard filter scanning using hand held probes has been used for non-nuclear systems for many years and to a very small extent in the UK Nuclear industry. However scanning systems have their advantages of being able to detect smaller leaks and not requiring any substantial downstream test length. Currently one site is looking at the use of scanning type T Probes where the downstream sample probe is formed into a pipe with a slot or multiple drilled holes is drawn at a set distance away from the filter rear face.

Unfortunately, there are currently no standards to cover such a scanning device, unlike for the traditional hand scanning "fish tail" or for the "mixing" length test. There also exists limited substantiation for the T Probe type devices. Further work will be required to substantiate a T probe device which should be performed at a repeatable distance away from the filter rear face. This would use a constant traverse velocity and a filter leakage rate equivalent to the site licence filter efficiency of interest, i.e. a DF between 1000 and 10,000. The T Probes have been successfully used within the Pharmaceutical industry and may in a limited number of cases provide a solution where insufficient mixing lengths have been provided in legacy plant. Current estimates are that the T probe will need to be situated within 25mm of the filter downstream face.

Fig 13. T Probe Scanning



Appendix A. Typical UK Multipoint Injection And Sampling Details

Provided in Annex A are typical single and multiple point sampling UK probe details.

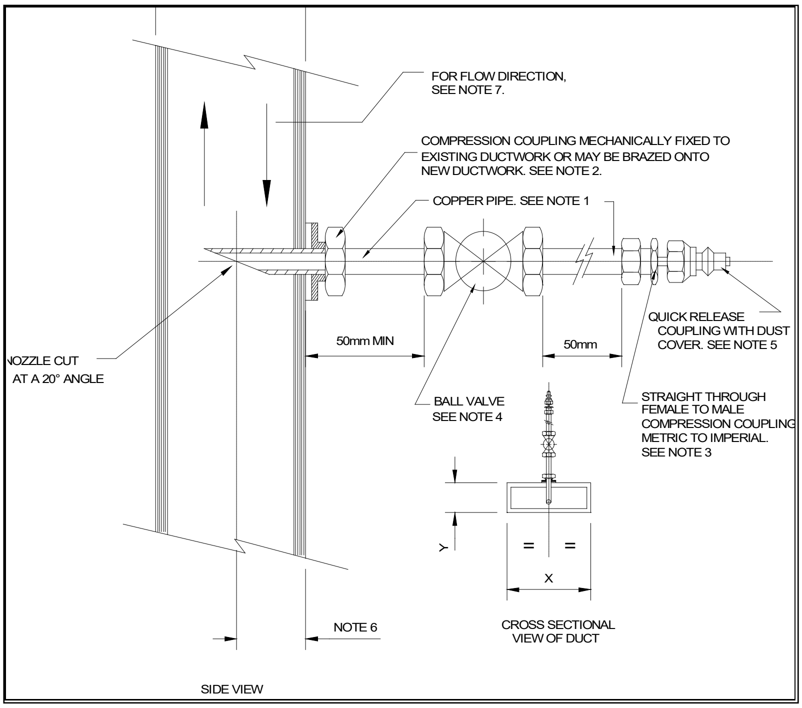


Fig 14. Typical Single Probe

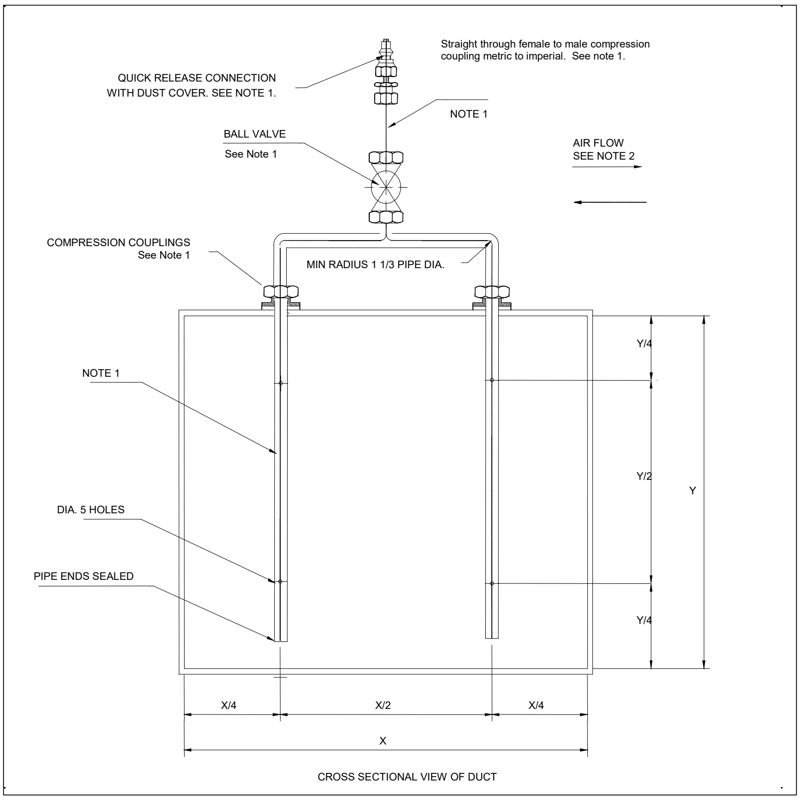


Fig 15, Typical 4 Hole Probe Array For Rectangular Ducts

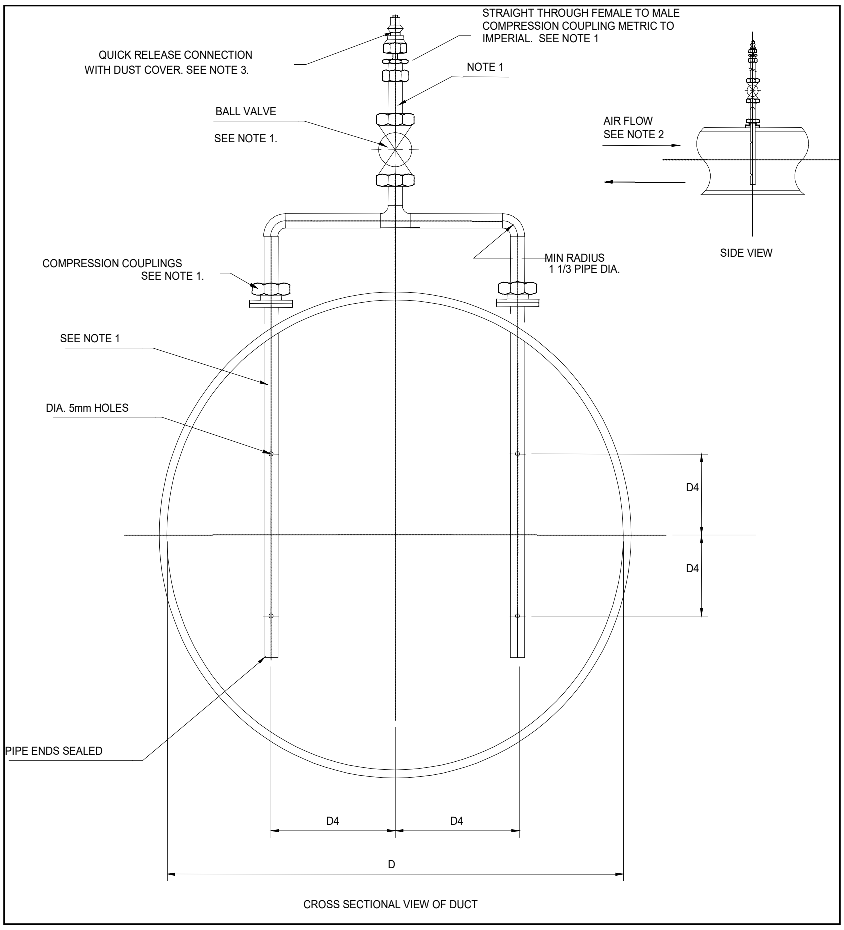


Fig 16, Typical 4 Hole Probe Array For Circular Ducts

References:

1. Private communication between G Hall/J Dyment
2. Filters, Filtration and DF's BNF.EG.0083_4, Ray Doig 1997.