RECOMMENDED METHODS FOR THE PRECONDITIONING OF ODOUROUS AIR PRIOR TO TREATMENT IN ORGANIC BIOFILTERS

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1 Summary

Operation of biofilters for piggery and poultry shed odour control in Korea, and in other parts of the world, has often been problematic for two reasons. Firstly, excessive dust in the incoming air can cause clogging of the organic biofilter material. Secondly, drying out of the organic biofilter can occur if the relative humidity of the incoming air is not close to 100%.

Dust is generated in sheds from the feed and bedding materials, and also dried out manure residue which is disturbed by animal movements. This is worse in hot dry summer conditions but may also be exacerbated in cold winter conditions where shed heating is used. Dust loadings from sheds are typically 1mg/m^3 but may exceed 10 mg/m^3. Dust particles may vary in size from less than 1µm to more than 100µm, with typically half the volume of the dust is less than 10µm in size.

For bacteria on the biofilm to be healthy and actively reduced odour, the humidity of air spaces inside an organic biofilter material should be as close to 100% as possible. This is achieved if the overall water content of the organic biofilter material is maintained at approximately 25% w/w. If the air entering an organic biofilter has lower than 100% humidity, the effect will be to dry out the organic biofilter material and the biofilm. The drier this air is, the more water is required to be sprayed onto the material and this may lead to poor organic biofilter performance.

The combined effects of dust and water together often leads to clogging causing inhomogeneous flow, preferential flow channelling, poor utilisation of all of the organic biofilter medium and reductions in odour removal efficiency. This can result in a significant decrease in the effective life of the organic biofilter medium. Replacement is expensive and inconvenient to do on a regular basis.

Recommended methods for air preconditioning are therefore :-

1) **Cyclone Dust Separation (CDS)** for coarse (>10µm) dust removal
2) **Trickling Biofiltration (TBF)** for fine (<10µm) dust removal, odour pre-treatment and humidification

It may be necessary to use multiple cyclones with a small diameter to remove fine particles (less than 10µm). Multiclones can be manufactured at relatively low cost and there are no moving parts so maintenance costs are minimal. Typical dust loadings are unlikely due cause clogging of the multiclone. Multiclones are therefore appropriate technology for intensive livestock industries.

Trickling biofilters are also easy and cheap to construct, the only component of significant cost being the flow controller units. As the trickling biofilter material is inorganic, water flushing can be relatively heavy and continuous to flushout and remove dust build-up. This should lead to an essentially maintenance free dust elimination process. Relative humidity of the organic biofilter incoming air should also be close to 100%.

2 Introduction

The air in Intensive Livestock sheds typically contains gases, odours, dust particles and microorganisms which are normally exhausted via ventilation systems to the surrounding atmosphere. All these contaminants can be easily carried by the wind causing a nuisance to nearby urban and rural neighbours.

The complete range of technologies available to treat odourous air has been classified by Georgaki et al (2003) as follows :

- **Biochemical** (activated sludge, bioscrubbers, biofilters)
- **Chemical** (scrubbers, thermal oxidation, catalytic oxidation, ozonation)
- **Physical** (condensation, adsorption)

Odour control in Waste Water Treatments Plants (WWTP) is commonly achieved using ***packed bed wet scrubbers,*** often with carbon absorbers used for final VOC removal or “polishing” (Quigley et al 2003). A cross-flow packed bed wet scrubber system specifically designed to treat odors from swine confinement buildings was originally described by Licht and Miner (1978). In addition to a 25% ammonia removal, they reported dust removals of 90% for particles larger than 5µm and 50% for particles larger than 1 µm, and 50% for airborne micro-organisms.

Packed bed scrubbers are referred to as ***trickling biofilters*** if a ***biofilm*** is allowed to develop upon the surfaces of the medium (Melse and Mol, 2003). Microbial communities reside in the biofilm and oxidize odourous compounds to less harmful products such as water, carbon dioxide and inorganic salts. Water exhausted from the filter medium is recirculated with small fraction continually replenished. An economic analysis of converting a wet chemical scrubbing system to a trickling biofilter filter is provided by (Gabriel and Deshusses, 2003)

Dry (or damp) packed scrubbers with an organic medium (and biofilm) are known as ***biofilters,*** and are being increasingly used as a successful odour control method in Europe and the USA (Classen et al 2000, Phillips et al 1995, Sheridan et al 2002). Biofilters may be of the open bed type (Nicoli and Janni, 1997) or closed bed (Phillips et al 1995, Classen et al 2000, Sun et al 2000, Sheridan et al 2002). Early biofilters are described by Noren (1985) consisted of peat and heather over slats. Odour removal efficiencies of biofilters was assessed at 50-90 % (O’Neill and Stewart, 1985). Several more recent studies have been aimed at identifying the optimum material for biofilters. This appears to be woodchips due to their structural integrity. A specialised product called biochips has been described by Martinec et al (19??).

For piggery shed exhaust air it has been demonstrated that odours are mostly in particulate form (Hammond et al 1977, Hammond and Smith, 1981). The problem of clogging of biofilters with dust has been mentioned by Noren (1985), Hartung (1985) and Nicolai and Janni (1997). Characteristics of dust generated by piggeries has been described by Stroik and Heber (1986), Heber et al (1988), Meyer and Manbeck (1986) and Hoff et al (1997). Filtering dust with a rock bed was attempted by Zeiziz and Munchen (1987). Classen at al 2000, Sheridan et al 2002 used conventional ***dust***

filters in their trials but emphasise that they require regular cleaning and maintainance. Large pressure losses can also occur across dust filters (Nicolai and Janni, 2001 and Sheridan et al, 2002). The use of ***cyclone separators*** has therefore been recommended by Iranpour (2002).

The moisture content of the biofilter medium has been identified as the most important parameter governing the efficiency of odour removal (Phillips et al m1995, Hartung, et al 1997, Classen et al 2000, Iranpour et al 2002, Sheridan et al 2002, Quigley et al 2003). It is likely that effective pre-humidification of the air entering the biofilters is required rather than water sprinkling, which may cause packing, anaerobic conditions and pressure loss within the organic filter material (Classen et al 2000, Sun et al 2000 and Sheridan et al 2002, Quigley et al 2003). Infra-Red measurements of the surface temperature of poorly performing biofilters has been carried out by Bockreis at al (2003).

Intensive Livestock odours (over 200 compounds) include the following :-

- Nitrogen compounds eg. amines, ammonia
- Sulfide compounds eg. H_2S, DMS, DMDS, mercaptans, thiophenol;
- Aromatic compounds eg. phenols, cresols, indoles, skatoles
- Volatile Fatty Acids: eg. acetic, butyric, propanoic and valeric acids.

Intensive Livestock shed odour concentrations can exceed 1000 OU.
Shed odour emission rates are approx 10 OU $m^3 s^{-1}$ ($\mu g\ m^{-3} . m^3 s^{-1}$) per SPU.
For a 1000 SPU piggery, the ou emission rate is 10000 ou $m^3 s^{-1}$. An Odour Unit (OU) is dimensionless and is defined as "the ratio of the volume of odour-free air required to dilute an odourous sample, so that only 50% of a group of human panellists are able to detect the odour"

The effectiveness of the organic biofilter depends on the health and effectiveness of microbes in the biofilm at capturing and decomposing pollutants and odours. Control of airflow and moisture are the most important tools in the maintenance of biofilm. Media that is too dry will not support a diverse and robust microbial community in the biofilter. Media that is too wet can become too dense and compact, resulting in reduced porosity, high back pressure and reduced airflow. If the airflow is not humidified to near 100% relative humidity, airflow though the biofilter will rapidly strip moisture from the resident media. This can occur rapidly even at modest airflow rates. The net effect will be negative impacts on the micro-organisms and reduced odour removal. In work carried out by Sheridan (2002), when the biofilter medium moisture content decreased by 16%, odour and ammonia removal efficiencies decreased by 7% and 23% respectively.

3 Cyclone Dust Separation

3.1 Intensive Livestock Dust

Intensive livestock dust is biologically active ie. it contains a variety of organic compounds, bacteria, fungi, endotoxins and dust mites and can pose a significant threat to health and comfort of both animals and people. Intensive livestock dust is highly concentrated ie. typically 10-100 times more concentrated than in buildings such as an office. This feature makes conventional air cleaning technologies such as filtration uneconomical because they require frequent cleaning or replacement of a filter element. Intensive livestock dust spans a wide spectrum of particle sizes and shapes: dust particles from a swine building are composed of dander, hair, feed dust and fecal materials, and range in size from less than one micron (one millionth of a meter) to a hundred microns in diameter. (Particles smaller than about 30 microns are generally not visible to the unaided eye.)

Defining the characteristics of animal building dust is very important to the applied odour control research. Quantifying the odour carried on different sizes of dust particles will allow scientists to optimise their strategies for removing the dust and odour. The size of a dust particle affects its behaviour in the air and in the human respiratory system. The respirable particles (smaller than 10 microns in diameter, similar to tobacco smoke) are responsible for the health and odour problems because, particles that size can travel deep into the lungs. Large particles (larger than 10 microns) usually bypass the nose or are trapped in the respiratory tract and are naturally kept out of the lungs. Particles of all sizes may contribute to odour transport from the animal housing.

The dust in animal housing originates from the feed, the bedding material and from the animals themselves. A small amount enters the animal house with the incoming ventilation air. The dust particles are carriers for gases, microorganisms, endotoxins and various other substances such as skin cells and manure particles (Donham, 1989). Animal house dust consists up to 90 % of organic matter (Aengst, 1984).
The amount of airborne dust fluctuates greatly both in the course of a day and according to the type of animal. Recent investigations carried out in 329 animal houses in four different EU countries revealed the dust concentrations given in Table 1. The results are given in 24 hours mean values for inhalable and respirable dust (Takai *et al.*, 1998). The highest dust concentrations are found in poultry shed followed by pig and cattle.

Table 1 Mean dust concentrations in the air of animal housings, mg/m^3, n = 329 (reproduced from Takai *et al.*, 1998)

Animal species	Inhalable dust	Respirable dust
Beefs	0.15-1.01	0.04-0.09
Calves	0.26-0.33	0.03-0.08
Cows	0.10-1.22	0.03-0.17
Fattening pigs	1.21-2.67	0.10-0.29
Sows	0.63-3.49	0.09-0.46
Piglets	2.80-5.50	0.15-0.43
Broilers	3.83-10.4	0.42-1.14
Laying hens	0.75-8.78	0.03-1.26

Most of this dust may leave the animal houses by way of the exhaust air and is distributed in the surroundings. Assuming a mean dust concentration of 2 mg/m^3 in the exhaust air of a piggery housing 1000 fattening pigs and a mean ventilation rate of 200 m^3 /LU per hour (LU = livestock unit equals 500 kg live weight) throughout the year the total dust emission per year will be about 500 kg. The emission rate of respirable dust from piggeries is about 60 mg/LU and hour. Presently it is unknown how far these fine particles are distributed in the environment of animal houses (Hartung, 1998).

3.2 Typical dust loading

The 24 h average concentrations of dust in Intensive Livestock sheds vary considerably. For example, in poultry sheds, dust concentrations can commonly exceed 10 mg m^{-3} . Stroik and Heber (1986) monitored 11 commercial swine finishing houses, and found dust concentrations up to 33mg m^{-3} , with a mean for all the houses of 7.5 mg m^{-3}.

3.3 Dust removal process

Dust control methods are summarised in the following Table :-

Table 2 Summary of dust control methods (need to check size ranges)

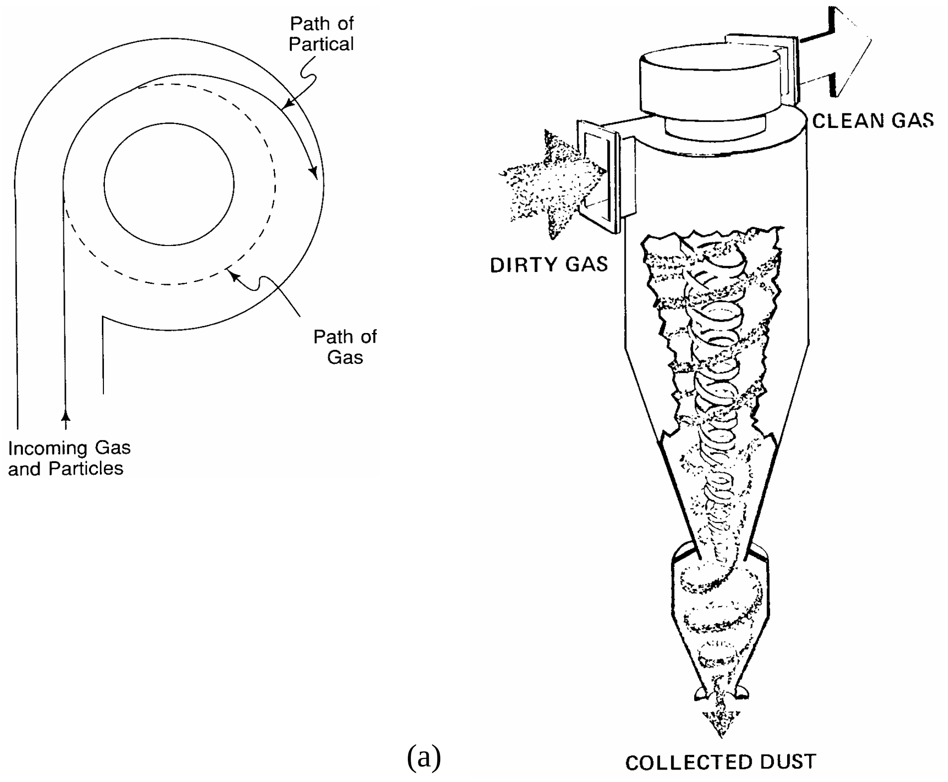
Dust Control Method	*Approximate particle size range controlled*
Cyclone	> 10µm
Multiclone	2 - 10µm
Filters	1-10µm
Liquid Venturi Scrubber	1 - 10µm
Electrostatic precipitation	0.1 – 10µm

For particle sizes greater than 10µm in diameter, cyclones represent the optimum control method. Vortex flow is generated through pumping air through a side entry port into a circular chamber. Particles migrate the inner wall of the chamber/cone where they decelerate, slide to the bottom and are removed (Figure 1). Cyclones work well with particles which have enough mass to separate from the airstream (ie. particles greater in diameter than 10µm). Several small diameter cyclones used together ("multiclone") are more efficient than a single large cyclone and may be used to remove particles down to about 5µm (need to confirm).

Cyclone units offer a significant advantage to the other methods listed in Table 1. Conventional filtration systems eg filter bag house have a marked tendency to clog and are difficult to clean and maintain. Venturi scrubbers and Electrostatic Precipitators are frequently used in industry for fine (< 10µm) particle removal, but are considered too expensive an option for the Intensive Livestock Industry.

The advantages of a cyclone are :

1) only one moving part, the fan that pulls air through the unit
2) no filters to clog up
3) the dust that is collected drops into a bin that can be easily
4) relatively low cost and energy usage per building



(a)

(b)

Figure 1 Movement of gas and particles (a) and reverse flow cyclone (b) illustrating tangential spiral motion along outer wall at inlet and flow reversal in the vertical direction in the conical taper region to form inner vortex which passed through the outlet tube.

3.4 Cyclone design

Cyclones are designed as follows

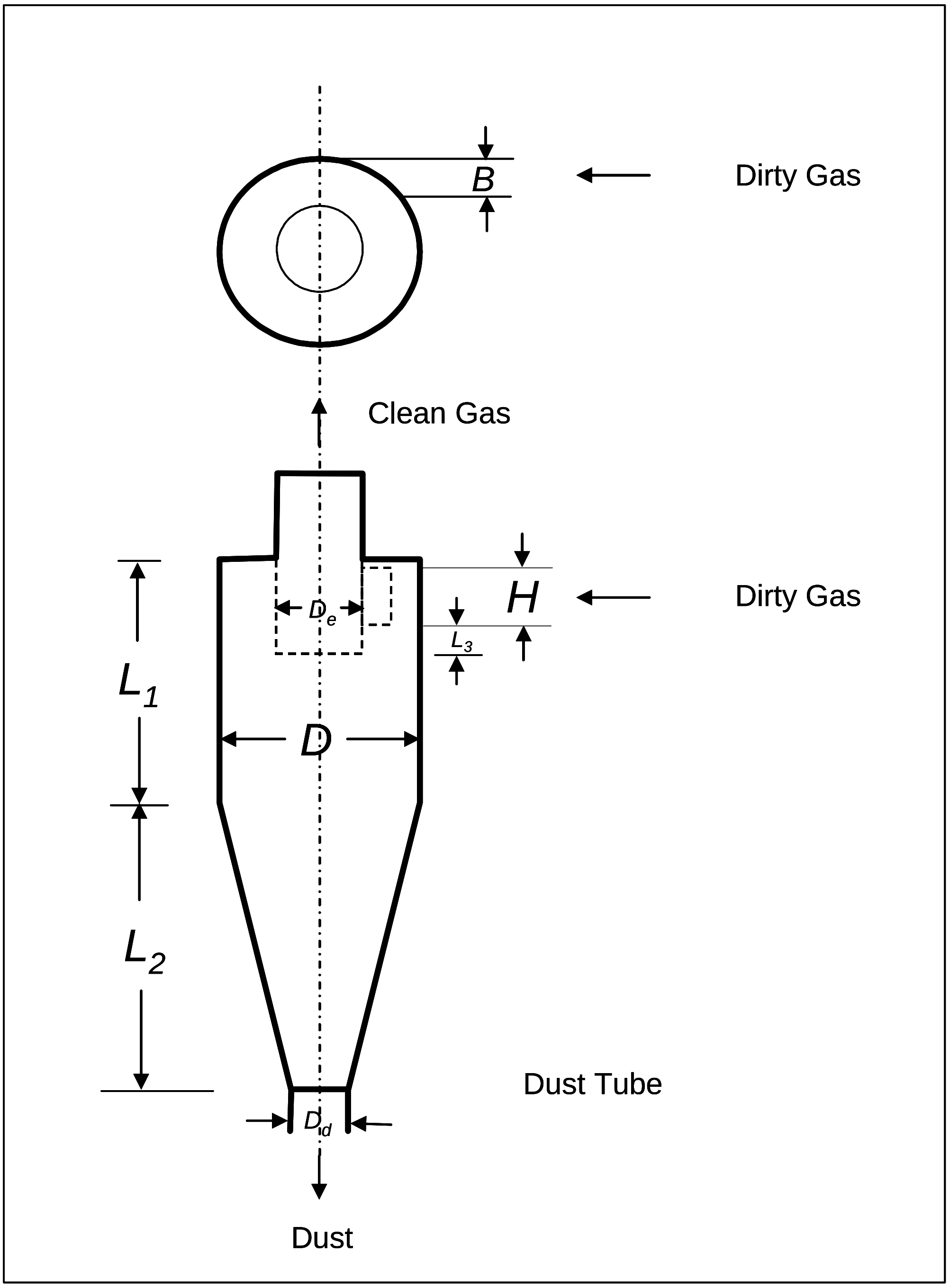


Figure 2 Cyclone design parameters

Standard reverse flow cyclone proportions are represented in the following table

Parameter	***Symbol***	***Proportion of D***
Length of cylinder	L_1	2D
Length of cone	L_2	2D
Diameter of exit	D_e	0.5D
Height of entrance	H	0.5D
Width of entrance	B	0.25D
Diameter of dust exit	D_d	0.25D
Length of exit duct	L_3	0.125D

Table 3 Standard reverse flow cyclone proportions

The key parameters (removal efficiency and pressure drop) of a cyclone are governed chiefly by its dimensions ie. cross-sectional areas and lengths of the cylinder and cone. (Storch, 1979). The diameter of a cyclone is important, with smaller diameters (200-600mm) providing greater collecting efficiency (Othmer, 1980). Increasing overall length increases flow resistance and decreases collection efficiency. The cone angle is usually about 10°, although may be smaller (7-8°) on higher efficiency units. The diameter of the dust exit should be sufficient to prevent clogging.

The cut diameter, $d_{0.5}$, ie. the particle diameter for which removal efficiency η, is 50%, is determined from the following empirical expression developed by Lapple, (1953)

$$d_{0.5} = \left[\frac{9\mu B^2 H}{\rho_p Q_g \theta} \right]^{1/2}$$

Once $d_{0.5}$, is determined, the removal efficiency for a particular particle diameter, d, can be determined from the following graph

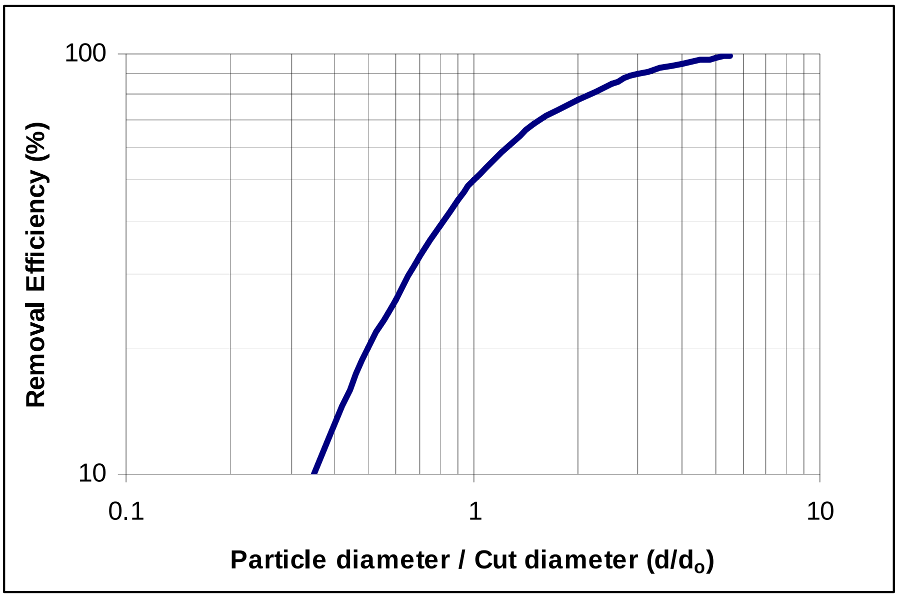


Figure 3 Emperical cyclone collection efficiency (Lapple, 1951)

The cut diameter is highly dependant upon the internal diameter of the cyclone cylinder, D. Using the Lapple formula, the effect on cut diameter for various values of D is illustrated as follows

(we need to do further work to check the validity of this graph – obtain data from manufacturers - need to check VALIDITY OF LAPPLE EQUATION BELOW 5µm)

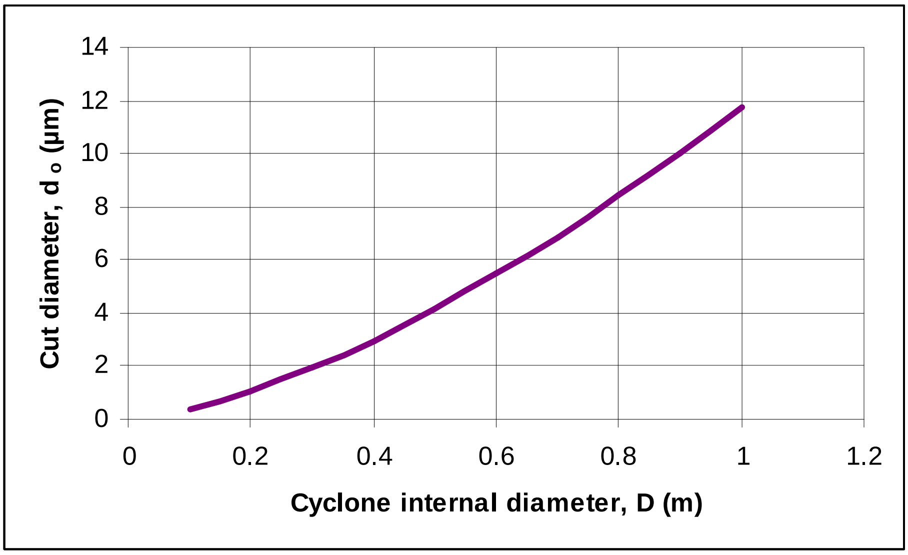


Figure 4 Effect of reducing cyclone internal diameter on the cut diameter ie. the particle diameter for which the removal efficiency of the cyclone is 50%

Figure 4 indicates that small narrow cyclones are required for removing fine particles less than 10µm in size. However, the flow capacity is reduced in smaller cyclones, so several are required in parallel. These are called “multi-clones”

3.5 Multi-cyclones or Multiclones

During rotation, the inertia of the dust particles carries them to the inner walls, where drag slows their velocity. They fall under the action of gravity and collect into a hopper. Particle re-entrainment limits gas inlet velocities to a maximum value. Higher removal efficiencies can be achieved for the same pressure drop for particles down to about 2 to 5 µm by reducing the diameter of the cyclone body. But it is then necessary to operate many cyclones in parallel in order to handle higher gas flow rates while maintaining low pressure drops. The complication in construction increases the cost.

The multi-clone shown in Figure 5embodies the parallel flow arrangement. As one can imagine, attainment of equal flow distribution to each cyclone of the multi-clone is difficult. Since the cyclones share a common hopper, if plugging of the inlet vanes occurs in one portion of the unit, it is possible for a flow reversal in another section to occur, undoing the work of the correctly functioning cyclones. In order to have high removal efficiencies for particles less than about 2 µm, it is necessary to go to prohibitively high pressure drops and unjustifiable operating costs.

Figure 5 Incinerator equipped with 5 parallel high efficiency (narrow) cyclones

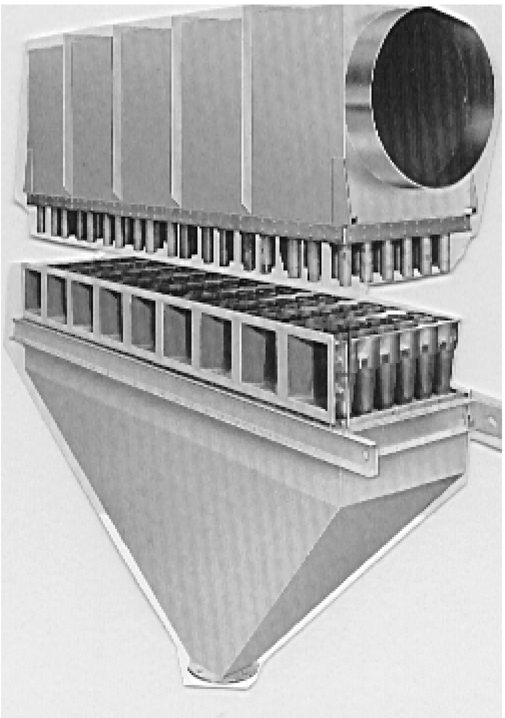
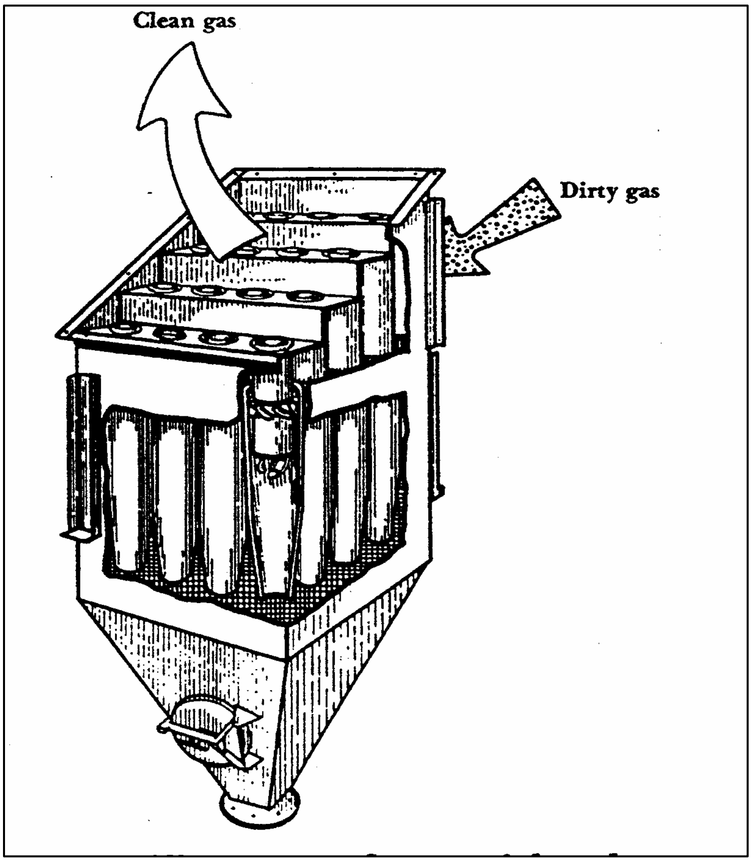
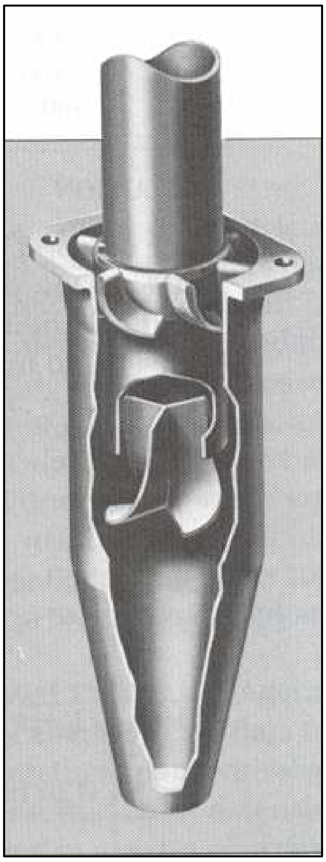


Figure 6 Photograph of a multiclone





3.6 Cyclone plus filter-bag option

Fractional efficiency is the ratio of particles collected to particles entering the cyclone. Figure 3 shows the efficiency of a cyclone collector with and without an optional filter bag assembly under clean, partial-load, and full-load conditions. Actual efficiency may vary depending on the application. Dust concentration, airflow, particle shape, and density affect filtration efficiency.

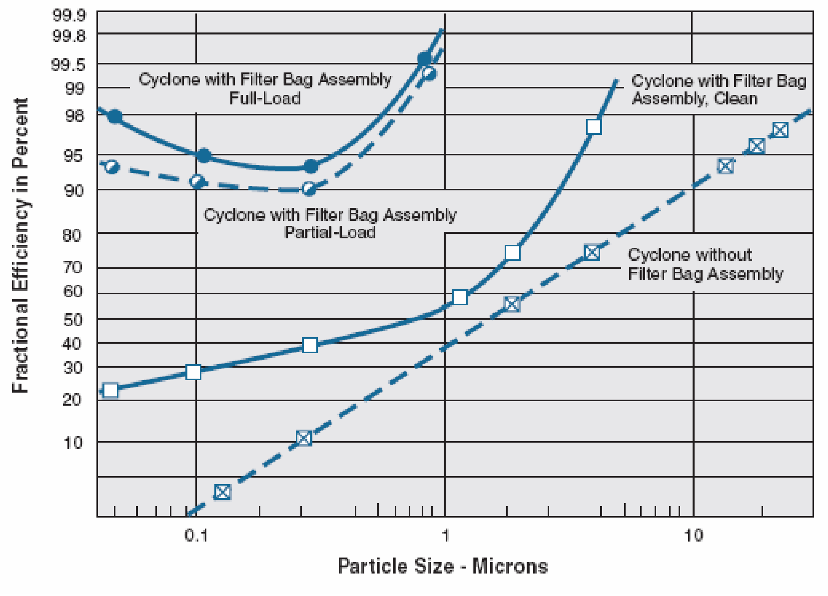


Figure 7 Fractional efficiency curve

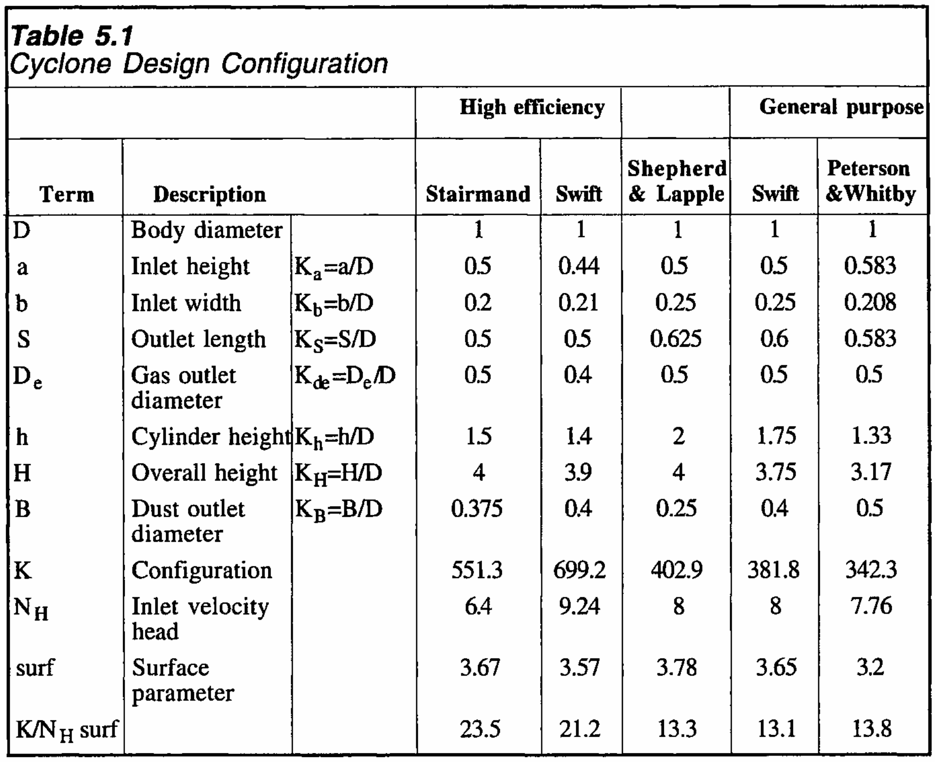


Table 5.1
Cyclone Design Configuration

Term	Description		High efficiency Stairmand	Swift	Shepherd & Lapple	General purpose Swift	Peterson &Whitby
D	Body diameter		1	1	1	1	1
a	Inlet height	K_a=a/D	0.5	0.44	0.5	0.5	0.583
b	Inlet width	K_b=b/D	0.2	0.21	0.25	0.25	0.208
S	Outlet length	K_S=S/D	0.5	0.5	0.625	0.6	0.583
D_e	Gas outlet diameter	K_{de}=D_e/D	0.5	0.4	0.5	0.5	0.5
h	Cylinder height	K_h=h/D	1.5	1.4	2	1.75	1.33
H	Overall height	K_H=H/D	4	3.9	4	3.75	3.17
B	Dust outlet diameter	K_B=B/D	0.375	0.4	0.25	0.4	0.5
K	Configuration		551.3	699.2	402.9	381.8	342.3
N_H	Inlet velocity head		6.4	9.24	8	8	7.76
surf	Surface parameter		3.67	3.57	3.78	3.65	3.2
K/N_H surf			23.5	21.2	13.3	13.1	13.8

4 Trickling Biofilter

4.1 Fine dust removal and humidification of air

To maintain a healthy biofilm and therefore effective odour control in the main organic biofilter (OBF), a trickling biofilter (TBF) is required to precondition air prior to entry to the OBF. Alternatively known as a “packed tower” or “bioscrubber”, the TBF is required to maintain optimum airflow/moisture characteristics in the OBF by achieving the following :-

1) removing fine (<5µm) particles not removed by the cyclone so that the organic biofilter (OBF) which is moist and has small pore spaces does not simply operate as a highly efficient dust filter and clog up
2) pre-humidifying the air prior to entry into the OBF to maintain the correct moisture level in the OBF and promote a healthy biofilm by avoiding problems due to over-drying or water-logging.

NB. some odour will also be removed by the TBF alone which will reduce the loading and further extend the life of the OBF.

4.2 TBF design considerations

It is recommended that the TBF has an inorganic filtering material rather than an organic filtering material. This is to minimise substrate degeneration due to bacterial consumption of the material, and subsequent erosion due to the high water flowrates necessary for dust flushing. Biofilms develop readily on inorganic substrates as well as organic substrates if sufficient nutrients (contained in odour) are available. The fundamental difference in operation between the (inorganic) TBF and the organic biofilter (OBF) is that water continually trickles or flows through the former to flush out particulates, whereas a much lower flowrate of moisture is allowed to “soak” through the OBF.

The TBF is required to maintain the required moisture levels in the organic biofilter material. Suggested methods (encompassed in Figure 8) include the use of a :-

1) tank scrubber (odourous air bubbles through a liquid tank)
2) trickling biofilter (inorganic medium eg. lava rock, pumice, plastic, polystyrene – *optimum choice of material for the TBF needs to be determined from trialwork*)
3) spray chamber (fine water droplets)

5 Recommendation

- The use of a cyclone (or multiclone) is recommended for removing coarse dust prior to entry of odourous air into subsequent trickling biofilter / organic biofilter systems. Cyclones cannot eliminate all of the dust, but they are able to reduce the dust loading significantly. Further research is required to optimise cyclone design, primarily from an economical point of view
- A biotricking filter / spray chamber with sump is recommended for fine dust removal and pre-humidification of air prior to its entry into the organic biofilter. Further research is required to optimise the design and identify suitable materials required for the inert medium.

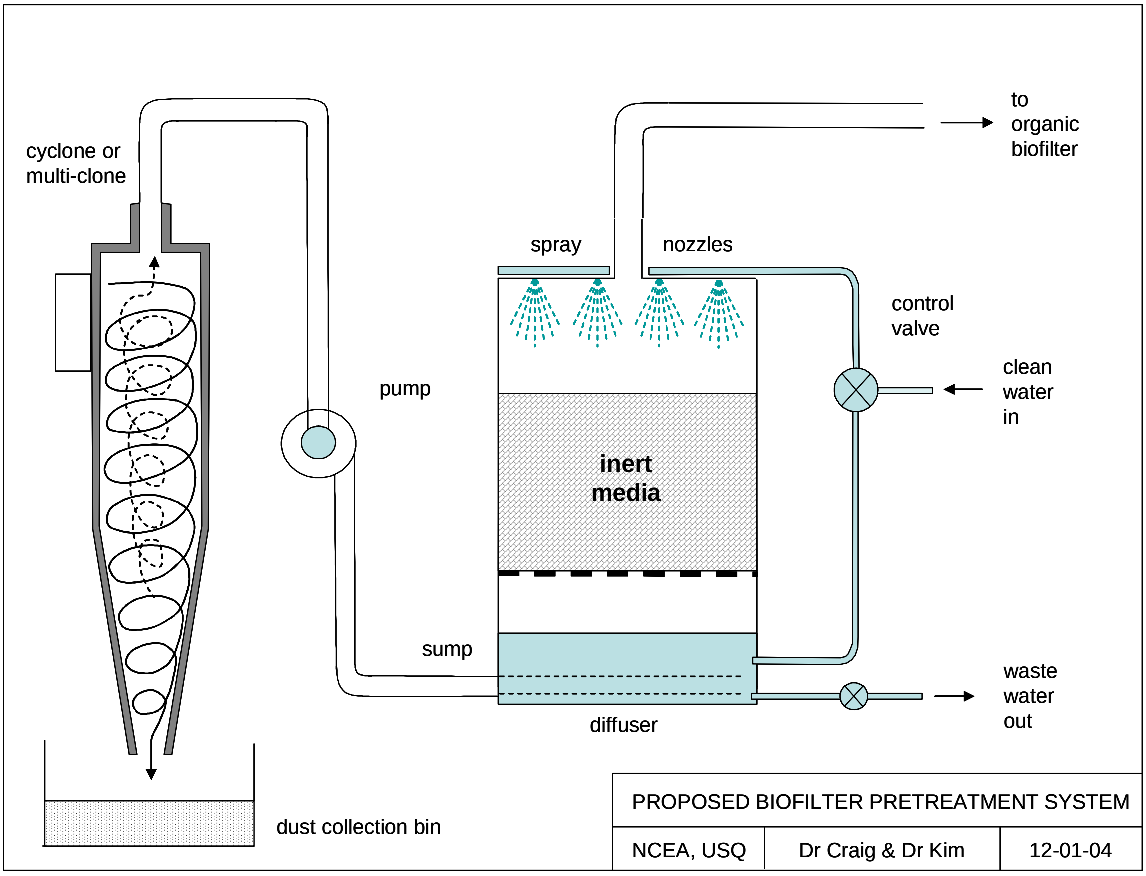


Figure 8 Suggested design of the organic biofilter pre-conditioning system

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(FSA Consulting is acknowledged for access to references on scrubbers and biofilters)

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