DUST COLLECTION

A. Buekens and **K. Schroyens**
Department of Chemical Engineering – CHIS 2, Vrije Universiteit Brussel, Belgium

Keywords: Collection efficiency, cyclones, electrostatic precipitators (ESP), fabric filters, fluidized bed filters, granular filters, health hazard, particle cut, wet scrubbers

Contents

1. Scope
2. Aims and some applications
3. Respirable Dust
4. Emission Codes
5. Collection efficiency
6. Principles of Dust Separation
6.1. Dry Methods
6.2. Wet Methods
7. Selecting a Filter
7.1.Selection Criteria: Plant and Process Factors
7.2. Selection Criteria: Filter Related Factors
7.3. Dry versus Wet Collection
7.4. Wet Scrubbers for Dust Removal
8. Safety Factors: Dust Explosions
8.1. Scope
8.2. Explosions
8.2.1. Dust Explosions
8.2.2. Dust Reactivity
8.2.3. Ignition
8.3. Explosion Characteristics
8.4. Prevention Strategy
8.4.1. Awareness of Hazards
8.4.2. Actual Prevention Measures
8.5. Explosion Protection Strategies
8.5.1. Ductwork
8.5.2. Collection Units
8.5.3. Cyclones
8.5.4. Bins or Hoppers
8.5.5. Interconnected Plant
8.5.6. Explosion Relief
8.5.7. Area Classification
8.5.8. Documentation
8.5.9. Plant Layout
9. Conclusions
Glossary
Bibliography
Biographical Sketches

Summary

This chapter is concerned with dust collection which relies on mechanical (gravity, centrifugal force, inertia, interception, diffusion) and on electrostatic forces. The bulk of the particulate is of a coarse mode, but the finest particles are inhaled much more easily and have a sizeable potential health impact.

This has caused a shift towards other types of filters, capable of reducing the emission of the tiniest particles.

1. Scope

Dust collection is a very important unit operation, both in the *process industries* and in *environmental applications*. The original emphasis was on product recovery and on maintaining equipment in good order, while avoiding clogging or fouling of downstream ducts, but it has now shifted towards the reduction of dust emissions to levels dictated by environmental codes and the safeguarding of cleaner and healthier working surroundings and avoiding occupational exposure. Moreover, interest has grown in proper management of the dust arising from air or gas cleaning operations, after its separation in filters: reuse, recycling, detoxification treatment, or safe disposal. These options must be carefully weighted, to avoid a mere shifting of the burden from the 'compartment' air to that of soil or water, or a shift of the original problem to a different location. Measures are also required to avoid prompt re-entrainment of the dust during its handling, by using entirely closed handling equipment (see also *Control of Particulate Matter in Gaseous Emissions*), including chutes, conveyors, and hoppers at bulk charging facilities.

Long ago dependable, high quality, easy-to-maintain equipment for dust collection was not readily available and far too expensive, so that the recovery of materials and separation of dust only proceeded as far as it was economically justified. Coal-fired power plant, cement kilns and metallurgy covered their surroundings under a layer of dust (see, wet and dry deposition in *Dust-Particle Formation and Characteristics*). In this approach, however, no attention was paid to the indirect costs, e.g. those of soil pollution, health damage, or aesthetic degradation. In the beginning of the 20th century, zinc industry first killed all trees by its SO_2 emissions, and then polluted the soil by deposition of cadmium-enriched dust! In the 1950s it was a challenge to dry linen outside in an integrated iron and steel basin and a matter of wind direction whether the linen would turn brownish red (like iron oxides) or black (like coke). Fortunately, these situations now belong to the past!

Mechanical— gravity, inertial, and centrifugal separators, fabric and granular filters, electrostatic precipitators, and wet scrubbers all can collect dust particles. Separating the bulk of a dust stream is relatively easy: the challenge is separating fine particles, especially around one µm in diameter! Sometimes a gradual approach is the best, separating coarse particles first, fine ones afterwards; each case is, however, different. Selection is based on space and power requirements, and especially - on the quality of separation required.

2. Aims and Some Applications

Depending on the process, the environmental limit values, and economic factors, the major aim of dust separation and collection varies and is sometimes even based on a combination of considerations, e.g.:

1. Air pollution control, by **cleaning off-gases** or **flue gas**.
2. Elimination of a **health hazard**, preventing occupational exposure to dust at large (respirable particles, asbestos fibers) or toxic dust in particular e.g. by containing and treating fumes from metallurgical smelters, or aspiring sawdust from woodworking equipment.
3. Elimination of a **safety hazard**, e.g. the occurrence of conditions that could lead to a dust explosion, e.g. in a flourmill, a sugar factory, an animal fodder plant, etc.
4. **Bulk handling** of commodities, e.g. the charging or treatment of ores, coal, or wheat inevitably gives rise to airborne dust and material losses, generally a fraction of a percent in each operation.
5. **Product recovery** of powders, e.g. after pneumatic conveying, spray drying of milk or other substances, manufacturing of finely divided carbon black or zinc oxides,
6. Recovery of an either particularly valuable or especially dangerous product, e.g. in the recovery of precious metals by smelting or the treatment of off-gases bearing radioactive particulate.
7. Preserving delicate product quality, e.g. in the manufacture of Printed Circuit Boards, photographic film, or pharmaceuticals.
8. Protecting the workforce, filtering breathing air through a dust mask.

In many large scale industrial processes dust is generated while contacting solids with gases, with the purpose of solid fuel combustion (coal, lignite, or peat in thermal power plants or industrial boilers – see, *Control of Pollution in Power Generation*), the production or use of finely divided materials (cement clinker production, calcination of limestone, sintering of iron ore), the transfer of heat or mass, e.g. in furnaces, calciners, dryers, fluidized bed units, or simply conveying in pneumatic systems (see, *Control of Pollution in the Chemical Industry* and *Control of Pollution in the Iron and Steel Industry*)

Dryers and smelters generate off-gases, requiring dust filtration, for reasons of loss prevention and environmental conservation. To avoid inhalation by the workforce, either under occupational conditions, or by the population at large, dust, fumes, and mist must be abated especially when bearing heavy metals or Polycyclic Aromatic Hydrocarbons (PAH, IUPAC name – polycyclic arenes). Fumes and mists are both most objectionable and difficult to control. The toughest technical requirements regarding dust levels are to be found in electronics and pharmaceutical industry, where a virtually dust free atmosphere is strictly required, e.g. by Good Manufacturing Practices Codes.

3. Respirable Dust

The human nasal cavities are adorned with wet hair, thus scrubbing out particulate matter from breathing air. Coarse dust (> 20 µm) is both easily separated and fairly unobjectionable from a health viewpoint. Fine dust (< 10 µm, or worse < 2.5 µm) is much more problematic as it penetrates deeply into the lungs and deposit in alveoli. Moreover, fine dust becomes enriched in organic or heavy metal compounds, adsorbed on its way through ovens and flues or – after emission - while suspended in the atmosphere. Semi-volatiles, such as dioxins, occur mainly in the ambient while adsorbed onto particulate. Whereas coarse dust has generally a 'common' chemical composition fine particulate at the surface consists of 'strange' chemicals, such as soot, salts, neutralization products of acid gases and is thus often much more objectionable and toxic.

A problem receiving increased attention is the susceptibility of a rising fraction of the population to pollen and various allergens. In some seasons many people resort to wearing dust masks in order to prevent the affections related to their allergies (see, Indoor Air in *Control of Gaseous Emissions*).

4. Emission Codes

Legal codes have gradually limited industrial dust emissions to lower and lower values.

The German TA-Luft Code (Technische Anleitung zur Reinhaltung der Luft) in 1974 already pioneered by imposing a limit value of 100 mg dust per Nm^3 for incinerator flue gas. Its second version (TA-Luft 1986) allowed only 50 mg per Nm^3, and some years later the 17.B.Im.Sch.V. (17th Bundes ImmissionsschutzVerordnung) lowered this value to 10 mg per Nm^3, with exemption of a one half hour average, which tolerated 30 mg per Nm^3. In each application particular limits may be required, depending on the hazard associated with the dust, or the technical possibilities of treatment.

These strict legal codes prompted the development of adequate analytical equipment, capable to monitor continuously most relevant emissions, with rather few exceptions (odors, dioxins, heavy metals) that still require sampling, followed by off-line analysis (See *Emission Sampling and Analysis*).

In turn, this tendency towards continuous registration made it possible to impose self-control systems, requiring mandatory notification of:

- Total emissions (notified at least annually), integrated over the entire period,
- Intermittent emission peaks, exceeding the emission levels granted,
- Serious incidents, with a large emission, e.g. discharged over an emergency stack.

Self control requires continuous care regarding emissions, operating conditions of process plant and analytical equipment, attention to incidents and their recording, and mandatory shut-down in case the emission levels can no longer be met for a prolonged period!

5. Collection Efficiency

Collection efficiency is normally expressed as a weight-to-weight ratio of

(*Dust collected by the filter*, kg h^{-1}) / (*Dust fed to the filter*, kg h^{-1})

or as

1 - (*Dust emitted by the filter*, kg h^{-1}) / (*Dust fed to the filter*, kg h^{-1})

Most filters achieve impressive collection efficiency values, with:

- Typically 80 to 95 percent for a preliminary separator (where available), and 98 to 99.8 percent for the filter proper. Some filters claim to arrest 99.9^+ percent,
- Residual dust loads in the order of 10 mg per Nm^3 in innocuous flue gases (cement or power plant) and of < 3 mg per Nm^3 in metallurgical smelters and waste incinerators.

Relating the efficiency of dust collection in mass units (only) is a problem, however, in case of objectionable dust. It is often feasible to collect 99^+ percent of the dust, and yet find out that the remaining much finer particulate, despite its low residual mass, is much more hazardous than the bulk of the collected dust, because of different composition, with the surface enriched in objectionable compounds and of much better penetration into the respiratory tract. Hence, there is a tendency towards counting particles rather than weighing them, but the methods for on-line numerical monitoring are not yet standardized or widely available.

For this reason dust collection efficiency should be differentiated in critical cases according to particle size. This criterion can ensure a proper selection of a filter for each particular application. Conversely, it is possible to measure collection efficiency as a function of particle size (Figure 1). It follows that cyclone separators and wet scrubbers are mainly efficient for coarse particles, whereas fine particles need fabric or electrostatic filters for deep retention of inhalable fine particles.

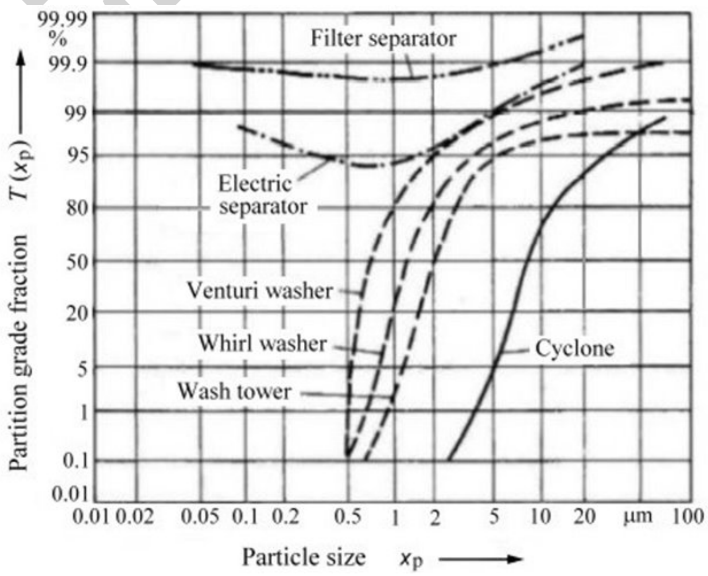

Figure 1: Partition grade curve of different separator systems

Figure 1 shows a pronounced distinct behavior for the collection efficiency exhibited by various separators for different classes of particulate:

- Settling chambers, inertial separators (both not shown), cyclones and wet scrubbers all show a sharp drop in collection efficiency when particles become smaller, as predicted by theory.
- Electrostatic precipitators and fabric filters do not show such a drop. Instead, there is a minimum collection efficiency occurring for particles between 0.5 and 1 µm (fabrics) or 0.5 and 2 µm (ESP). The precise location of this minimum is both difficult to measure and to explain, because it stems from a combination of factors, i.e. the added effects of impaction, interception, diffusion and electrostatic forces on the one hand, the constitution of filtering layer and membrane and the interactions between particles and between particle and obstacles on the other.

Some authors define a particle cut or limit size as a size at which the collection efficiency reaches 50 percent. This value reads as follows from Figure 1:

- Cyclone: 8 µm
- Wash tower: 2 µm
- Vortex or whirl scrubber: 1.3 µm
- Venturi Scrubber: 0.7 µm

The electrostatic precipitator never descends below a collection efficiency of ca. 93 %, a fabric filter below 99.6 %. All values obviously refer to a specific test plant.

An essential feature of particle separators is the head loss incurred when moving large gas flows through ducts and equipment. This duty requires large fans consuming lots of power. Another essential feature is the operating principle on which particle collection is based.

6. Principles of Dust Separation

6.1. Dry Methods

The action of **mechanical separators** is generally based on gravity, inertia, or centrifugal force. For particles of a few µm also interception and diffusion becomes important, the latter mainly for submicron particles.

Coarse particles (above 50 microns, 1 µm = 10^{-6} m) can be removed by settling, when sufficient residence time is provided, or by inertia, when the gas flow direction is abruptly changed, either once or repeatedly. Settling is inefficient for small particles, but a factor to take into account in transfer lines, plenum chambers, etc.

Cyclone separators are based on centrifugal force; they are highly compact, and most efficient for particles with a diameter above 20 microns. Below this particle diameter collection efficiency drops rapidly and it becomes negligible below 5 microns. Cyclone separators are used to separate coarse dust, in small plants, where air pollution codes are lenient, or as a preliminary separator taking out a large share out of the dust load. Current codes on dust emissions can no longer be met with cyclone separators alone, when at least a fraction of the dust is below 10 µm.

Electrostatic precipitators offer high collection efficiency, low pressure drop and trouble free operation in a wide range of particle sizes, at a low operating cost. Initial investment and plant volume are high, for they operate at low linear gas velocities. They are mainly used for treating large gas flows at thermal power plant, cement kilns, incinerators, metallurgical furnaces, etc. Collecting flammable powders creates a large explosion hazard, since sparking is frequent. The operating temperature is limited to 350° C.

Fabric filters can operate at a very high efficiency, also in the submicron range. Traditionally, they are used in the food and fodder industry, at ambient temperature. Their use has considerably expanded in environmental applications, especially where stringent codes have been imposed (dioxin adsorption, heavy metal emissions). They require high investment and the lifetime of the filter bags may be limited at high temperature or due to chemical attack. The filter material selected restricts the operating temperature.

Granular filters, on the contrary, can be used even without flue gas cooling; dust is intercepted in a slowly descending layer of sand, screened for removing the collected dust before being recycled.
Fluidized bed filters are also temperature resistant, but have only a moderate efficiency and a fairly high pressure drop. Both granular and fluidized bed filters are rather seldom used.

6.2. Wet Methods

In the 1970s **wet scrubbers** were rarely used in Western Europe, because of high operating cost, erosion and corrosion problems and a visible steam plume, but much more in the USA, e.g. in the cleaning of flue gases, say from incineration. Sometimes the problem merely shifts from the gas phase to the water phase.

Wet scrubbers have been used increasingly, to eliminate acid gases and meet very stringent HCl-emission codes, but combining dust separation with acid gas scrubbing is not recommended for a number of reasons, such as different rate determining steps and – hence – optimum operating conditions, and the enhanced creation of operating problems due to clogging and synergetic effects of acid corrosion and erosion by suspended particles in the wastage of construction materials.

7. Selecting a Filter

7.1.Selection Criteria: Plant and Process Factors

Important considerations in filter selection are plant location, the size of the gas stream, and the particle size and nature of the dust to be collected. To evaluate the various possibilities attention is paid to the following factors:

- Volume of the plant, and required space and surface,
- Volume of the gas flow and its intrinsic variability,
- Temperature, pressure, and composition of the raw gas,
- Raw gas dust loading,
- Dust particle size distribution,
- Operating and safety characteristics, including the tackiness, flammability, formation of explosive mixtures with air, toxicity, of the dust, and
- Handling characteristics, such as angle of repose, solidification and caking tendency, hygroscopic or deliquescent nature.

There are many process-related parameters that need to be taken into account, e.g. the precise location where a filter must be installed, and expected operating conditions (temperature, pressure, humidity). The latter determine the selection of materials. Some filters need to be installed in order to protect downstream equipment from further fouling and clogging. Particles may be tacky at high temperatures and need to be 'frozen' before removal. Some particles react chemically: chlorides, deposited in flues, are gradually converted into sulfates, if the temperature is lower than say 500° C.

Sometimes, dust collection proceeds in a succession of steps, either to remove the bulk of the load at an early stage, or to take advantage of differences in vapor pressure: in non-ferrous industry coarse dust is separated at a temperature at which arsenic compounds are still present as a vapor.

A final removal allows collecting this element in a concentrated form, ready to be sluiced out of the system. At the lower side of the temperature range it is ill-advised operating below dew point, for this may solidify discrete particles, converting them into a mass. Also deliquescence of salts is sometimes problematic. Most filters are thermally insulated. Local occurrence of cold bridges to the support structure causes condensation of moisture, and often corrosion.

-
-
-

Bibliography

[1] Bank M. (2000). *Basiswissen Umwelttechnik: Wasser, Luft, Abfall, Lärm und Umweltrecht – 4., komplett neue, bearbeitete Auflage*, Wurzburg: Germany: Vogel, ISBN 3-8023-1797-1. [An excellent comprehensive work on all aspects of the environment, in German].

[2] "Dust explosion prevention and protection: A practical guide", (2000), Institution of Chemical

Engineers, UK, ISBN 0 85295 410 7. [Excellent reference work on Dust explosion prevention and protection]

[3] http://www.chemeng.ed.ac.uk/~emju49/SP2001/webpage/deh/deh1.html, "The dust explosion hazard". [This Woodworking Fact Sheet discusses dust-handling hazards in this particular sector]

[4] http://www.hse.gov.uk/hid/land/comah/level3/5CEDFEE.HTM, BS EN 50281-1 (Parts 1 and 2, 1999; Part 3, 2002), [European standards - cover requirements for the design, construction and methods of test for electrical apparatus where combustible dust may be present]

[5] http://www.hse.gov.uk/pubns/wis32.pdf, Health and Safety Executive (HSE) information sheet, Woodworking Sheet No 32, Reprint 1/03.

[6] http://www.pharmamag.com/Web_First/PhM.nsf/ArticleID/KLAN-5SSMVA De Palma, A. *Pharmaceutical Manufacturing - Minimize Dust Explosion Hazard*, October 29, 2003". [A case-study of a dust explosion in a pharmaceutical plant]

[7] (UK) *HSE Books 1993*. HSG37: An introduction to local exhaust ventilation, , ISBN 0 7176 1001 2. [A primer on exhaust ventilation].

[8] (UK) *HSE Books 1994*. HSG103: Safe handling of combustible dusts., , ISBN 0 7176 0725 9. [This book discusses dust-handling procedures]

[9] (UK) *HSE Books 1998*. CRR176: Dust explosions from unenclosed sock filters, ISBN 0 7176 1577 4. [A study on dust explosions]

Biographical Sketches

Alfons Buekens was born in Aalst, Belgium; he obtained his M.Sc. (1964) and his Ph.D (1967) at Ghent University (RUG) and received the K.V.I.V.-Award (1965), the Robert De Keyser Award (Belgian Shell Co., 1968), the Körber Foundation Award (1988) and the Coca Cola Foundation Award (1989). Dr. Buekens was full professor at the Vrije Universiteit Brussel (VUB), since 2002 emeritus. He lectured in Ankara, Cochabamba, Delft, Essen, Sofia, Surabaya, and was in 2002 and 2003 Invited Professor at the Tohoku University of Sendai.

Since 1976 he acted as an Environmental Consultant for the European Union, for UNIDO and WHO and as an Advisor to Forschungszentrum Karlsruhe, T.N.O. and VITO. For 25 years, he advised the major industrial Belgian Bank and conducted more than 600 audits of enterprise.

Main activities are in thermal and catalytic processes, waste management, and flue gas cleaning, with emphasis on heavy metals, dioxins, and other semi-volatiles. He coordinated diverse national and international research projects (Acronyms Cycleplast, Upcycle, and Minidip). Dr. Buekens is author of one book, edited several books and a Technical Encyclopedia and authored more than 90 scientific publications in refereed journals and more than 150 presentations at international congresses. He is a member of Editorial Boards for different journals and book series.

He played a role in the foundation of the Flemish Waste Management Authority O.V.A.M., of a hazardous waste enterprise INDAVER, and the Environmental Protection Agency B.I.M./I.B.G.E. He was principal ministerial advisor in Brussels for matters regarding Environment, Housing, and Classified Enterprise (1989). Since 1970 he has been a Member of the Board of the Belgian Consumer Association and of Conseur, grouping more than a million members in Belgium, Italy, Portugal, and Spain.

He is licensed expert for conducting Environmental Impact Assessments (Air, Water, Soil) and Safety Studies regarding large accidents (Seveso Directive).

Kathleen Schroyens has studied Industrial Engineer in Chemistry (1998) at the KAHO – Ghent.

Since 1999 she is working as scientific collaborator at the Chemical Engineering Department of the Vrije Universiteit Brussel. She is collaborating in projects for the European Union (MINIDIP, Haloclean) and The Flemish Government, AMINAL, preparing an inventory of all waste or product streams, derived from thermal processes that are contaminated with dioxins, performing (succinct) risk analysis and devising the measures required in order to monitor and control such streams'. She is also a collaborator in smaller assignments concerning dioxins emissions of MSWI and other industrial plants.