WET SCRUBBERS

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Contents

Summary

Wet scrubbers are used when dry dust collection creates excessive explosion hazards, when dust collection is combined with acid gas removal, and when the dust is to be applied as slurry.

Wet scrubbers are capable of collecting submicron dust if they operate at a very high pressure drop. Inconvenient is the occurrence of erosion, corrosion, and a wet plume of entrained droplets that can only be eliminated by high-efficiency fibrous mat demisters.

Wet electrostatic precipitators are a premium solution for a deep low temperature removal of volatile gases, salt fumes, and other specific applications.

Atomizers are used in numerous industrial processes, including spray cooling and conditioning of flue gases.

Wet deposition is a major process in cleaning the atmosphere from particulate matter; it is based on rainout and on washout.

1. Survey

Wet scrubbers can serve two different duties, namely, the absorption of water-soluble gases or vapors, and arresting dust. Since the mechanism is fundamentally different their design and operating mode also differs and combining both duties is not always appropriate.

Dissolution of soluble gases is basically driven by:

1) Contacting surface, available for mass transfer between the gas phase and the liquid, and
2) Difference between actual concentration and equilibrium conditions.

Hence, absorption normally requires a very large gas to liquid interface surface.

Arresting dust particles by wet scrubbing proceeds by high velocity impaction of dust particles in their first contact with droplets. After this initial impact the relative velocity becomes too small to create collisions, so that the initial contact of particles and droplets drives almost entirely a successful separation of dust and is little helped by providing supplemental surface.

Dust collection can be subdivided into three-steps, with the first step often only implicitly implemented:

1) ***Preconditioning*** of dust, i.e. saturation of the original dust particles with vapors from the scrubbing liquor. Thus particles become denser and acquire a larger affinity for the scrubbing liquor. Preconditioning proceeds by injecting a metered amount of finely divided scrubbing liquor into the gas, leading to

almost instantaneous evaporation, bridging the temperature gap between the original hot gas temperature (requiring a heat-resistant material) and the scrubber operating temperature (often with glass fiber mats-reinforced polyester as a corrosion resistant construction material),

2) ***Contacting*** the dust laden gas with a water spray or surface at very high relative speed, since dust is largely captured by inertia, i.e. a high-speed collision with droplets, followed by being incorporated into these,
3) ***Separating*** the dust-laden droplets from the gas stream. This last step seems straightforward, but high-energy contact of gas and water often generates fine droplet dispersions so that the resulting mist must be carefully collected. Failing to do so causes emission of salts and jeopardizes compliance with stringent Codes.

2. Liquid Atomizers

2.1. Scope

Many industrial processes (spray cooling, conditioning of flue gases, humidification, fire fighting, oil burners, spray drying, granulation of pills etc.) require some liquid or melt to be atomized into fine or very fine drops. The orifices of spray nozzles are designed to break-up liquid into a multitude of droplets, for the purpose of increasing surface area, or concentrating liquid to create high impact force. In many applications, droplet size is critical:

- Gas scrubbing, cooling or conditioning depends on exposing a maximum liquid surface area to a gas stream.
- Other applications require large droplets, e.g. when a spray must project into a fast moving gas stream.

Liquid atomizers serve such purposes. They can be driven by liquid pressure, or by using a compressible auxiliary medium (air, steam or a gas). The latter use internal mixing, for clean, non-viscous liquid, or external mixing, for viscous and particle-laden fluids. Choosing a suitable atomizer nozzle requires specification of factors, such as:

- flow-rate versus pressure characteristics,
- spray angle,
- material of construction and the piping which feeds the nozzle.

Three important characteristics of any spray are:

- the amount of liquid it contains,
- how the volume is distributed within the spray envelope, and
- the sizes of the droplets that make up the spray.

Measuring flow rate and pressure characteristics of most nozzles is relatively simple, but this is frequently not true for pattern and droplet size data.

2.2. Droplet Particle Size

Many industrial processes require the availability of fine atomized droplets and the techniques to produce finely atomized sprays have been largely improved in the recent years, with new types of atomizers being developed. In addition, sophisticated process techniques have heightened the demand for a precise definition about the characteristics of the spray.

Most interesting parameters are:

- Arithmetic Mean Diameter, or AMD (D10): calculated from the diameters of the drops in the sample spray.
- Volume Mean Diameter, or VMD (D30): diameter of a drop whose volume equals the arithmetic mean of volume values of the drops in the spray.
- Sauter Mean Diameter, or SMD (D32): diameter of a drop with a volume/surface ratio value the same as the arithmetic mean of volume/surface values in the sample spray under examination.

The following histograms and diagrams are usually used to define a sample spray:

- Volume percentage cumulative curve,
- Distribution curve of droplet diameters,
- Distribution curve of droplet velocities.

During laboratory testing a computer-driven laser interferometer is used to detect and record the spray parameters, while fluid capacities and feed pressure values are monitored. Above parameter values make it possible to define data about atomization degree, heat exchange efficiency and jet behavior in a given operational ambient.

2.2.1. Liquid-pressure atomizer

These droplets may be obtained in a **liquid-pressure atomizer**, simply by forcing the liquid at high pressure through a small dimension orifice.

Two major inconveniences are to be expected by such a method:

- It requires costly high-pressure pumps and lines.
- The small orifice of a hydraulic atomizer is easily clogged, impairing reliability.

The atomization of a liquid by means of a compressible auxiliary fluid like air, steam or a gas, is defined pneumatic, two-phase or twin-fluid atomization.

2.2.2. Air-assisted atomizers

In a majority of cases **air-assisted atomizers** are being used, in which compressed air supplies most of the energy required for atomizing the liquid. These devices provide a high velocity air stream impacting onto a liquid flow, obtaining liquid atomization by simple shear action.

This technology allows producing fine and very fine droplets, satisfying the requirements of almost any industrial application. A wide range of spray patterns atomizer types and accessories have been developed in the time to suit many different industry requirements.

An air atomizing system has, however, two inherent limitations:

- water and air must be filtered, because of narrow inside passages,
- jets with limited spray angles are obtained, because of the high speed of the spray. Multiple orifice air nozzles are used to overcome this problem.

In spite of their inherent low efficiency and because of the low flow rates involved, conventional atomizers are the most convenient solution for most of the current applications.

2.2.3. Internal or External Mixing

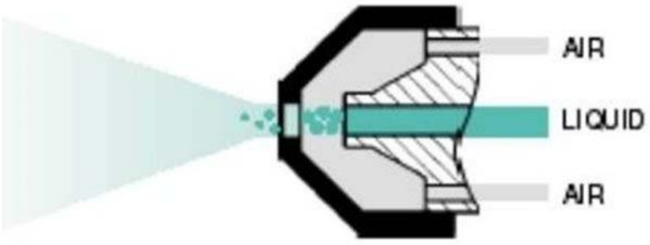
The set-up can be so designed that air and liquid:

- are mixed inside the atomizer, and ejected through the same orifice, or
- impact, mix and generate the atomized spray after having been ejected from the atomizer through separate orifices.

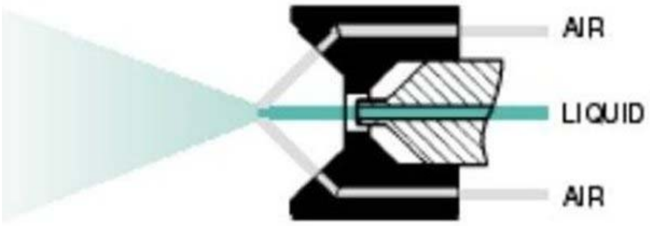
The most commonly used type uses internal mixing (Figure 1) with a wide range of flow values and spray patterns available. The two fluids come in contact inside the nozzle, and the resulting mist spray exits from the nozzle orifice(s). Changes in the pressure value of one of the fluids will affect the flow rate of the other one: increasing air pressure will result in lower liquid flow rate and finer droplets, and vice-versa.

Viscous or contaminated liquids are generally atomized with an external mix set-up. Here the two fluids exit from separate orifices, they impact and mix outside the nozzle, pressure values can be easily and independently adjusted and their flow rates easily controlled.

Increase in air pressure will result in finer atomization, but normally the spray droplet size is slightly larger as compared to an internal mix set-up.
These set-ups can only produce a flat spray pattern.



Internal mixing



External mixing

Figure 1: Types of Internal and External Mixing

2.2.4. Ultrasonic atomizers

Ultrasonic atomizers produce very fine sprays, with rather uniform drop dimensions, and supply low capacity sprays, lower than 0.1 m^3 per hour. The sound waves generate a typical noise and the local noise level must be tested lower than legally admissible levels.

Ultrasonic atomizers atomize liquid through a two-step process:

- Liquid is ejected through a number of small orifices into the nozzle outlet channel, where a high velocity air stream provides for the first liquid breakup, through shear action onto the jets surface.
- The air stream carrying the droplets impacts onto a resonator placed in front of the nozzle outlet orifice, generating a field of high frequency sound waves. Flying through the sound wave field, the droplets undergo an additional breakup step.
- Ultrasonic atomizers produce the finest sprays, as a full cone spray with a narrow spray angle. Since water and compressed air are ejected from different orifices, their pressure can be adjusted separately, avoiding mutual influence; this allows for obtaining satisfactory operating conditions along a very wide range of fluid capacities. Ultrasonic atomizers offer the following distinct advantages:
- The droplets show a low mean value and a very narrow range for SMD values (see, *Control of Particulate Matter in Gaseous Emissions*). This means very predictable spray behavior, without drops much bigger or smaller than the spray SMD value: for example there will be no large drop falling to the ground before

complete evaporation and causing a wet spot.

- The high variations in local air pressure induced by the sound waves prevent dust and lime particles from building up at the orifice and impairing atomizer performance.

2.3. Spray Modeling

A spray of evaporating particles can be modeled mathematically. The source terms in the spray equations are specified at the injector, based on the droplet data taken from experiments. Liquid drops are moving and evaporating in a gas; the droplets can undergo break-up and collision processes.

The application of the distribution function leads to conservation equations of mass, impulse, and energy in the form of the instantaneous Navier-Stokes equations in the Eulerian formulation. Then, the ensemble-averaging procedure is applied to get the final form of governing equations. A volume used in the averaging must be large compared to the drop radii.

The spray is represented by a finite number of discrete parcels and every parcel contains a number of droplets with the same properties. The particles are tracked through the flow field in the Lagrangian fashion. The gas/spray interactions are accounted for by introducing appropriate source terms in the governing equations. The Monte Carlo method is applied in the sense that one samples randomly from assumed probability distribution functions, governing droplet properties at injection, collision, and turbulent modulation.

3. Scrubber Types

3.1. High-velocity Units

3.1.1. Venturi scrubbers

A Venturi scrubber is conceptually the simplest, most compact, yet also most efficient wet dust collector. Its collection efficiency extends down to 0.2 µ particles, if very high linear gas velocities (typically 50 to 150 m s^{-1}) are reached in the throat, where the gas is first contacted with water. Hence, collection efficiency mainly depends on the pressure drop experienced during this operation.

In its simplest form a Venturi scrubber consists of a long tube, composed of consecutive converging and diverging sections, with steeply rising velocity in the convergent section, contact with the scrubbing liquor in its throat, and a conversion of kinetic energy into pressure in the downstream divergent diffuser.

Designs differ mainly in the way water is introduced, e.g.

- using spray nozzles, generating fine or coarser droplets,
- having water flowing down by gravity along the walls towards the throat,
- letting water being aspired by under pressure created in the throat (cf.

Bernoulli's Equation), or even by
- impacting a high velocity gas flow onto a water surface, causing wide dispersion of droplets.

A second classification is based on the geometry of the converging and diverging sections; instead of a simple, but lengthy tubular arrangement more compact designs are possible, such as:

- Conventional Venturi, but with a very short convergent entrance section, a normal sized diffuser (divergent section), and a simple cylindrical, centrifugal droplet separator,
- Venturi with an annular diffuser with a possibility to widen or constrict the annular space,
- Radial flow scrubbers.

When the gas flow rate to be treated is variable, it is necessary to adapt the cross-section of the throat, thus maintaining a constant linear velocity and hence collection efficiency. In a simple tubular design the throat can be made in rubber and pinched pneumatically. Other types feature a mechanical control to adapt this cross-section area.

The amount of water injected can be varied as well. Often the water moves in closed circuit, incorporating a settling basin to separate collected dust as slurry. Given the high gas velocities erosion and abrasion are factors to consider, as well as corrosion following the absorption of acid gas compounds. Water treatment may cause considerable cost in Venturi dust collectors.

The droplets normally coalesce to a size of the order of 0.1 mm and can be separated by centrifugal forces (conventional cyclones), by lamellae separator, based on sick-sack flow, inertial forces and wetted collecting surfaces, or – if required - wire or fiber gauge packages.

Entrainment of droplets from scrubbers may be significant. Hence, droplet separators are important. Sometimes a two-step arrangement is preferred, with a first contact using recycle water, a second wetted with pure make-up water.

3.1.2. Jet scrubber

The construction and operation of a water jet scrubber resembles that of the Venturi scrubber, with as distinctive features:

1) The water jet is thus self aspiring, drawing in the gas to be treated and,
2) The injected water supplies the energy for both water dispersion and dust collection.

Since the dust collection efficiency is only medium it is not unusual to operate jet scrubbers in a cascade of two or even more units.

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Biographical Sketch

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).