An Introduction to Wet Scrubber Control Technologies

An eBook generated to provide the reader with a generic overview of the wet scrubber technologies commonly utilized to control Industrial and Municipal waste gas and particulate air pollution. AirPol continues to provide educational material in support of Industry and the need to utilize properly designed and configured Air Pollution Control equipment.

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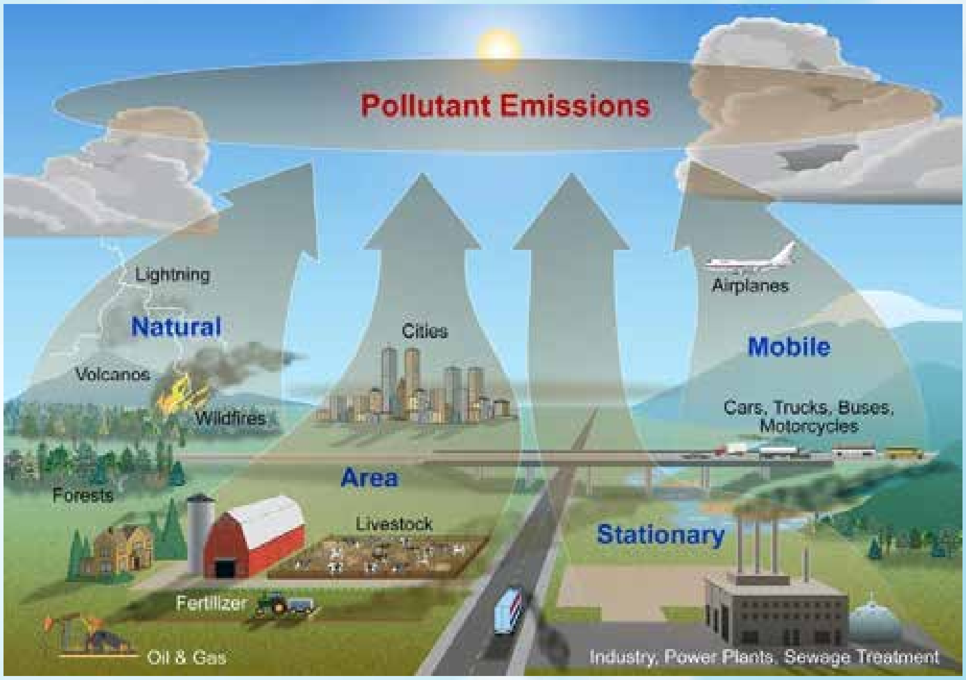
Introduction:

What is an Air Pollutant?

Answer: Any substance in the air that can cause harm to humans and the environment. Pollutants can be in the form of solid particles, liquid droplets, or gases. In addition, they may be natural or man-made.



Pollutants can be classified as primary or secondary. Usually, primary pollutants are directly emitted from a process, such as ash from a volcanic eruption, the carbon monoxide gas from a motor vehicle exhaust or sulfur dioxide released from factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. An important example of a secondary pollutant is ground level ozone — one of the many secondary pollutants that make up photochemical smog. Some pollutants may be both primary and secondary: that is, they are both emitted directly and formed from other primary pollutants.

Air pollution is controlled to protect the environment from the harmful effects of industrial and municipal pollutants. We must eliminate the impact air pollution has on humans, animals, plants and all other life supporting systems.

Air Pollution Control (APC) can be described as a “separation” technology. The pollutants, whether they are gaseous, aerosol, or solid particulate, are separated from a carrier gas which is usually air. The pollutants are categorized as follows:

- ✓ Gaseous pollutants are compounds that exist as a gas at normal conditions.
- ✓ Aerosols are finely divided solid and liquid particles that are typically under 0.5 microns in diameter. They often result from the sudden cooling of a gaseous pollutant.
- ✓ Solid particulates can be evolved through combustion or through common processing operations such as grinding, roasting, drying, coating, forming or metalizing

Pollutants are commonly referred to as Volatile Organic Compounds (VOC's) or Hazardous Air Pollutants (HAPs). As defined by the US EPA, "Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions." On the other side of the equation, APC defines HAPs, also known as toxic air pollutants or air toxics, as those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

- ✓ Paint and Coatings Manufacturers
- ✓ Wood Products Manufacturing
- ✓ Petroleum Refining
- ✓ Chemical/Petro-Chemical Manufacturing
- ✓ Pharmaceutical Manufacturing
- ✓ Semi-Conductor and Solar
- ✓ Food and Beverage Industry
- ✓ Industrial and Municipal Waste Water

The following industries commonly employ Air Pollution Control (APC devices as an integral part of their manufacturing process.

Typical industrial and municipal air streams contain a very diverse and wide range of compound pollutants. As a result, numerous technologies have been developed to address the specific control needs as determined by local, regional, state and national regulatory agencies.

APC systems can be very specific relative to their treatment capability, broad based and can effectively treat a wide range of compounds. APC is broken into two functional categories, Particulate Control and Gaseous (Waste gas) Pollutant Control

The information presented in this overview is intended to provide the reader with a general understanding of the current technologies available for the control of air pollution. The technologies presented are currently being utilized by Industrial and Municipal companies globally. Control is specific to the compounds found in the air stream, the loadings associated with each compound and the level of removal that must be achieved. As such, each system must be configured to meet the desired results based on the specifics associated with the air stream.

The following technologies are typically used to control VOCs and HAPs emissions:

- ✓ Wet Scrubbers
- ✓ Incineration
- ✓ Bio Scrubbers/Bio trickling Filters
- ✓ Carbon Adsorption

The eBook will focus on RTO Systems.

Wet Scrubbers

WET SCRUBBERS

Industrial scrubbers are pollution systems that utilize water and/or chemicals to remove gas pollutants and odors from exhaust streams. In wet scrubbing processes, gaseous liquid or solid particles are removed from a gas stream by transferring them to a liquid. That liquid is usually water; however, if gaseous pollutants are also being removed, it may be an aqueous solution that contains chemicals selected to react with the absorbed contaminants. Most wet scrubbing systems operated with removal efficiencies >95%.

The main advantages of industrial scrubbers used to treat waste gas exhaust streams include:.

- ✓ Low-risk processing of incendiary gases
- ✓ Ability to handle high-temperature, high-humidity gas streams without temperature limits or condensation problems.
- ✓ Smaller space requirements when compared to other technologies.
- ✓ Lower capital costs and site location
- ✓ No secondary dust sources - once particulate matter is collected, it cannot escape from hoppers or during transport
- ✓ Ability to absorb gas and solid particulate matter via a single device
- ✓ Ability to neutralize corrosive gases

Dry vs. Wet Scrubbers

Industrial scrubbers are categorized as either "dry" or "wet". Dry scrubbers generally cannot achieve the same level of pollutant removal as wet scrubbers, but they are well-suited for applications in facilities that lack the infrastructure to properly handle the produced wastewater resulting from wet scrubber applications.

Dry scrubbers remove pollutants from exhaust gases without the use of liquids. Instead, they utilize a dry reaction material known as "sorbent", such as an alkaline slurry, and they are primarily installed for the removal of acid from waste gas streams by moving the gas through the sorbent "dust" to maximize binding.

Wet scrubbers move was gas through a liquid that is designed to remove the pollutants. Wet scrubbers are very versatile and in most applications are cost-effective options. They are capable of removing up to 99.9+% of treatable waste contaminants.

How Wet Scrubbers work?

Water is the most common solution used to remove inorganic contaminants. In the most basic form of the wet scrubbers, water is entrained within a metal or composite vessel, waste gas is passed through the water, the water then absorbs the contaminants, and clean gas exits the scrubber.

Other liquids can be used as absorbing solutions to effectively remove a wide variety of contaminates . By changing the chemical composition of the absorbing solution, the charge can be changed. A caustic solution (sodium hydroxide, NaOH) is the most common scrubbing liquid used for acid-gas control (e.g., HC;, SO_2, or both. In some cases sodium carbonate

Wet Scrubbing of Particulate Matter

Wet scrubbers can remove particulate matter by capturing them in liquid droplets. The droplets are then collected, with the liquid dissolving or absorbing the pollutant gases. Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream using a mist eliminator.

A wet scrubber's ability to collect particulate matter is often directly propranolol to the power input into the scrubber. Additionally, a properly designed and operated mist eliminator is important to achieve high removal efficiencies.

If the gas stream contains both particulate matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants.

Wet Scrubbing System Types

- ✓ Spray Tower wet scrubbers
- ✓ Packed Bed wet scrubbers
- ✓ Tray Tower wet scrubbers
- ✓ Fiber Bed Mist Eliminators
- ✓ Venturi wet scrubbers
- ✓ Quench Scrubber

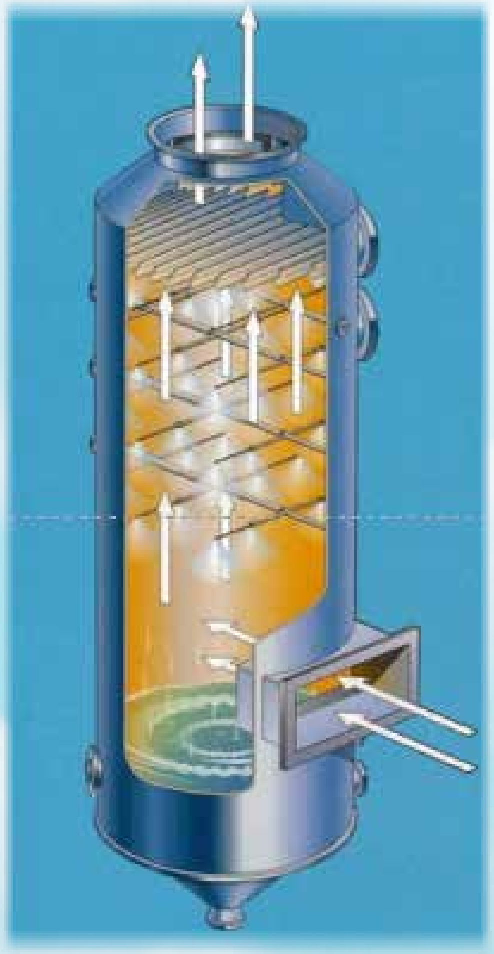
The common types of air pollution control wet scrubber systems for particulates are:

These systems incorporate Mist Eliminators or Entrainment Separation methods that remove final or exit droplets. This is done with Chevrons, Mesh Pads, or Cyclones.

Wet scrubber types by energy use:

There are many equipment designs for contacting the liquid with the contaminated gas stream. The capability of a particular design can be approximated from the gas stream pressure drop across the unit scrubber. In general, high pressure drops indicate more aggressive contact between the liquid and the gas stream, causing smaller particles to be collected with greater efficiency. Scrubbers with pressure drops less than about 5 inches of water are capable of efficiently removing particles greater than about 5-10 micrometers in diameter. Wet scrubbers that have pressure drops from 5 to 25 inches of water are capable of removing micrometer-sized particles, but are not very efficient on sub-micrometer particles. Removal of sub-micrometer particles requires significant energy input, ranging from 25 to over 100 inches of water, depending on the particle size. These collectors are referred to as high energy wet scrubbers. Not all scrubber designs will conform to these generalized categories.

Collectors that may collect smaller particles than their pressure drop would indicate include wet electrostatic precipitator scrubbers, WESP or ESP.



Spray Towers

The spray tower is a low energy device and is the simplest wet scrubber used for particle collection. It consists of an open vessel with on or more sets of spray nozzles to distribute the scrubbing liquid. Typically, the gas stream enters at the bottom and passes upward through the sprays. The particles are collected when they impact the droplets. This is referred to as counter-current operation. Spray towers can also be operated in a cross-current arrangement. In cross-current scrubbers, the gas flow is horizontal and liquid sprays flow downward. Cross-current spray towers are not usually as efficient as counter-current units.

Modular Design for easy shipping and quick installation

Packed Bed Scrubbers:

Packed-Bed scrubbers remove air pollutants through reaction with a sorbent or reagent slurry, or absorption into liquid solvent.

Packed-bed scrubbers consist of a chamber containing randomly dumped packing material (e.g., spherical balls) that creates and mixes water droplets allowing for area for gaseous mass transfer as well as provides a surface area for liquid-particle contact. The packing's shape, weight, surface area and cost all influence the efficiency of the low gas-phase pressure drop and gas-liquid contact. The packing is held in place by wire mesh retainers, and is supported by a plate near the bottom of the scrubber.

Waste gas is forced into the bottom of the scrubber's chamber and flows vertically or horizontally through the packing while scrubbing liquid is simultaneously and evenly introduced above the packing and flows down through the bed to coat the packing and establish a thin film. In vertical designs (packed towers), the gas stream flows up the chamber ("counter-current" to the liquid). However, some packed beds are designed horizontally for gas flow across the packing ("cross-current").

The cleaned gas is then passed through a mist eliminator built into the top of the structure, and the waste slurry drops to the bottom of the chamber.

Packed bed scrubbers are another type of medium energy collector. Packed bed collectors spread the liquid over packing material in order to provide a large surface area for particle impaction.

There are many designs for the packing materials, but they all have large surface area while maintaining open areas for the gas flow.

Although they are usually made of plastic, metal and ceramic packings are available when plastic cannot be used. Like spray towers, packed beds are classified according to the relative direction of the gas and liquid flows.

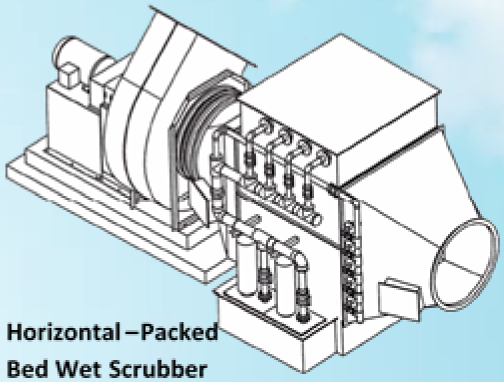
In the counter-current design, the liquid is introduced at the top of the tower using sprays or weirs and flows downward over the packing material.

The contaminated gas stream enters at the bottom of the tower and flows upward through the packing. Because of limitations in the amount of liquid that will move downward against the upward gas flow, this orientation is susceptible to plugging when the concentration of solid particles is high.

In the cross-flow scrubber, the gas stream flows horizontally through the packed bed, while the liquid flows down through the packing material. Because greater amounts of liquid can be used in this arrangement, the cross-flow scrubber can tolerate slightly higher concentrations of solid particles before plugging. In some designs, the particles are charged before entering the packed bed, in order to increase collection efficiency. These devices are referred to as ionizing wet scrubbers.

The advantages of Packed-Bed wet scrubbers are consistent with industrial scrubbers in general and include:

- ✓ Relatively low pressure drops - Pressure drop is the pressure difference that occurs as exhaust gas is pushed or pulled through the scrubber, disregarding the pressure that would be used for pumping or spraying the liquid into the scrubber.
- ✓ Fiberglass-reinforced plastic (FRP) construction permits operation in highly corrosive atmospheres.
- ✓ Capable of achieving relatively high mass-transfer efficiencies
- ✓ The height and/or type of packing can be changed to improve mass transfer without purchasing new equipment.
- ✓ Relatively low capital cost
- ✓ Relative small space requirements
- ✓ Ability to collect Particulate Matter (PM) as well as gases.

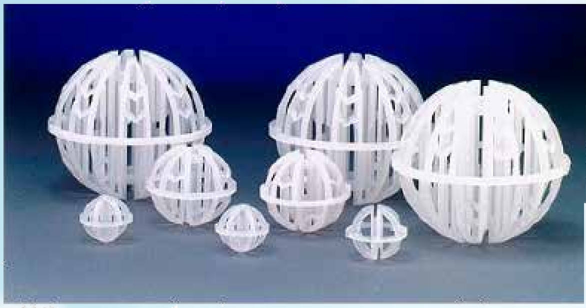

Horizontal –Packed Bed Wet Scrubber

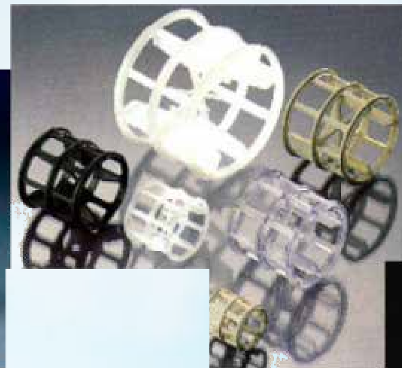
Packed-Bed wet scrubbers are used to control::

Inorganic fumes, vapors, and gases (e.g. Hydrochloric acid, hydrogen sulfide, ammonia, chlorides, fluorides, and SO_2) - Inorganic fumes, vapors and gases are the primary pollutants controlled by Packed-Bed wet scrubbers. They typically achieve removal efficiencies in the range of 95-99%.

Wet scrubbers are occasionally used to control volatile organic compounds (VOCs). Removal efficiencies for gas absorbers have removal efficiencies in excess of 90%, and packed-tower absorbers may achieve efficiencies greater than 99% for some pollutants. The typical collection efficiency range is from 70% to greater than 99%.

Packed-bed wet scrubbers are limited to applications in which dust loading is low, and collection efficiencies range from 50-95%, depending upon the application.

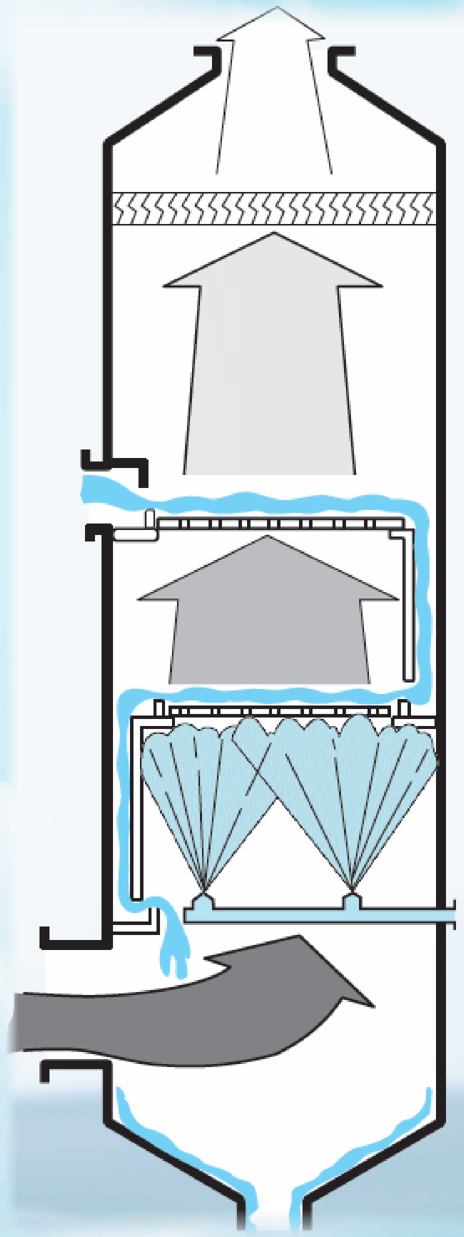




Packing Media

Tray Towers:

The tray tower is a medium energy scrubber and consists of a vertical column with one or more trays mounted horizontally inside. The simplest tray is a perforated plate that is referred to as a sieve tray.



Other tray designs include:

1. Impingement trays that have small impingement targets above each perforation to enhance gas-liquid contact,.
2. Bubble cap trays that can operate over a wide range of gas and liquid flow rates without adversely affecting collection efficiency.
3. Valve trays that have liftable valves or caps that improve gas-liquid contact when the gas flow rate varies. Tray scrubbers are vulnerable to solids accumulation and plugging problems.

How do tray towers work?

Regardless of the tray design, all of these units operate in a similar manner. The contaminated gas stream enters at the bottom and flows upward through the holes in the plates. The liquid enters at the top of the tower, flows across the tray and then through a down comer to the tray below until it reaches the bottom of the tower. The function of the trays is to disperse the liquid into droplets and the gas stream into bubbles, creating the gas-liquid contact necessary for particle collection.

Applications

AirPol tray scrubbers are ideal for use in many industries, such as petroleum, pulp ad paper, chemical, electrical utility, food processing, metal processing, textiles, rubber, plastics and mining. They are used for SO_2 removal, gas absorption and particulate removal in a wide range of processing operations and equipment:

- ✓ Municipal sludge
- ✓ Industrial Incinerators
- ✓ Kilns and Ovens
- ✓ Rotary Dryers
- ✓ Fluidized Beds
- ✓ Flash and Multiple Hearth Roasters
- ✓ Flue Gas Desulfurization (SO_2)
- ✓ Spent Liquor Recovery
- ✓ Boilers
- ✓ Reaction Vessels
- ✓ Spray Dryers
- ✓ Acid and Fertilizer Operations
- ✓ Oil and Coal-Fired Power Boilers
- ✓ Steam Generation

Quench Scrubber:

Two-stage scrubber solution for applications involving corrosive air from hot processes and corrosive air contaminants from processes such as thermal or catalytic oxidizers - HCl, HF, SO_2, Cl_2, HB. A quench can be used to reduce the waste gas temperature prior to entering another scrubber system. A common application is a waste gas exhaust from a thermal oxidizer that requires an acid gas scrubber prior to exhaust to atmosphere. The quench system will reduce the temperature to an acceptable level.

High efficiency - Up to 99.9% removal efficiency of acid or toxic gases

Maximum reliability and value with corrosion and chemical resistance materials

Two-stage system consists of:

Quencher stage designed to cool the hot gases - constructed of a suitable metallic material

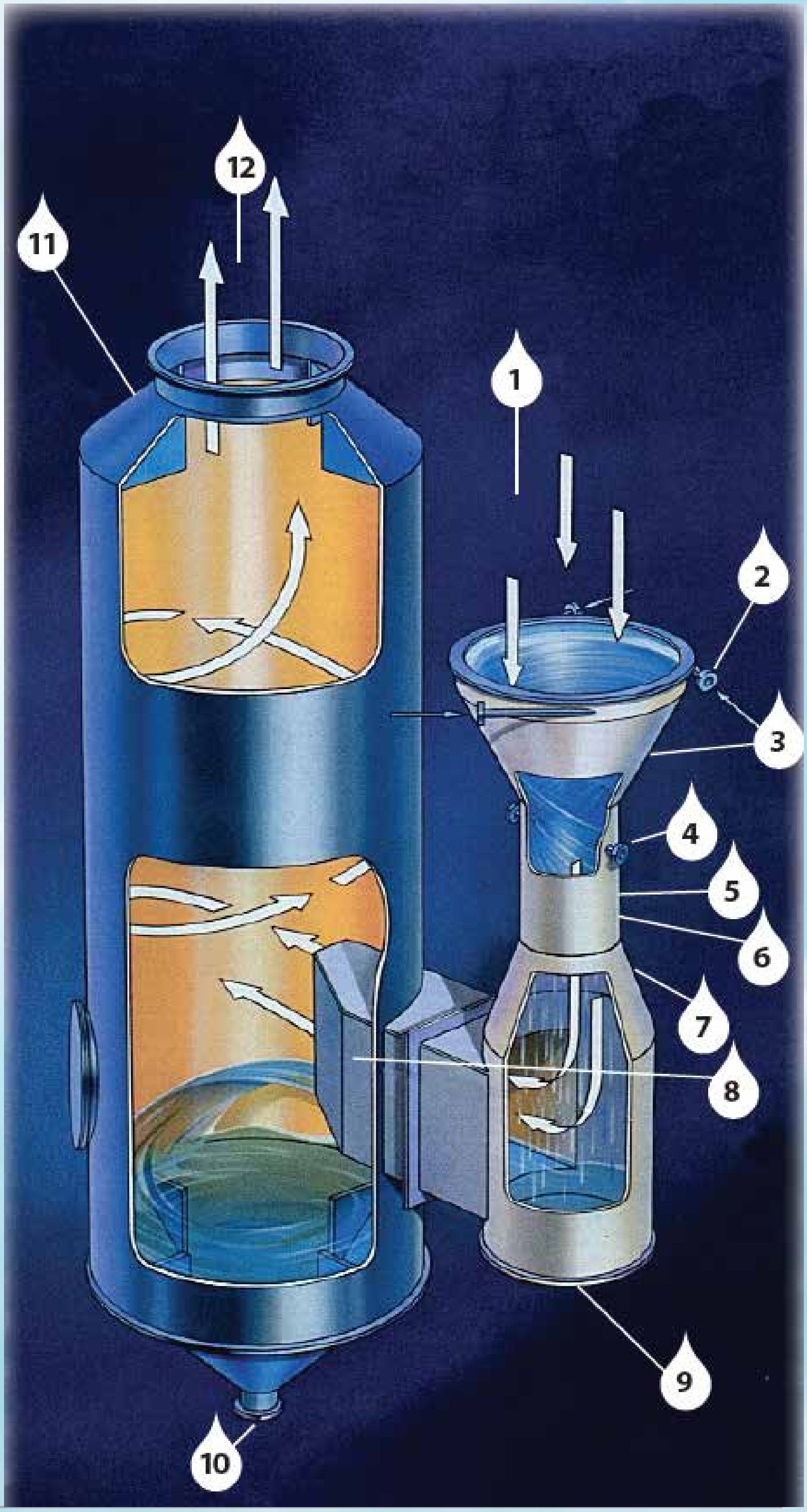
Scrubber stage to remove the corrosive gases and mists - constructed of FRP material and is filled with a high efficiency packing material, mist eliminator and liquid distribution system

Venturi Scrubbers

The most common high energy wet scrubber is the venturi, although it can also be operated as a medium energy scrubber. In the fixed-throat venturi, the gas stream enters a converging section where it is accelerated toward the throat section. In the throat section, the high-velocity gas stream strikes liquid streams that are injected at right angles to the gas flow, shattering the liquid into small drops. The particles are collected when they impact the slower moving drops. Following the throat section, the gas stream passes through a diverging section that reduces the velocity. Some particle collection also occurs in this section.

General Design of a Venturi Scrubber:

1. Raw Gas Inlet
2. Scrubbing liquid from recycle pump. Straight pipes: no nozzles, no plugging.
3. Liquid swirls with “dentist bowl” effect and prevents particulate build-up and erosion.
4. Additional recycle liquid for complete liquid coverage in the Venturi throat
5. Collision zone. Particulates get entrapped in the recycle liquid
6. Pressure drop (gas velocity) in Venturi throat determines collection efficiency. At fluctuating gas volumes, a damper in the throat maintains constant pressure drop (=constant efficiency)
7. Long diverging section promotes extended contact of particulates & liquid and increases pressure drop regain.
8. Gas/liquid mixture enters Separator spin zone. Liquid (with entrapped particulates) drains via bottom cone to recycle pump. Clean gas swirls upward to gas exit.
9. Liquid reservoir in “flooded” elbow bottom prevents abrasion of metal surfaces
10. Liquid with entrapped particulates drains to the pump for recycle back to Venturi and to bleed for disposal
11. Anti-spin baffles stop gas spin and straighten the flow before gas enters the stack.
12. Clean Gas Outlet



One variation of the standard venturi scrubber is the wetted-approach design. In this design, the scrubbing liquid is introduced at the beginning of the converging section using overflow weirs and a central spray nozzle. This is done to wet the converging section and protect it from particle erosion. High efficiency >99% on very fine particulates

- ✓ Energy savings - no pumps.
- ✓ Maintenance savings - no moving parts, spray nozzles, or recirculation piping.
- ✓ Floor space - efficient geometry.
- ✓ Water savings - integral water saving sludge concentrator

Another variation is the variable-throat venturi. Since the scrubbing energy is a function of the gas velocity in the throat, venturi's that can change their throat dimensions are used when the gas flow rate from the process varies. The position of the adjustable-throat mechanism is usually set to maintain a fixed pressure drop across the collector.

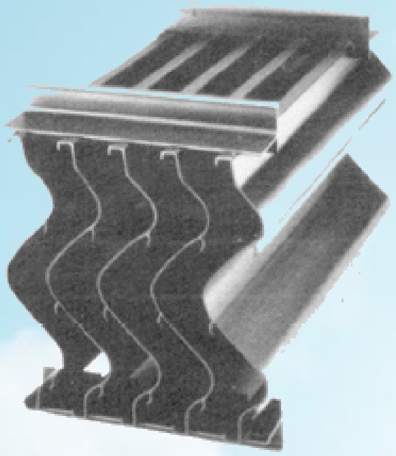
Eductor scrubbers are designed to remove soluble gases and particulate by inducing a gas flow using high pressure liquid focused into a Venturi throat, which eliminates the need for a separate exhaust fan or blower to transport the contaminated gas stream to the filtration device.

Design incorporates a high-pressure spray for maximum entrainment and scrubbing efficiency, and is the optimal choice where high temperatures, heavy contaminant loads, and corrosive conditions are present. Maximum efficiency - up to 99% removal efficiency of mists 3 microns or larger.

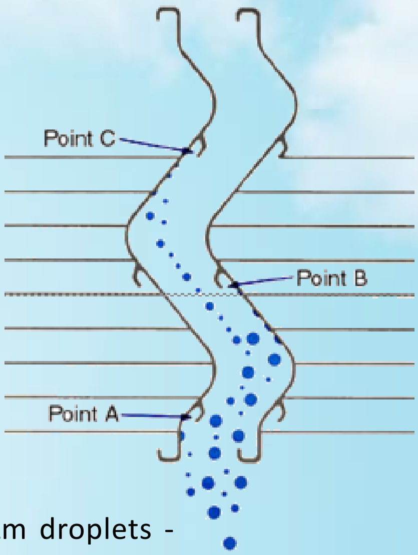
Ideal applications for Venturi scrubbers include:

- ✓ Chemical
- ✓ Food / Dairy Industry
- ✓ Paper
- ✓ Dryer
- ✓ Pharmaceutical
- ✓ Roofing materials
- ✓ Asphalt
- ✓ Mining
- ✓ Steel
- ✓ Brick & Tile
- ✓ Fiberglass Insulation
- ✓ Power Generation
- ✓ Plastic Extrusion

Mist Eliminators



In all wet scrubbers, the process of contacting the gas and liquid streams results in entrained droplets. Since these droplets contain the contaminants, they must be removed before the gas stream exists the unit. This is referred to as mist elimination or entrainment separation.



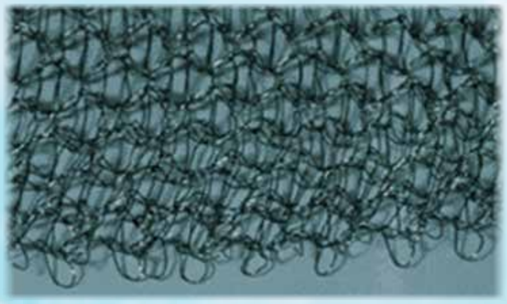
The most common mist eliminators are chevrons, mesh pads and cyclones. Chevrons are simply zig-zag baffles that cause the gas stream to turn several times as it passes through the mist eliminator. The liquid droplets are collected on the blades of the chevron and drain back into the scrubber.

Advantages:

- ✓ Highest throughput (12-20 ft/s)
- ✓ Lowest fouling tendency - 1-3/8" spacing
- ✓ Low pressure drops
- ✓ Effective down to 35-40 µm droplets - lowest cost for large scrubbers

Disadvantages:

- ✓ Lower efficiency



Mesh pads are made from interlaced fibers that serves as the collection targets.

Advantages:

- ✓ High efficiency down to 2µm droplets

Disadvantages:

- ✓ High pressure drops
- ✓ Limited throughput (10-12 ft/s)
- ✓ High fouling tendency

A cyclone is typically used for the small droplets generated in a venturi scrubber. The control efficiency a device has in capturing contaminants is affected by Particulate Size and Pressure Drop.

Wet Scrubber Selection Guide:

A general guide that can be used to select the scrubber configuration based on the criteria listed in the chart. Note, there are numerous considerations that must be factored into the selection process.

Scrubber Type	Gas Absorption		Mists <10 Micron	Mist >10 Micron	Solids/Dusts >5 Microns	
	High Sol.	Low Sol.			Low	High
Packed Tower	E	E	G	E	NR	NR
Crossflow	R	G	G	E	NR	NR
Tray Tower	E	E	G	E	G	NR
Venturi (High Energy)	F	NR	G	E	E	E
Venturi (Low Energy)	F	NR	F	G	E	E
Eductor Venturi	F	NR	F	E	E	G
E: Excellent; G: Good; F: Fair; NR: Not Recommended						

Causes of decreased performance:

There are several operating problems that can occur in wet scrubbing systems. The most common of these include the following:

- ✓ Inadequate liquid flow.
- ✓ Improper liquid pH
- ✓ Liquid re-entrainment
- ✓ Poor gas-liquid contact
- ✓ Plugged nozzles, beds or mist eliminators
- ✓ Corrosion
- ✓ Is the system working efficiently?

The ability to evaluate potential problems during a field inspection will depend on how well the system is instrumented. Most large systems are well instrumented; however, smaller systems may have limited instrumentation. Performance evaluation of these systems will be difficult unless measurements of important parameters are made.

There should be two goals in any field inspection. First is to evaluate the source's compliance with any rule-specific monitoring requirements and with the provisions of the Title V permit.

In addition, parameters that influence performance should be evaluated to see if there are shifts from their baseline values that could indicate reduced collection efficiency

The most direct indicator of system performance is the opacity of the outlet gas stream. However, since the gas stream is usually close to saturation at the outlet of the scrubber, the presence of condensing moisture may make the observation difficult. For the same reason, opacity monitors are not typically used on wet scrubbers, since it is not possible to differentiate between light scattering due to particles and that due to water droplets. Therefore, less direct indicators of performance are typically used. .

Performance Monitoring:

Perhaps the best indicator of adequate gas-liquid contact is the difference in temperature between the inlet and outlet of the scrubber. If that temperature difference has decreased, it is likely that the collection efficiency has also gone down. For example, a higher-than-normal temperature at the outlet of a scrubber, may indicate a decreased liquid flow rate.

The liquid flow rate into the scrubber is also important. If the flow rate is being monitored, the value during the inspection should be compared to the baseline or permit value. A decrease in the liquid flow rate, without a proportional decrease in the gas flow rate, will usually cause a decrease in the collection efficiency. If the flow rate is not being monitored, other indicators can be used. Indirect indications of decreased liquid flow rate include a decrease in the pump discharge pressure or an increase in the pressure in headers supplying spray nozzles. Increased pressure in a supply header is usually due to plugging of the nozzles, which reduces the liquid flow rate.

The pH of the inlet and outlet liquid should be evaluated. An inlet pH above 10 indicates a potential for scale accumulation that can plug nozzles, packed beds, and trays, reducing liquid flow rate and impairing gas-liquid contact. An outlet pH below 6 can cause severe corrosion of metal components.

Causes of changes in scrubber pressure:

Changes in scrubber pressure drop can occur for several reasons. Increased pressure drop across the packed bed or tray scrubber may indicate plugging of the bed or trays or packed beds. Increased pressure drop on a venturi scrubber may be caused by increased liquid flow rate or by adjusting a variable throat damper to a more closed position.

A decrease in the pressure drop across a tray scrubber may indicate warped or collapsed trays, while for a venturi scrubber it may be caused by decreased liquid flow rate or by adjusting a variable throat damper to a more open position.

Mist eliminator performance:

Similarly, the pressure drop across the mist eliminator provides an excellent indicator of its physical condition. For mist eliminators that are used to remove the relatively large droplets created in the scrubber, the increased pressure drop usually results from a buildup of material on the mist eliminator surfaces, narrowing the openings for the gas to flow through. The resulting higher gas velocities can drag the collected liquid through the mist eliminator and back into the outlet gas stream, reducing collection efficiency. A decrease in the pressure drop across the mist eliminator may indicate structural failure.

The performance of the mist eliminator can also be evaluated by observing the stack and areas adjacent to the stack. Rain-out droplets around the stack, mud-lips and discolored streaks at the stack discharge, or heavy drainage from open ports all indicate a poorly performing mist eliminator.

System parameter checklist:

To review: to determine if a wet scrubber system is working properly, field personnel should observe if possible:

1. Outlet Gas Stream Opacity, but take into consideration the presence of water droplets,
2. Temperature Difference between the Gas Inlet and Outlet, and
3. Liquid Flow Rate into the scrubber.

Other parameters include:

- ✓ pH Levels of the inlet and outlet liquids, and
- ✓ Pressure Drop changes in the wet scrubbers and mist eliminators.

As with any inspection of an air pollution control device, attention must be given to the systems:

- ✓ Records & Physical Condition
- ✓ Compliance with Applicable Rules