

INDUSTRIAL PROCESS

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SESSION 1 GENERAL PROCESS

Industrial processes are procedures involving [chemical](#), [physical](#), [electrical](#) or [mechanical](#) steps to aid in the [manufacture](#) of an item or items, usually carried out on a very large scale. Industrial processes are the key components of [heavy industry](#).



Liquid nitrogen

Liquefaction of gases is physical conversion of a [gas](#) into a [liquid](#) state ([condensation](#)).

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Details

The processes are used for scientific, industrial and commercial purposes. Many gases can be put into a liquid state at normal [atmospheric pressure](#) by simple cooling; a few, such as [carbon dioxide](#), require pressurization as well. [Liquefaction](#) is used for analyzing the fundamental properties of gas molecules (intermolecular forces), for storage of gases, for example: [LPG](#), and in [refrigeration](#) and [air conditioning](#). There the gas is liquefied in the *condenser*, where the [heat of vaporization](#) is released, and evaporated in the *evaporator*, where the heat of vaporization is absorbed. [Ammonia](#) was the

first such refrigerant, and is still in widespread use in industrial refrigeration, but it has largely been replaced by compounds derived from [petroleum](#) and [halogens](#) in residential and commercial applications.

[Liquid oxygen](#) is provided to hospitals for conversion to gas for patients with breathing problems, and [liquid nitrogen](#) is used in the medical field for [cryosurgery](#), and by inseminators to freeze [semen](#). Liquefied [chlorine](#) is transported for eventual solution in water, after which it is used for water purification, sanitation of [industrial waste](#), sewage and swimming pools, bleaching of pulp and textiles and manufacture of [carbon tetrachloride](#), [glycol](#) and numerous other organic compounds as well as [phosgene](#) gas.

Liquefaction of [helium](#) (^4He) with the [Hampson-Linde cycle](#) led to a [Nobel Prize](#) for [Heike Kamerlingh Onnes](#) in 1913. At ambient pressure the boiling point of [liquefied helium](#) is 4.22 K (-268.93°C). Below 2.17 K liquid ^4He becomes a [superfluid](#) ([Nobel Prize 1978](#), [Pyotr Kapitsa](#)) and shows characteristic properties such as heat conduction through [second sound](#), zero [viscosity](#) and the [fountain effect](#) among others.

The liquefaction of gases is a complicated process that uses various compressions and expansions to achieve high pressures and very low temperatures, using, for example, [turboexpanders](#).

The liquefaction of air is used to obtain [nitrogen](#), [oxygen](#), and [argon](#) and other atmospheric [noble gases](#) by separating the air components by [fractional distillation](#) in an [cryogenic air separation unit](#).

History

Further information: [Timeline of low-temperature technology](#)

Linde's Process

Air is liquefied by the [Linde](#) process, in which air is alternately compressed, cooled, and expanded, the expansion resulting each time in a considerable reduction in temperature. With the lower temperature the molecules move more slowly and occupy less space, so the air changes phase to become liquid, this makes it to lose heat and become a liquid

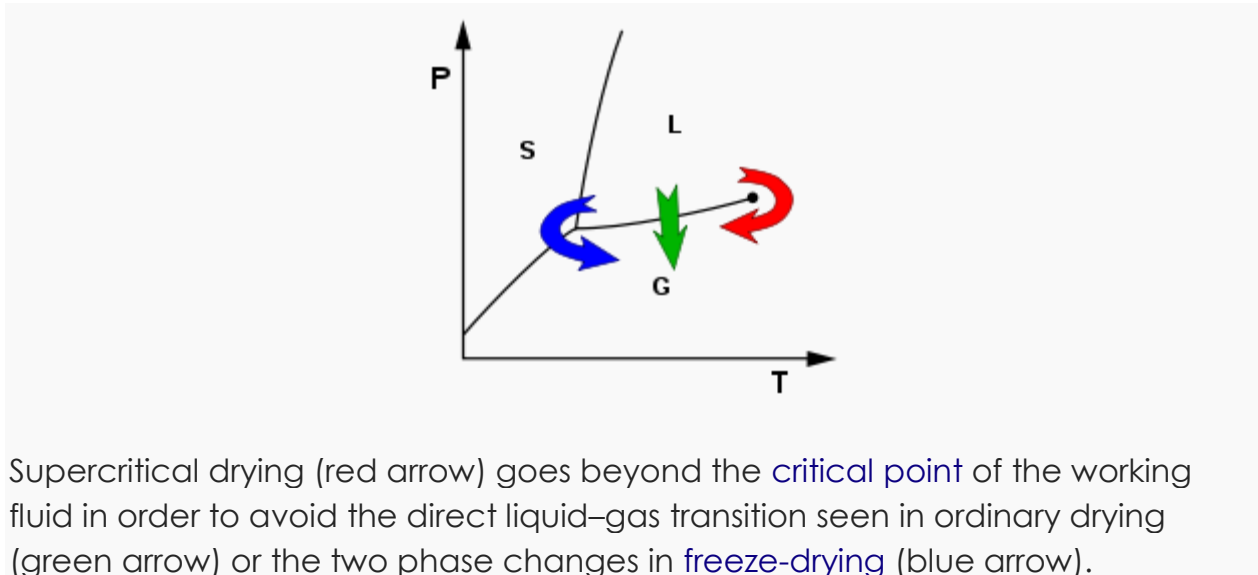
Claude's Process

Air can also be liquefied by [Claude's](#) process in which the gas is allowed to expand [isentropically](#) twice in two chambers. While expanding, the gas has to

do work as it is led through an [expansion turbine](#). The gas is not yet liquefied, since it would destroy the turbine. Final liquefaction takes place by [isenthalpic expansion](#) in a [Joule-Thomson-Valve](#).

Supercritical drying

From Wikipedia, the free encyclopedia



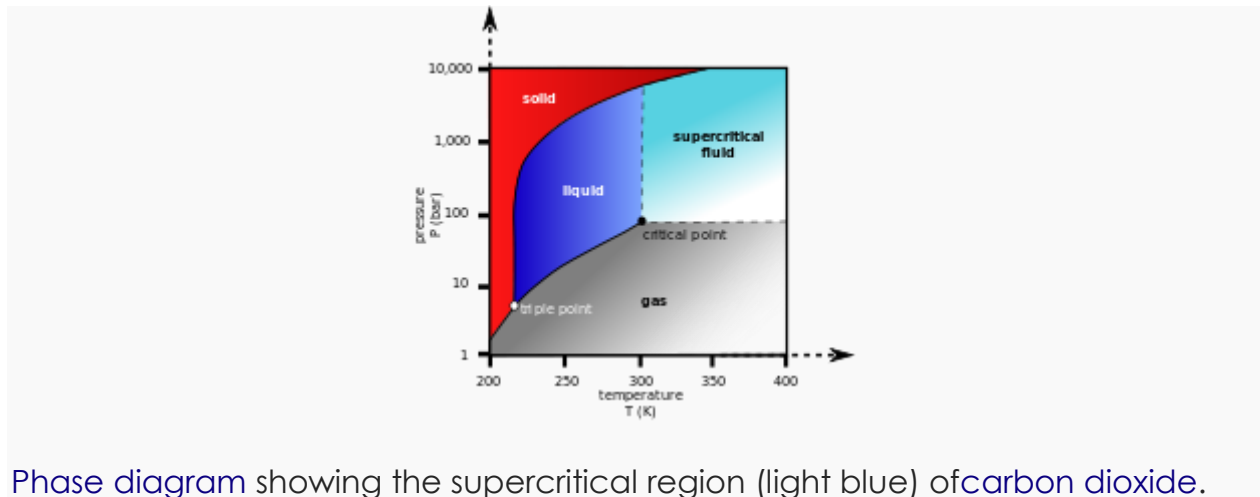
Supercritical drying (red arrow) goes beyond the [critical point](#) of the working fluid in order to avoid the direct liquid–gas transition seen in ordinary drying (green arrow) or the two phase changes in [freeze-drying](#) (blue arrow).

Supercritical drying is a process to remove [liquid](#) in a precise and controlled way. It is useful in the production of [microelectromechanical systems](#) (MEMS), the drying of [spices](#), the production of [aerogel](#), the [decaffeination](#) of coffee and in the preparation of biological specimens for [scanning electron microscopy](#).

As the substance in a liquid body crosses [the boundary from liquid to gas](#) (see green arrow in [phase diagram](#)), the liquid changes into [gas](#) at a finite rate, while the amount of liquid decreases. When this happens within a heterogeneous environment, [surface tension](#) in the liquid body pulls against any solid structures the liquid might be in contact with. Delicate structures such as [cell walls](#), the dendrites in [silica gel](#), and the tiny machinery of microelectromechanical devices, tend to be broken apart by this surface tension as the liquid–gas–solid junction moves by.

To avoid this, the sample can be brought via two possible alternate paths from the liquid phase to the gas phase without crossing the liquid–gas boundary on the phase diagram. In [freeze-drying](#), this means going around to the left (low temperature, low pressure; blue arrow). However, some structures are disrupted even by the [solid–gas boundary](#). Supercritical drying, on the other hand, goes around the line to the right, on the high-temperature, high-pressure side (red arrow). This route from liquid to gas does not cross any [phase boundary](#), instead

passing through the [supercritical](#) region, where the distinction between gas and liquid ceases to apply. Densities of the liquid phase and vapor phase become equal at critical point of drying.



Phase diagram showing the supercritical region (light blue) of carbon dioxide.

Fluids suitable for supercritical drying include [carbon dioxide](#) (critical point 304.25 K at 7.39 MPa or 31.1 °C at 1072 psi) and [freon](#) (≈ 300 K at 3.5–4 MPa or 25–0 °C at 500–600 psi). [Nitrous oxide](#) has similar physical behavior to carbon dioxide, but is a powerful [oxidizer](#) in its supercritical state. Supercritical [water](#) is inconvenient due to possible heat damage to a sample at its critical point temperature (647 K, 374 °C)^[1] and corrosiveness of water at such high temperatures and pressures (22.064 MPa, 3,212 psi).

In most such processes, [acetone](#) is first used to wash away all water, exploiting the complete [miscibility](#) of these two fluids. The acetone is then washed away with high pressure liquid carbon dioxide, the industry standard now that [freon](#) is unavailable. The liquid carbon dioxide is then heated until its temperature goes beyond the critical point, at which time the pressure can be gradually released, allowing the gas to escape and leaving a dried product.

perishable material or make the material more convenient for transport. Freeze-drying works by [freezing](#) the material and then reducing the surrounding [pressure](#) to allow the frozen water in the material to [sublimate](#) directly from the solid phase to the gas phase.

The origins of freeze drying[

The [Andean civilizations](#) preserved potatoes using a freeze drying process. They called this foodstuff [chuño](#).^[1]

Modern freeze-drying was developed during [WWII](#). [Serum](#) being sent to Europe from the US for medical treatment of the wounded required refrigeration, but because of the lack of simultaneous refrigeration and transport, many serum

supplies were spoiling before reaching their intended recipients. The freeze-drying process was developed as a commercial technique that enabled serum to be rendered chemically stable and viable without having to be refrigerated. Shortly thereafter, the freeze-dry process was applied to penicillin and bone, and lyophilization became recognized as an important technique for preservation of biologicals. Since that time, freeze-drying has been used as a preservation or processing technique for a wide variety of products. These applications include the following but are not limited to: the processing of food,^[2] pharmaceuticals,^[3] and diagnostic kits; the restoration of water damaged documents;^[4] the preparation of river-bottom sludge for hydrocarbon analysis; the manufacturing of ceramics used in the [semiconductor](#) industry; the production of synthetic skin; the manufacture of sulphur-coated vials; and the restoration of historic/reclaimed boat hulls.

The freeze-drying stages[

There are four stages in the complete drying process: pretreatment, freezing, primary drying, and secondary drying.

Pretreatment[

Pretreatment includes any method of treating the product prior to freezing. This may include concentrating the product, formulation revision (i.e., addition of components to increase stability and/or improve processing), decreasing a high vapor pressure solvent or increasing the surface area. In many instances the decision to pretreat a product is based on theoretical knowledge of freeze-drying and its requirements, or is demanded by cycle time or product quality considerations. Methods of pretreatment include: freeze concentration, solution phase concentration, formulation to preserve product appearance, formulation to stabilize reactive products, formulation to increase the surface area, and decreasing high vapor pressure solvents.^[5]

Freezing[

In a lab, this is often done by placing the material in a freeze-drying flask and rotating the flask in a bath, called a shell freezer, which is cooled by mechanical refrigeration, [dry ice](#) and [methanol](#), or [liquid nitrogen](#). On a larger scale, freezing is usually done using a freeze-drying machine. In this step, it is important to cool the material below its [triple point](#), the lowest temperature at which the solid and liquid phases of the material can coexist. This ensures that sublimation rather than melting will occur in the following steps. Larger crystals are easier to freeze-dry. To produce larger crystals, the product should be frozen slowly or can be

cycled up and down in temperature. This cycling process is called [annealing](#). However, in the case of food, or objects with formerly-living cells, large ice crystals will break the cell walls (a problem discovered, and solved, by [Clarence Birdseye](#)), resulting in the destruction of more cells, which can result in increasingly poor texture and nutritive content. In this case, the freezing is done rapidly, in order to lower the material to below its [eutectic point](#) quickly, thus avoiding the formation of ice crystals. Usually, the freezing temperatures are between $-50\text{ }^{\circ}\text{C}$ and $-80\text{ }^{\circ}\text{C}$. The freezing phase is the most critical in the whole freeze-drying process, because the product can be spoiled if improperly done. [Amorphous](#) materials do not have a eutectic point, but they do have a [critical point](#), below which the product must be maintained to prevent melt-back or collapse during primary and secondary drying.

Primary drying

During the primary drying phase, the pressure is lowered (to the range of a few [millibars](#)), and enough heat is supplied to the material for the water to [sublime](#). The amount of heat necessary can be calculated using the sublimating molecules' [latent heat of sublimation](#). In this initial drying phase, about 95% of the water in the material is sublimated. This phase may be slow (can be several days in the industry), because, if too much heat is added, the material's structure could be altered.

In this phase, pressure is controlled through the application of [partial vacuum](#). The vacuum speeds up the sublimation, making it useful as a deliberate drying process. Furthermore, a cold condenser chamber and/or condenser plates provide a surface(s) for the water vapour to re-solidify on. This condenser plays no role in keeping the material frozen; rather, it prevents water vapor from reaching the vacuum pump, which could degrade the pump's performance. Condenser temperatures are typically below $-50\text{ }^{\circ}\text{C}$ ($-60\text{ }^{\circ}\text{F}$).

It is important to note that, in this range of pressure, the heat is brought mainly by conduction or radiation; the convection effect is negligible, due to the low air density.

Secondary drying

The secondary drying phase aims to remove unfrozen water molecules, since the ice was removed in the primary drying phase. This part of the freeze-drying process is governed by the material's [adsorption isotherms](#). In this phase, the temperature is raised higher than in the primary drying phase, and can even be above $0\text{ }^{\circ}\text{C}$, to break any physico-chemical interactions that have formed

between the water molecules and the frozen material. Usually the pressure is also lowered in this stage to encourage desorption (typically in the range of microbars, or fractions of a [pascal](#)). However, there are products that benefit from increased pressure as well.

After the freeze-drying process is complete, the vacuum is usually broken with an inert gas, such as nitrogen, before the material is sealed.

At the end of the operation, the final residual water content in the product is extremely low, around 1% to 4%.

Properties of freeze-dried products[



Freeze dried [ice cream](#)

If a freeze-dried substance is sealed to prevent the reabsorption of [moisture](#), the substance may be stored at [room temperature](#) without refrigeration, and be protected against spoilage for many years. Preservation is possible because the greatly reduced water content inhibits the action of [microorganisms](#) and [enzymes](#) that would normally [spoil](#) or degrade the substance.

Freeze-drying also causes less damage to the substance than other [dehydration](#) methods using higher temperatures. Freeze-drying does not usually cause shrinkage or toughening of the material being dried. In addition, flavours, smells and nutritional content generally remain unchanged, making the process popular for preserving food. However, water is not the only chemical capable of [sublimation](#), and the loss of other volatile compounds such as acetic acid (vinegar) and alcohols can yield undesirable results.

Freeze-dried products can be rehydrated (reconstituted) much more quickly and easily because the process leaves microscopic pores. The pores are created by the ice crystals that sublime, leaving gaps or pores in their place. This is especially important when it comes to pharmaceutical uses. Freeze-drying

can also be used to increase the shelf life of some [pharmaceuticals](#) for many years.

Freeze-drying protectants[

Similar to [cryoprotectants](#), some molecules protect freeze-dried material. Known as lyoprotectants, these molecules are typically polyhydroxy compounds such as [sugars](#) ([mono-](#), [di-](#), and [polysaccharides](#)), [polyalcohols](#), and their derivatives. [Trehalose](#) and [sucrose](#) are natural lyoprotectants. Trehalose is produced by a variety of [plant](#) (for example [selaginella](#) and [arabidopsis thaliana](#)), [fungi](#), and [invertebrate animals](#) that remain in a state of [suspended animation](#) during periods of drought (also known as [anhydrobiosis](#)).

Applications of freeze-drying[[edit](#)]

Pharmaceutical and biotechnology[[edit](#)]

Pharmaceutical companies often use freeze-drying to increase the shelf life of the products, such as vaccines and other injectables. By removing the water from the material and sealing the material in a vial, the material can be easily stored, shipped, and later reconstituted to its original form for injection. Another example from the pharmaceutical industry is the use of freeze drying to produce tablets or wafers, the advantage of which is less [excipient](#) as well as a rapidly absorbed and easily administered dosage form.

Food and agriculturally-based industries[



Freeze dried [bacon](#) bars



Freeze-dried coffee, a form of [instant coffee](#)

Although freeze-drying is used to preserve [food](#), its earliest use in agriculturally based industries was in processing of crops such as peanuts/groundnuts and tobacco in the early 1970s . In freeze drying moisture is removed from frozen material through negative pressure in the chamber where that material is located. Because the removed moisture may damage the vacuum pump, the removed moisture/vapor must be refrozen to the surface of a condenser, which is then brought to room temperature to drain the moisture out. The process came to wide public attention when it was used to create [freeze-dried ice cream](#), an example of [astronaut food](#). It is also widely used to produce essences or flavourings to add to food.

Because of its light weight per volume of reconstituted food, freeze-dried products are popular and convenient for [hikers](#). More dried food can be carried per the same weight of wet food, and remains in good condition for longer than wet food, which tends to spoil quickly. Hikers reconstitute the food with water available at point of use.

[Instant coffee](#) is sometimes freeze-dried, despite the high costs of the freeze-driers used. The coffee is often dried by vaporization in a hot air flow, or by projection onto hot metallic plates. Freeze-dried fruits are used in some breakfast cereal or sold as a [snack](#), and are an especially popular snack choice among [toddlers](#), [preschoolers](#) and [dieters](#), as well as being used by some pet owners as a treat for [pet birds](#).

Culinary herbs are also freeze-dried, although air-dried herbs are far more common and less expensive. Freeze dried tofu is a popular foodstuff in Japan ("[Koya-dofu](#)" or "shimi-dofu" in Japanese).

Technological industry

In [chemical synthesis](#), products are often freeze-dried to make them more stable, or easier to [dissolve](#) in [water](#) for subsequent use.

In bioseparations, freeze-drying can be used also as a late-stage purification procedure, because it can effectively remove solvents. Furthermore, it is capable of concentrating substances with low molecular weights that are too small to be removed by a [filtration](#) membrane.

Freeze-drying is a relatively expensive process. The equipment is about three times as expensive as the equipment used for other separation processes, and the high energy demands lead to high energy costs. Furthermore, freeze-drying

also has a long process time, because the addition of too much heat to the material can cause melting or structural deformations. Therefore, freeze-drying is often reserved for materials that are heat-sensitive, such as [proteins](#), [enzymes](#), [microorganisms](#), and [blood plasma](#). The low [operating temperature](#) of the process leads to minimal damage of these heat-sensitive products

Other uses[

Organizations such as the Document Conservation Laboratory at the United States National Archives and Records Administration (NARA) have done studies on freeze-drying as a recovery method of water-damaged books and documents. While recovery is possible, restoration quality depends on the material of the documents. If a document is made of a variety of materials, which have different absorption properties, expansion will occur at a non-uniform rate, which could lead to deformations. Water can also cause mold to grow or make inks bleed. In these cases, freeze-drying may not be an effective restoration method.

In [bacteriology](#) freeze-drying is used to conserve special [strains](#).

In high-altitude environments, the low temperatures and pressures can sometimes produce [natural mummies](#) by a process of freeze-drying.

Advanced [ceramics](#) processes sometimes use freeze-drying to create a formable powder from a sprayed [slurry](#) mist. Freeze-drying creates softer particles with a more homogeneous chemical composition than traditional hot [spray drying](#), but it is also more expensive.

Freeze drying is also used for floral preservation. Wedding [bouquet](#) preservation has become very popular with brides who want to preserve their wedding day flowers^[6]

A new form of burial which previously freeze-dries the body with [liquid nitrogen](#) has been developed by the Swedish company [Promessa Organic AB](#), which puts it forward as an environmentally friendly alternative to traditional casket and cremation burials.

Freeze-drying equipment[[edit](#)]



Unloading trays of freeze-dried material from a small cabinet-type freeze-dryer

There are essentially three categories of freeze-dryers: the manifold freeze-dryer, the rotary freeze-dryer and the tray style freeze-dryer. Two components are common to all types of freeze-dryers: a vacuum pump to reduce the ambient gas pressure in a vessel containing the substance to be dried and a condenser to remove the moisture by condensation on a surface cooled to -40 to -80 °C (-40 to -112 °F). The manifold, rotary and tray type freeze-dryers differ in the method by which the dried substance is interfaced with a condenser. In manifold freeze-dryers a short usually circular tube is used to connect multiple containers with the dried product to a condenser. The rotary and tray freeze-dryers have a single large reservoir for the dried substance.

Rotary freeze-dryers are usually used for drying pellets, cubes and other pourable substances. The rotary dryers have a cylindrical reservoir that is rotated during drying to achieve a more uniform drying throughout the substance. Tray style freeze-dryers usually have rectangular reservoir with shelves on which products, such as pharmaceutical solutions and [tissue extracts](#), can be placed in trays, vials and other containers.

Manifold freeze-dryers are usually used in a laboratory setting when drying liquid substances in small containers and when the product will be used in a short period of time. A manifold dryer will dry the product to less than 5% moisture content. Without heat, only primary drying (removal of the unbound water) can be achieved. A heater must be added for secondary drying, which will remove the bound water and will produce a lower moisture content.

Tray style freeze-dryers are typically larger than the manifold dryers and are more sophisticated. Tray style freeze-dryers are used to dry a variety of materials. A tray freeze-dryer is used to produce the driest product for long-term storage. A tray freeze-dryer allows the product to be frozen in place and performs both primary (unbound water removal) and secondary (bound water removal) freeze-drying, thus producing the driest possible end-product. Tray freeze-dryers

can dry products in bulk or in vials or other containers. When drying in vials, the freeze-dryer is supplied with a stoppering mechanism that allows a stopper to be pressed into place, sealing the vial before it is exposed to the atmosphere. This is used for long-term storage, such as vaccines.

Improved freeze drying techniques are being developed to extend the range of products that can be freeze dried, to improve the quality of the product, and to produce the product faster with less labor.



Product viewable single shelf freeze-dryer



Production freeze-drier



Development freeze-dryer

Scrubber systems are a diverse group of [air pollution](#) control devices that can be used to remove some [particulates](#) and/or gases from industrial exhaust streams. The first air scrubber was designed to remove carbon dioxide from the air of an early submarine, the [Uctineo I](#), a role which they continue to be used for to this day.^[1] Traditionally, the term "scrubber" has referred to pollution control devices

that use liquid to wash unwanted pollutants from a gas stream. Recently, the term is also used to describe systems that inject a dry [reagent](#) or [slurry](#) into a dirty exhaust stream to "wash out" [acid gases](#). Scrubbers are one of the primary devices that control gaseous emissions, especially acid gases. Scrubbers can also be used for heat recovery from hot gases by [flue-gas condensation](#).^[2]

There are several methods to remove toxic or corrosive compounds from exhaust gas and neutralize it.

[Combustion](#)[\[edit\]](#)

[Combustion](#) is sometimes the cause for harmful exhaust gas, but, in many cases, combustion may also be used for exhaust gas cleaning if the temperature is high enough and enough oxygen is available.^[3]

Wet scrubbing[\[edit\]](#)

The exhaust gases of combustion may contain substances considered harmful to the environment, and the scrubber may remove or neutralize those. A [wet scrubber](#) is used to clean [air](#), [fuel gas](#) or other [gases](#) of various [pollutants](#) and [dust](#) particles. Wet scrubbing works via the contact of target compounds or particulate matter with the scrubbing solution. Solutions may simply be [water](#) (for dust) or solutions of reagents that specifically target certain compounds.

Process exhaust gas can also contain water soluble toxic and/or corrosive gases like [hydrochloric acid](#) (HCl) or [ammonia](#) (NH₃). These can be removed very well by a wet scrubber.^[4]

Removal efficiency of pollutants is improved by increasing residence time in the scrubber or by the increase of surface area of the scrubber solution by the use of a [spray nozzle](#), [packed towers](#) or an [aspirator](#). [Wet scrubbers](#) may increase the proportion of water in the gas, resulting in a visible stack plume, if the gas is sent to a stack.

Dry scrubbing[\[edit\]](#)

A dry or semi-dry scrubbing system, unlike the [wet scrubber](#), does not saturate the flue gas stream that is being treated with moisture. In some cases no moisture is added, while in others only the amount of moisture that can be evaporated in the flue gas without condensing is added. Therefore, dry scrubbers generally do not have a stack steam plume or [wastewater](#) handling/disposal requirements. Dry scrubbing systems are used to remove [acid gases](#) (such as [SO₂](#) and [HCl](#)) primarily from [combustion](#) sources.

There are a number of dry type scrubbing system designs. However, all consist of two main sections or devices: a device to introduce the [acid gas sorbent](#) material into the gas stream and a particulate matter control device to remove reaction products, excess sorbent material as well as any particulate matter already in the [flue gas](#).

Dry scrubbing systems can be categorized as dry sorbent injectors (DSIs) or as [spray dryer absorbers \(SDAs\)](#). Spray dryer absorbers are also called semi-dry scrubbers or spray dryers.

Dry scrubbing systems are often used for the removal of odorous and corrosive gases from [wastewater treatment plant](#) operations. The medium used is typically an [activated alumina](#) compound impregnated with materials to handle specific gases such as [hydrogen sulfide](#). Media used can be mixed together to offer a wide range of removal for other odorous compounds such as [methyl mercaptans](#), [aldehydes](#), [volatile organic compounds](#), [dimethyl sulfide](#), and [dimethyl disulfide](#).

Dry sorbent injection involves the addition of an [alkaline](#) material (usually [hydrated lime](#) or [soda ash](#)) into the gas stream to react with the [acid gases](#). The sorbent can be injected directly into several different locations: the combustion process, the [flue gas](#) duct (ahead of the particulate control device), or an open reaction chamber (if one exists). The acid gases react with the alkaline [sorbents](#) to form solid [salts](#) which are removed in the particulate control device. These simple systems can achieve only limited acid gas (SO₂ and HCl) removal efficiencies. Higher collection efficiencies can be achieved by increasing the flue gas [humidity](#) (i.e., cooling using water spray). These devices have been used on [medical waste](#) incinerators and a few [municipal waste](#) combustors.

In **spray dryer absorbers**, the [flue gases](#) are introduced into an absorbing tower (dryer) where the gases are contacted with a finely atomized alkaline [slurry](#). Acid gases are absorbed by the slurry mixture and react to form solid [salts](#) which are removed by the particulate control device. The heat of the flue gas is used to evaporate all the water droplets, leaving a non-saturated flue gas to exit the [absorber](#) tower. Spray dryers are capable of achieving high (80+%) acid gas removal efficiencies. These devices have been used on industrial and utility [boilers](#) and [municipal waste incinerators](#).

Absorber

Many chemicals can be removed from exhaust gas also by using absorber material. The flue gas is passed through a cartridge which is filled with one or several absorber materials and has been adapted to the chemical properties of the components to be removed.^[5] This type of scrubber is sometimes also called dry scrubber. The absorber material has to be replaced after its surface is saturated.

Mercury removal

[Mercury](#) is a highly toxic element commonly found in [coal](#) and municipal waste. [Wet scrubbers](#) are only effective for removal of soluble mercury species, such as oxidized mercury, Hg^{2+} . Mercury vapor in its elemental form, Hg^0 , is insoluble in the scrubber slurry and not removed. Therefore, additional process of Hg^0 conversion is required to complete mercury capture. Usually addition of the halogens to the flue gas are used for this purpose. The type of coal burned as well as the presence of a [selective catalytic reduction](#) unit both affect the ratio of elemental to oxidized mercury in the flue gas and thus the degree to which the mercury is removed.

Wet scrubbers can be used for heat recovery from hot gases by [flue-gas condensation](#).^[2] In this mode, termed a condensing scrubber, water from the scrubber drain is circulated through a cooler to the nozzles at the top of the scrubber. The hot gas enters the scrubber at the bottom. If the gas temperature is above the water [dew point](#), it is initially cooled by [evaporation](#) of water drops. Further cooling cause [water vapors](#) to [condense](#), adding to the amount of circulating water.

The condensation of water release significant amounts of low temperature heat (more than 2 gigajoules (560 kWh) per ton of water), that can be recovered by the cooler for e.g. [district heating](#) purposes.

Excess condensed water must continuously be removed from the circulating water.

The gas leaves the scrubber at its [dew point](#), so even though significant amounts of water may have been removed from the cooled gas, it is likely to leave a visible stack plume of water vapor.

Scrubber waste products

One side effect of scrubbing is that the process only moves the unwanted substance from the exhaust gases into a liquid solution, solid paste or powder form. This must be disposed of safely, if it can not be reused.

For example, mercury removal results in a waste product that either needs further processing to extract the raw mercury, or must be buried in a special hazardous wastes [landfill](#) that prevents the mercury from seeping out into the environment.

As an example of reuse, limestone-based scrubbers in coal-fired [power plants](#) can produce a synthetic [gypsum](#) of sufficient quality that can be used to manufacture [drywall](#) and other industrial products.¹⁶¹

Bacteria spread

Poorly maintained scrubbers have the potential to spread disease-causing bacteria. The problem is a result of inadequate cleaning. For example, the cause of a 2005 outbreak of [Legionnaires' disease](#) in [Norway](#) was just a few infected scrubbers. The outbreak caused 10 deaths and more than 50 cases of infection.¹⁷