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Compressed Air: The Best Choice
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The Adsorption Dryer Process

The Process of Drying the Process of Drying Compressed Air

The drying of compressed air is a multi-step process. A compressor pressurizes ambient air containing moisture to an elevated pressure, and temperature. The air is then cooled below the elevated vapor pressure of the water and a large amount of condensation is produced. The drying process begins with a mechanical separator followed by a coalescing filter to remove the bulk lquid and water mist from the compressed air stream; then a regenerable adsorption unit to reduce the water vapor content to a very low level. A final filter removes the adsorbent fines entrained in the purified compressed air.

The adsorption system consists of the adsorbate, principally water vapor, a solid adsorbent, or desiccant for drying air, and the carrier gas, compressed air.

Adsorption System

Adsorption is a physical phenomenon. Gaseous molecules are attracted to solid surfaces by van der Waals forces, a collective term incorporating polar-polar attraction, ion-ion attraction, polar-ion attraction, London forces, gravitational attraction, and other intermolecular forces, some of which have not been defined. Some of these forces are effective even at significant ranges, 500 to 1000 angstroms. Because of these adhesive forces, gaseous molecules adsorb onto solid surfaces even at very low concentrations in a carrier gas.

The degree of attraction is dependent on the properties of the adsorbate and the adsorbent. Water vapor exhibits a high degree of attraction, or affinity, because its molecule has a permanent dipole moment. The two hydrogen atoms chemically bond to the oxygen atom of a water molecule are separated by an angle of about 104.5°, the asymmetry of which results in the dipole nature of water.

Adsorbents of practical importance have surfaces with high adsorption potentials and they are capable of being produced with very high internal surface areas. Activated alumina, molecular sieves and silica gels are the most common industrial adsorbents. Activated alumina, an amorphous transitional state aluminum oxide, has an internal surface area of 300 to 350 square meters per gram, and a pore volume of about 40%. Silica gel, produced from sodium silicate, is an amorphous silicon oxide with an internal surface area of approximately 600 square meters per gram, and a pore volume of about 40%. Molecular sieves are crystalline hydrous aluminosilicates with very large internal surface areas, 800 to 1000 square meters per gram, and an internal pore volume of 25% to 30%.

In the design of an adsorption system, the quantity of adsorbate must be determined and the adsorption capabilities of the adsorbent must be known.

Dalton's rule can be applied to determine the quantity of the adsorbate, or water vapor in an air drying system. At elevated pressure, especially at pressures above 300 psig, compressibility effects are significant and the quantity of water vapor present in a compressed air system is noticeably higher than predicted by the ideal gas laws.

The adsorbent properties are typically provided graphically, the most important being the isotherm, which defines the adsorption capacity as a function of either relative saturation, or relative humidity, or the partial pressure at constant temperature. The isotherm provides the adsorbent capacity for an adsorbate at a constant temperature. Capacities at other temperatures can be determined by application of the Polanyi equation, and for other adsorption systems, by the Polanyi-Dubinin method based on the adsorption potential of the adsorbent and the affinity coefficient of the adsorbate.

Other graphical representations of the adsorbent properties include the isosteres, constant capacity curves, and isobars or isopiestics, constant vapor pressure curves as a function of system temperature. The isosteres are particularly useful in determining the outlet dewpoint potential of an adsorption system. They indicate the dryer outlet vapor content as a function of the regeneration gas temperature and dewpoint, and the operating temperature of the adsorption system.

The operating temperature of an adsorption system is equal to the influent temperature plus the temperature elevation produced by adsorption. By Gibbs law, as water vapor passes from a gaseous state with three degrees of molecular freedom to an adsorbed state with two degrees of molecular freedom, energy must be released. This is termed the heat of adsorption and it elevates the temperature of both the adsorbent and the carrier gas. In compressed air systems, the temperature elevation is typically 10°F to 25°F. The temperature rise can be determined from an energy balance around the system.

Adsorbent Regeneration

The adsorber, or dryer, is typically manufactured as a two, or more, chamber process with interconnecting piping and valves to permit removal of the adsorbate from one chamber while the other is placed in service to purify the compressed air on a continuous basis.

The method of adsorbent bed regeneration is the distinguishing feature of the adsorption process.

An adsorbent bed can be regenerated by either elevating its temperature or by decreasing its pressure, and purging. Purging serves a dual function. It provides a means of conveying heat into the adsorbate contaminated region of the bed and it absorbs the contaminant vapor and conveys it out of the adsorbed chamber.

The preferred method of heat regeneration is by use of an external blower to provide a large flow of atmospheric air, passed through a heater to elevate its temperature, to the adsorbent bed. After the bed is heated and the adsorbate is released by thermal desorption, the adsorbent is cooled to prevent moisture and temperature spikes in the downstream piping during the chamber switch-over period. Without bed cooling, high dewpoints and elevated temperatures will be transmitted downstream for an extended period of time, often for 30 minutes or more.

Cooling can be accomplished by one of two methods. In the first method, a small quantity of purified air is diverted from the outlet of the on-stream adsorbent bed and is directed through the heated adsorbent bed until it is cooled to a low temperature. This is the simplest method, but some of the purified compressed air is consumed in the process. In the second method, a closed loop of atmospheric air is circulated through the heated adsorbent bed and a cooler is installed to remove the heat from the air. This method results in no consumption of compressed purified air, but it does involve a more sophisticated valve and piping arrangement.

The heatless dryer regenerates a contaminated adsorbent bed by the pressure swing method. The heat required to desorb the adsorbate is furnished from the outlet region of the adsorbent bed, which is used to store the heat of adsorption released during the on-stream drying phase of the operation. Purge air is used to convey the heat from the outlet end of the bed into the contaminated region, and then to convey the contaminant vapors out of the bed. The cycle time of the adsorbent beds used in a heatless dryer is relatively short, 2 to 5 minutes per bed, so that most of the heat released in the adsorption process will be retained for regeneration.

Optimization of Regeneration Method

The optimal regeneration method is dependent on the application and is determined by an analysis of the system service requirements and costs. The cost analysis includes consideration of the operating, maintenance and initial investment costs. In practice, heat regenerated blower types are most often chosen for larger, higher flow rate, systems where the higher initial capital investment is outweighed by much lower operating costs. Smaller systems most commonly are designed with the heatless technology to keep the capital investment low.

Regardless of which technology is used, load dependent cycling, instead of the standard fixed cycle, can optimize the operating cost. The purpose of the load dependent control is to adjust the adsorption cycle to the actual operating conditions. With this system, purge air can be saved because regeneration will only take place when the desiccant is saturated and not time controlled as in fixed cycles.

The pressure dewpoint at the dry air outlet is used as the criterion for the saturation level of the desiccant and determines the extension of the adsorption cycle. A dewpoint transmitter can be installed and connected to the controller of the dryer system for this purpose.

By using the load dependent control, a user can save up to 85% of purge air when the dryer is not used but stays online. In normal operation, savings of 20 to 30% of operating costs is realistic when using this control feature.