Adsorbents for Compressed Air Industry:
Saving Energy with Sorbead® Air

Compressed air is indispensable in many industrial applications, although it is one of the most expensive forms of energy. It is therefore particularly important to realize all possible saving potentials not only in the generation and compressed air network, but also in compressed air drying.

Heat-regenerating compressed air dryers are part of modern compressed air supply systems and are used when pressure dew points of about - 40 to - 75 °F are required. In the field of externally heated adsorption dryers there is a large variety of different systems on the market which offers customers substantial flexibility in terms of process flows, dewpoints and energy demand. Often, economic parameters and project-specific requirements ultimately define the individual customer-specific solution. Although there is an abundance of choice, especially in heat-regenerated adsorption dryers segment, customers' perception of the total costs associated with using the machine is often inconsistent and sometimes misleading.

The energy consumed by a compressed air system is often greatly underestimated. Electricity costs make up as much as 80 % of the overall costs for a compressed air plant and this is where the most meaningful costs saving opportunities are. While operational costs are strongly related to the type of the dryer used (i.e. heatless, heated blower purge, heated purgeless), there is a common misconception that adsorbent plays a minor role in the energy consumption optimization process.

This paper reviews the basic types of desiccants used in compressed air dryers and introduces **Sorbead® Air – premium adsorbent** for high energy efficiency air dehydration.

Activated Alumina

Activated alumina is one of the most popular and probably the most established adsorbent used in the compressed air industry. Produced by thermal decomposition and subsequent activation of aluminum trihydroxide (gibbsite) it offers high surface area and high porosity matrix with good affinity towards polar compounds, especially water.

The surface of alumina is composed of basic oxygen atoms, acidic low coordinated aluminum (Lewis acid sites) atoms, hydroxyls (dissociatively adsorbed water molecules) and physisorbed water molecules. Their relative concentrations depend essentially on synthesis conditions of alumina and its degree of hydration affected by the temperature and the water partial pressure. Highly hydrophilic nature of alumina surface makes it perfect choice for adsorbing polar molecules and especially water.

Dynamic capacity of activated alumina adsorbent might vary depending on the specific manufacturing process, degree of hydration (i.e. Loss on Ignition), impurities but generally lies around 12–14 wt % at 7 bar and 35 °C/ 95 °F saturated. Dew points down to - 51 °C/ - 60 °F are possible to achieve under certain conditions (i.e. regeneration with dry air, low inlet air temperature etc.). Activated Alumina usually requires regeneration temperatures of about 170 °C to 230 °C (340 °F to 450 °F).

Major advantages of activated alumina include fairly high robustness in a presence of liquid moisture and high stability towards alkaline components, for example, ammonia, amines or other high-basicity organics. Combined with wide availability and relatively low cost, this makes activated alumina a good conservative choice for heat-regenerated dryers.

However, there are also some drawbacks associated with activated alumina which include sensitivity towards long-chain, heavy hydrocarbons (i.e. compressor oil vapors) which tend to deposit on a surface and block

the pore system of alumina reducing its water adsorption properties. Another disadvantage frequently encountered when working with activated alumina is its degradation via rehydration. Rehydration is a process when a portion of aluminum oxide is converted to aluminum hydroxide (i.e. Boehmite) in a presence of moisture at elevated temperatures which are frequently referred to as steaming conditions. Unlike aluminum oxide, aluminum hydrates do not exhibit high surface area and porosity needed for efficient water sorption. Rehydration and contamination with heavy hydrocarbons are the primary mechanisms of alumina deactivation when in service in heated compressed air dryers.

Activated alumina adsorbents are most often offered as smooth spheres or in a granular shape. Spherical alumina has been a preferred solution for most of compressed air dryers manufacturing companies for over 40 years. Activated alumina has been established as conservative standard in compressed air industry, but not always the most optimal solution from efficiency standpoint.

Molecular Sieves

The commercial molecular sieves generally belong to the zeolite class of minerals, i.e., hydrated alkali metal or alkaline earth aluminosilicates. The crystals have a robust cubic structure, which does not collapse on heating, so that activation results in a geometric network of cavities connected by pores. The pores are of molecular dimensions and cause the sieving action of these materials. Molecular sieves are crystalline aluminosilicates with frameworks stabilized by monovalent or multivalent cations from the alkali or alkaline earth group, as well as water in its as-synthesized form. This crystal water can be removed by thermal treatment without damaging the crystalline structure to create the conditions for a reversible process such as water adsorption/desorption.

About 150 different zeolite structures have been discovered, however, only Zeolite A and Faujasite (X and Y) are widely used in commercial applications related to dehydration of gases and liquids. The pores of Zeolite A are restricted by 8-membered oxygen rings. The free aperture for this structure (i.e. measured pore size) is about 3.3 Å for the K^+ form (3A), 3.9 Å for the Na^+ form (4A), and 4.3 Å ~ for the Ca^{++} form (5A). Faujasite is represented by two forms – X and Y-with pores restricted by 12-membered oxygen rings. The pores of these materials are relatively large with a free aperture of about 7.4–12.5 Å. The X and Y zeolites differ from each other only with regard to the Si/Al ratio which controls cation density, and therefore, affects adsorptive properties.

The two most common types used in commercial dehydration applications are zeolite A and zeolite X. Zeolite A has a relatively simple cube-like structure composed of four truncated octahedrons. In zeolite X, the truncated octahedrons are interconnected in a way which results in a different spatial structure. The pores lead to a cavity with an adsorption surface. The pore diameter is defined precisely by the synthesis of the zeolite. A change of the pore opening diameter is achieved by replacing some of the sodium ions of the zeolite A by other monovalent and multivalent alkali or alkaline earth ions.

The microporous and highly ordered structure of molecular sieves ensures very high surface areas in such materials, often in a 700–900 m^2/g range.

Although molecular sieves are not the standard desiccant solution in compressed air drying, they are used for applications where very low dew points – down to - 100 °C/ - 150 °F are required. Molecular sieves are extremely efficient as desiccants. While static water uptake is normally about 21 wt % for most commonly used 4A type (equilibrium capacity at 25 °C/ 77 °F and relative humidity 80 %), the shape of the isotherm allows to reach very low dewpoints. Another important difference between molecular sieves and activated alumina/silica gels is their ability to maintain water uptake at elevated temperatures and low water partial pressures. For example, water uptakes of ~ 12–14 wt % are feasible over 4A at 93 °C/ 200 °F while activated alumina retains only residual water loading at this temperature. The downside of such high affinity to moisture is the need to heat up molecular sieve beds to high temperatures to drive the water off. Regeneration temperatures in 230–290 °C (450–550 °F) region are often used for efficient reactivation.

A major disadvantage of molecular sieves for gas dehydration is relatively high sensitivity towards impurities in the gas such as heavy hydrocarbons, highly acidic (traces of acids, SO_x, NO_x et) or highly basic components (i.e. amines, NaOH et.). Structural disintegration of molecular sieves under impact of aggressive and reactive contaminates results in dust formation and pressure drop increase across the adsorbent layer. Although fouling problems could frequently be minimized by installation of a buffer layer, gas composition needs to be carefully monitored. Molecular sieves do not tolerate liquid water, breaking when exposed, so beds must be protected against carryover of free water into the bed.

Silica Gels

Silica gel is an amorphous and highly porous form of silicon dioxide (SiO_2) exhibiting high surface areas and favorable water adsorption properties. The most common production method involves precipitation of Si-precursor under optimized and well-controlled conditions. In this process $Si(OH)_4$ molecules condense to form a siloxane matrix. Hydrolysis and condensation occur simultaneously resulting in a three-dimensional siloxane network. The formed hydrogel is subject to aging and drying to remove bound water yielding high pore volume high surface Si-O-Si-OH matrix. Silica gel is commercially available as granular and spherical bead material of various size-ranges and have been widely used in compressed air industry for more than 60 years.

Sorbead® Air

The perception of adsorbent being of marginal importance is frequently seen among users of heatless but also of heat regenerating compressed air dryers. While most attention in terms of cost optimization is normally focused on a compressor, which is a major cost driver in a compressed air system, compressed air users neglect to recognize the role and function of adsorbent and its energy-saving potential. Often, the adsorbent is viewed as a pure "commodity" and a cost-adding factor as users are looking for cheaper, standardized adsorbent to refill the dryer and optimize operational costs. This assessment is reinforced as often users do not have detailed information on hand about the exact type and properties of the desiccant loaded in a dryer.

BASF challenged this vision and has introduced **Sorbead® Air**.

Sorbead® Air is the most economical and efficient adsorbent for compressed air drying available on the market, specifically designed for heat regenerating adsorption dryers. Due to its high dynamic capacity and lower desorption temperatures, the product enables significant cost and energy savings over the entire operating lifetime of a dryer.

Unlike standard market silica gels, Sorbead® Air from BASF is an alumino-silicate gel produced using a unique manufacturing process. The patented BASF Sorbead® Air is a line of highly efficient adsorbents in the form of hard, spherical beads with high resistance to crushing and a low attrition rate.

Characterized by exceptionally high pore surfaces (up to 850 m^2/g) and large pore volume, Sorbead® Air allows for exceptional dynamic adsorption capacities, often up to 20 wt % (at 7 bar, 35 °C/ 95 °F saturated). This implies that 1 kg Sorbead® Air adsorbs up to 200 grams of moisture. The associated enormous moisture uptake allows one to operate a dryer on a longer cycle time which in practice implies less frequent regeneration and thus lower average electrical power consumption.

Another important advantage of Sorbead® Air is substantially lower regeneration temperature required to desorb water as compared to activated alumina and molecular sieves. Temperatures of 120–140 °C (~ 250–280 °F) are sufficient for reactivation to reach - 40 °F dewpoint, making these products the least energy-demanding in industry. While Sorbead® Air is used routinely to achieve - 40 °C/ - 40 °F pressure dew points, under optimum operating conditions dew points down to - 60 °C/ - 75 °F are feasible.

High dynamic capacity and low regeneration temperature combined with optimized cycles allow users to **save up to 1.8 kWh per 1,000 m^3** of compressed air (36,000 ft^3 compressed air).

To put it in perspective, for a standard heat-regenerative blower-purge dryer rated for 1,250 scfm (2,125 Nm^3/h) and a working time at 8,760 hours per year **savings of 33,500 kwh per year** and **emissions reduction of 16.12 ton CO_2** are achievable. Depending on electricity cost, this equates to approximately USD 20,000 in savings realized over five years, a standard adsorbent service cycle.

Sorbead® Air adsorbents are offered in two types: the regular Sorbead® Air R and liquid water stable Sorbead® Air WS. While both types are fully moisture resistant under normal operating conditions of the dryer, Sorbead® Air WS is often used as a protection layer at the moist air inlet for protection against liquid water on top of Sorbead® Air R. The split ratios of 1:6 or 1:5 (volume ratio) is normally used.

The common misconception frequently seen in the compressed air industry associated with the use of silica gel-type adsorbents is their very low stability and tendency to partially disintegrate in a presence of high moisture levels or liquid water. This concept is a bit misleading and some clarifications are needed. While exposure of liquid water on freshly regenerated (i.e. dry) silica gel bead is likely to enforce a stress, which could lead to sphere disruption, such conditions are rarely seen in commercial dryers while those are in a regular service. In a standard dehydration process moisture is transferred from gas phase to a solid and accumulated in a well-developed pore system via adsorption. Such “wetted” silica gels are stable and normally resistant even to liquid water. It is the stability in a dry state (i.e. regenerated) towards liquid water which is addressed with a liquid water-resistant type.

It is also important to highlight the major advantages of Sorbead® Air as compared to standard mid and low grade silica gels available on the market. Regular silica gels are highly inferior to Sorbead® Air due to much lower mechanical strength and lower robustness. Those materials tend to generate dust while in a dryer and are also subject to pronounced hydrothermal aging which is seen in declining water uptakes (i.e. surface area, pore volume) making it difficult to reach the required air dew point.

Any Questions?
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