MAKING THE RIGHT CHOICE

Artem Vityuk, BASF Corp., USA, and Arno Goertz, Air Consulting, Germany, explain the process behind selecting adsorbents for heat-regenerated compressed air dryers.

Compressed air is an important utility in the refining and chemical industries, widely used to drive pneumatic equipment and machinery. Air is also utilised as an oxygen/nitrogen source in manufacturing processes.

Drying of compressed air upstream of process equipment is crucial to avoid moisture condensation in downstream piping and to satisfy moisture specifications if air is used as the process gas. Among the available technologies, desiccant drying has been recognised as one of the most cost-efficient and versatile options, permitting water dew points of as low as -70°C.

The desiccants that are conventionally offered into this service include activated alumina, molecular sieves, and silica gels. Although these materials have been well established in industry over the years, there are often misconceptions about some of the benefits that they offer in compressed air plants. This is especially pronounced for silica gels, as there are a variety of grades offered in a market, with substantial variability in properties and performance characteristics in compressed air applications. This article will briefly review the relevant benefits and challenges associated with using the most common desiccants, and discuss the use of Sorbead® Air – an adsorbent for high energy efficiency air dehydration.

Adsorbents

Activated alumina is one of the most established adsorbents used in the compressed air industry. It offers high surface area and a high porosity matrix with good affinity towards polar compounds – especially water. The highly hydrophilic nature of the alumina surface makes it a sound choice for adsorbing moisture. Dew points of down to -50°C are achievable with activated alumina, and regeneration temperatures are normally within the 200 – 250°C range. Advantages of activated alumina include fairly high 'in service' robustness and high stability towards alkaline components, such as ammonia, amines or alkali hydroxides. Combined with wide availability and comparably low cost, this makes activated alumina a suitable adsorbent for heatless dryers, and a good conventional choice for heat-regenerated dryers.

Molecular sieves are crystalline aluminosilicates with frameworks stabilised by monovalent or multivalent cations from the alkali or alkaline earth group, as well as water in its as-synthesised form. This crystal water is removed by thermal treatment without damaging the crystalline structure to create the conditions for a reversible water adsorption/desorption. 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. Molecular sieves are normally used for applications where very low dew points down to -100°C are required, or the compressed air needs to be dried at higher temperatures. The steep shape of the isotherm allows for low moisture content in the product gas to be reached. However, 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 the 240 – 290°C range are often used for efficient reactivation.

Silica gel is an amorphous and highly porous form of silicon dioxide (SiO_2), exhibiting high surface areas and favourable water adsorption properties. Silica gel is commercially available as a granular and spherical bead material of various size ranges, and has been widely used in the compressed air industry for more than 50 years. Despite its long commercial history, users are often challenged when selecting the proper silica gel desiccant for the dehydration of compressed air. This is mostly due to the abundance of various silica gel grades and types on the market, as well as poor understanding of the difference in properties and performance between these materials. These factors often result in the unfavourable decision being made towards a lower cost but less efficient product.

Highly efficient adsorbents

Unlike standard market silica gels, Sorbead Air is an alumino-silicate gel produced using a unique proprietary manufacturing process. The patented technology is a line of highly efficient adsorbents optimised for energy efficient drying.

Some of the key factors that are normally considered when selecting the adsorbent include equilibrium and dynamic water capacities, regeneration temperature related to heat of moisture adsorption on the desiccant, and durability and hydrothermal stability of the adsorbent in service. Benefits of the technology include high dynamic water uptake combined with comparatively low moisture desorption temperatures as well as hydrothermal resistance.

Desiccant selection for a compressed air plant is of crucial importance. The proper adsorbent not only warrants steady and reliable operation of the dryer, but it also saves costs for the user. As adsorbent replacement terms are often advised by the dryer manufacturer, the changeouts are conducted in accordance with these guidelines. The desiccant selection and service periods are normally not challenged by users, and the associated costs are taken as granted. Part of this is due to the

Table 1. Comparison of properties of Sorbead Air R product vs competitive regular grade silica gel products. Activated alumina properties are provided for reference only

		Sorbead Air R	Product A	Product B	Activated alumina
	Type	Alumino-silicate-gel Moisture resistant	Silica gel	Silica alumina gel	Activated alumina
Performance data	Form	Sphere	Sphere	Sphere	Sphere
	Dynamical capacity for water vapour	up to 20 % ++++	++	++	12 – 14
	Moisture (g/kg desiccant)	up to 200			
	Desorption temperature (°C)	120 – 140 ++++	150 – 160	160	170 – 200
	Lowest obtainable dew point (°C)	-60 (-70) 4 ++++	+++	++	-40
	Pressure drop adsorber per meter bed (mbar)	38 ++++	+++	+++	
	Attrition rate (%)	0.05 ++++	++	++	0.1
	Ageing rate (%)	8 – 12 ++++	++	++	
	Life span (years)	5 – 10 ++++	++	++	3 – 4
Specific data	Composition	SiO_2 97%, Al_2O_3 3%	SiO_2 99.8%	SiO_2 80%, Al_2O_3 20%	Al_2O_3
	Surface area (m^2/g)	700 – 750	740	600	340
	Total pore volume (cc/g)	0.41 – 0.43	0.4	0.35 – 0.45	0.5
	Equilibrium capacity for water vapour (wt%)	40	38	35	30
	Bulk density (kg/m^3)	800	N/A	720	770
	Crush strength (N/bead)	180 – 200	N/A	200	
	Liquid water resistant	No	No	No	Yes

adsorbent being viewed as a commodity, and the poor differentiation between products offered on the market. It is especially relevant to silica gels, which are available in various grades, shapes, compositions and colours. The fundamental misconception is equating Sorbead Air adsorbents to conventional silica gels or alumina promoted silica gels.

The data provided in Table 1 compares the properties and performance of Sorbead Air against some of the most common silica gels offered on the market, and underlines the importance and necessity of comparing adsorbents in order to select the proper product. Performance is compared with conventional and alumina promoted silica gels that are widely offered. To make this comparison meaningful, the desiccants were divided into two types – regular grade, which is compared with Sorbead Air R in Table 1, and water stable grades, which are compared with Sorbead Air WS in Table 2.

Regular grade silica gels are normally characterised by high surface area and pore volume. The products A and B in Table 1 exhibit high surface area pore volumes, which point to similarities with Sorbead Air at first glance. However, closer inspection shows that high values of these commonly-recognised parameters are not sufficient to derive performance features. Product A is a conventional, pure SiO_2-based adsorbent, and was shown to exhibit inferior mechanical properties: on average, a higher attrition rate and more pronounced ageing under thermal swing cycling. It is important to highlight that lower mechanical strength and enhanced fines generation are among the common features exhibited by pure silica gel desiccants.

Another meaningful disadvantage of SiO_2 adsorbents is comparatively low hydrothermal stability. As desiccant is subject to multiple thermal regeneration cycles in commercial service, hydrothermal ageing plays a role. While equilibrium moisture uptake on 'fresh' Product A was measured as reasonably high, there was a pronounced decline in moisture pick-up when the sample was exposed to prolonged thermal regeneration cycles. The precise effect is highly dependent on the specific operating conditions of the machine.

Alumina is often added to the formulation to enhance the hydrothermal stability of silica gel adsorbents and modify some of the adsorbent properties. Product B contains approximately 20 wt% aluminium oxide (Al_2O_3). While silica gel desiccants promoted with a certain amount of alumina could feature enhanced stability towards liquid water, the exact response is highly dependent on manufacturing process and the amount of alumina added in a composition. An important aspect to consider when selecting SiO_2-Al_2O_3 desiccants with high Al_2O_3 content is the altered shape of the water adsorption isotherm as compared to pure silica gels. As alumina content increases, water adsorption isotherm deviates from the isotherm typically observed for pure SiO_2, and shows features more typical for alumina. Without elaborating on the fundamental scientific nature of this phenomena, the direct consequence of this – relevant to operations of industrial dryer – is reduced water dynamic capacity of the desiccant at humidities and pressures normally used for commercial compressed air dryers. While heat of adsorption and moisture uptake properties are normally not substantially affected at alumina levels of 1 – 5 wt%, higher content often results in lower moisture pick-up as compared to pure SiO_2 adsorbents.

Product B with Al_2O_3 content of 20 wt% reports equilibrium uptake much lower than normally observed for Sorbead Air products. As a result, more adsorbent would be required, and therefore a larger vessel size, to achieve similar

Table 2. Comparison of properties of Sorbead Air WS product vs water stable grade silica gel products. Activated alumina properties are provided for reference only

		Sorbead Air WS	Product D	Product E	Activated alumina
	Type	Alumino-silicate-gel Liquid water resistant	Alumina silica gel	Silica alumina gel	Activated alumina
Performance data	Form	Sphere	Sphere	Sphere	Sphere
	Dynamical capacity for water vapour	up to 18% ++++	+	++	12 – 14
	Moisture (g/kg desiccant)	up to 180			
	Desorption temperature (°C)	120 – 140 ++++	160	160	170 – 200
	Lowest obtainable dew point (°C)	-60 ++++	+	++	-40
	Pressure drop adsorber bed (mbar)	38 ++++	+++	+++	
	Attrition rate (%)	0.05 ++++	++	++	0.1
	Ageing rate (%)	8 – 12 ++++	+++	+++	
	Life span (years)	5 – 10 ++++	++	++	3 – 4
Specific data	Composition	SiO_2 97%, Al_2O_3 3%	SiO_2 99.8%	SiO_2 84%, Al_2O_3 16%	Al_2O_3
	Surface area (m^2/g)	630 – 650	240	450	340
	Total pore volume (cc/g)	0.43 – 0.45	0.5	0.35 – 0.50	0.5
	Equilibrium capacity for water vapour (wt%)	36	21	30	30
	Bulk density (kg/m^3)	700	N/A	670	770
	Crush strength (N/bead)	120 – 140	N/A	80	
	Liquid water resistant (%)	100	100	N/A	Yes

performance. Another consideration not to be neglected when comparing SiO_2 adsorbents promoted with alumina is water desorption temperature. Desiccants promoted with high amounts of alumina often exhibit higher heat of moisture adsorption and require somewhat higher regeneration temperatures. Since an increase in moisture heat of adsorption is almost directly proportional to alumina content, higher alumina content in silica gels often translates into an increase in nominal regeneration temperature. A temperature of approximately 140°C is sufficient for regenerating Sorbead Air R, and Product B needs approximately 160°C for reactivation, on average. Although some manufacturers do claim regeneration temperatures of as low as 160°C for high-alumina-containing SiO_2-based desiccants, users and dryer OEMs always need to execute caution when using or designing dryers with these adsorbents.

Properties of some of the market-available water stable desiccants are shown in Table 2, compared against Sorbead Air WS. This type of adsorbent is resistant to liquid water and often used as protective layers on top of regular grade desiccants. Product D is 99.8 wt% SiO_2 pure silica gel with a surface area of 240 m^2/g. Comparably low surface area is in agreement with reduced equilibrium moisture uptake, which is almost 30% lower than what Sorbead Air WS offers. As a result, Product D would have limited contribution to the overall desiccant bed moisture removal performance, so a larger vessel size would be needed for newly designed dryers which use this adsorbent. Another related disadvantage is lower achievable dew point temperatures for a fixed volume of adsorbent, even for configurations where water stable grade is used as the layer protecting regular grade adsorbent.

Product E is alumina promoted silica gel with reported 16 wt% Al_2O_3 content with a surface area of approximately 450 m^2/g. It features somewhat higher equilibrium moisture uptake as compared to Product D, but still less than Sorbead Air WS, which offers approximately 20% higher loading. An important aspect to consider when selecting a high alumina promoted silica gel based desiccant as a protective layer is long-term hydrothermal stability. Activated alumina is known to undergo partial rehydration in the presence of liquid moisture at elevated temperatures upon extensive thermal swing cycling – conditions typical for the front section of the adsorbent in heat-reactivated dryers. Sorbead Air WS is designed to deliver excellent performance under severe hydrothermal conditions due to its proprietary manufacturing process, with compositional alumina of about 3 wt%.

Conclusion

Selecting an adsorbent for a compressed air dryer is important, and could be very challenging if a user or OEM is not well educated on the properties of common desiccant grades offered on the market. This is especially pronounced for silica gels, with abundant product selection across applications in dryer plants. Sorbead Air adsorbents from BASF are high-performance desiccants optimised for air drying, with a very clear value proposition.