PURIFICATION SOLUTIONS

MARCH 2013

ADVANCED Energy Saving Pressure Swing Nitrogen Generators

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Introduction

Nitrogen is primarily used as a clean, dry inert gas where the reduction of Oxygen is required for certain products and processes. It is widely used in the food and beverage, electronics, laser cutting, chemical and oil & gas industries. The cost of producing Nitrogen by separating compressed air using Pressure Swing Adsorption (PSA) is significantly impacted by the treatment of the compressed air supply. The introduction of Adsorbent Media Tube (AMT) technology in order to dry the compressed air prior to separation offers the potential to reduce compressed air energy costs up to 25%.

Background

The production of Nitrogen gas from a compressed air source is well known. Employing selected Carbon Molecular Sieve (CMS) and utilizing Pressure Swing Adsorption (PSA) technology enables the supply of various purities of Nitrogen to be produced by the user on site. The purity of the compressed air supply is however an important consideration since it is unsuitable for use without some form of treatment to improve its purity.

Compressed air contains contaminants such as water, oil and particulate which must be removed before use. Treating compressed air has generally involved filtering (to remove oil/water aerosols and dirt) and drying (to remove water vapour). The cleanliness of the compressed air has a direct effect on the operation of PSA Nitrogen generators.

Pressure Swing Adsorption Process - Simplified

A twin tower dryer PSA Nitrogen generator (Figure 1) operates by removing Oxygen through molecular adsorption onto a bed of granular CMS from the feed air (typically at 100 to 150 psi) as it flows up through a packed bed of CMS (Column A). Column B (having been previously used) is depressurised and Oxygen is released from the CMS due to the expansion of the clean, dry Nitrogen gas within the bed. Dry purge gas from the outlet of Column A is fed through a control orifice, expanded to near atmospheric pressure and flowed in counter-current flow down through column B to sweep the bed of concentrated Oxygen. The cycle of operation is set to achieve the desired output purity of the Nitrogen outlet stream. When the CMS in column A becomes saturated with Oxygen (usually determined by a simple timer controller) the feed air is switched back to Column B after it has been pressurized and the cycle continues.

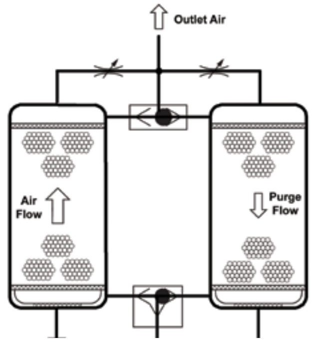

Figure 1 - PSA Process (Simplified)

Effects of Water Vapour on the Generation Process

Fast gases such as water vapour and CO_2 along with Oxygen are adsorbed by the CMS. Water vapour content is significant and its presence will affect the efficiency of the Nitrogen generation process (US 4,439,213). It has been recognized that the treatment of the inlet compressed air is therefore an important consideration. Suppliers of PSA Nitrogen generators recommend various levels of dryness. Generally, the drier the compressed air, the better.

Compressed air at 95°F (35°C) and 100 psig (7 barg) has a water vapour content of 4,950 mg/m3.

There are 2 main options to reduce the water loading:

- Refrigerated dryers typically provide a 38°F to 50°F (3°C to 10°C) pressure dew point. At 100 psig (7 barg) the water vapour content in compressed air is up to 1,170 mg/m3, a 76% reduction.
- Desiccant dryers typically provide a -40°F (-40°C) pressure dew point. At 100 psig (7 barg) the water vapour content in compressed air is 15 mg/m3, a 99.5% reduction.

Desiccant dryers may be preferred due to the low residual water vapour; however, the requirement for regeneration air, at typically 20% of the inlet air, results in a need for a larger compressor which increases capital investment, lengthens the ROI period and increases the per cubic foot Nitrogen production costs. The use of a refrigerated dryer eliminates the requirement for purge air and reduces the capital cost but introduces up to 78 times the water vapour onto the CMS bed. Generally, it is assumed that for high Nitrogen purities, higher quality inlet air is most important. The dryness of the delivered Nitrogen is generally expected to be very dry so, the use of the CMS column to carry out drying, for which it is not best suited, is best avoided.

The selection of the dryer type is therefore often a compromise between the dryness of the air produced and the impact on the cost of Nitrogen produced.

Granular Adsorbent Limitations

Granular desiccant adsorbents are widely used to remove contaminants such as water vapour from gases including air (see Figure 2). The properties of such technologies are well defined but their use is limited in certain applications. These limitations include orientation, vibration, high pressure loss, attrition, channelling, by-pass and high regeneration energy (purge).

Figure 2 - Granular Desiccant

The irregular size and shape of the beads can lead to attrition and channelling due to poor packing of the bed.

The powdery appearance of the adsorbent beads indicates that dust is readily shed in use, contaminating the outlet air stream. Typical life expectancy is 24,000 hours or less .

Exposure to Bulk Water

Typically desiccant material has to be changed every 36 months due to the limitations described above. Exposure to bulk water is common when water in liquid and aerosol phase is not adequately removed prior to the dryer resulting in the breakdown of desiccant beads. Desiccant breakdown is not reversible since, once exposure to liquid water occurs, the entire adsorption bed will require replacement. This is costly and disruptive to operators and is not a practical proposition to integrate into large systems.

In small systems (such as a 0.2 cfm module used for beverage dispense), a beaded desiccant dryer may be integrated. However, the life of the relatively small quantity of desiccant is aligned to that of the compressor which typically has a life of up to 10,000 hours where duty is not continuous.

Larger Industrial Systems

For larger systems requiring continuous duty, this scenario is not practical. CMS is not normally considered to be subject to regular servicing (replacement) since it has an expected life of 10 years assuming a high standard of inlet air purity. In this case, the service life of desiccant beaded material is not aligned with the life of the CMS. Should the air treatment system malfunction and bulk water come into contact with the desiccant material, the CMS would be damaged and require replacement, an unacceptable and costly scenario to users.

Innovative Technology

A novel approach is now available whereby the benefits of an integrated drying stage can be realized.

Adsorbent Media Tube (AMT®) tube technology is manufactured from multi-layer materials which incorporate application specific adsorbents in their structure. They are best described as adsorbent tubes (typically 2 mm in diameter and 0.7 mm bore) consisting of a high level of adsorbent (≥ 80%) and a non-adsorbing durable polymeric binder called Polyether Sulphone. AMT is extruded into a water bath where a phase inversion takes place and its structure is formed. AMT is therefore totally resistant to bulk water. The open structure of the AMT provides for low mass transfer resistance enabling the flow of air or gas to permeate easily into the structure while offering very low pressure losses.

AMT technology leverages the proven adsorption capabilities of Zeolite Molecular Sieve powder but packages this powder in a proprietary way to allow faster and easier adsorption and regeneration.

Rather than using a clay binder necessary to form the adsorbent crystals into beads, AMT uses a durable polymer. The polymer has microscopic voids formed during the manufacturing process which allows easier access for the contaminant into the active pores in the sieve.

SEM image of the macro-porous polymer binder used in the adsorbent media tubes and 1 - 2 µm Zeolite crystals.

SEM image of the cross section of an adsorbent media tube. Typical dimension are: 2 mm outside diameter and 1 mm bore. Air flows through the bore of the AMT where adsorption/desorption takes place.

The open structure and clear adsorption sites allow contaminants to move in to and out of the structure very rapidly, making the adsorbent tubes extremely efficient adsorption devices. With the fast kinetics, it can be regenerated quickly and efficiently.

Dust

AMT does not shed dust due to the use of the polymeric binder.

Failure Mode

If the adsorbent tubes are overloaded with water there is no physical damage. Outlet dew point will be affected but will recover after normal operation is resumed.

Figure 3 below shows the release of powder from adsorbent beads in water. The crush strength of the beads is reduced significantly. Under pressurized conditions experienced in pressure swing adsorption dryers, the beads will break down in the presence of bulk water (Figure 3 - left).

The Adsorbent Media Tubes (Figure 3 - right) do not release any powder since the binder is a durable polymer which is not soluble in water.

The polymeric binder in the adsorbent tube has good temperature and chemical stability. Extended heat trials at elevated temperature with humid air confirm the durability of the adsorbent tubes.

Applying AMT to PSA Nitrogen Generators

AMT has a long life aligned with that of the CMS. It therefore can be integrated into the CMS column and use the purge air used by the Nitrogen generation process for regeneration. This offers the advantage of achieving very dry air at the entry to the CMS adsorption bed but without the requirement for any additional purge air. Additionally the pressure loss across the AMT drying stage is very low. With the elimination of the separate dryer, associated pipe work and filters, a pressure saving in the order of 10 psig (0.7 bar) is achieved. The improved design saves energy and increases the outlet pressure accordingly.

An example of the invention is shown below in Figure 4 The Nitrogen generator design is of modular construction and scalable. Instead of using welded tanks, sets of extruded twin columns are used. Each pair of columns is equivalent to those shown in Figure 1.

Column A and column B are identical. Each has a charge of CMS. Each has an AMT drying module located in the bottom of the column pair. As filtered compressed air enters the bottom of the column it passes through the AMT dryer cartridge and is

Figure 3 - Granular Desiccant vs. AMT in water

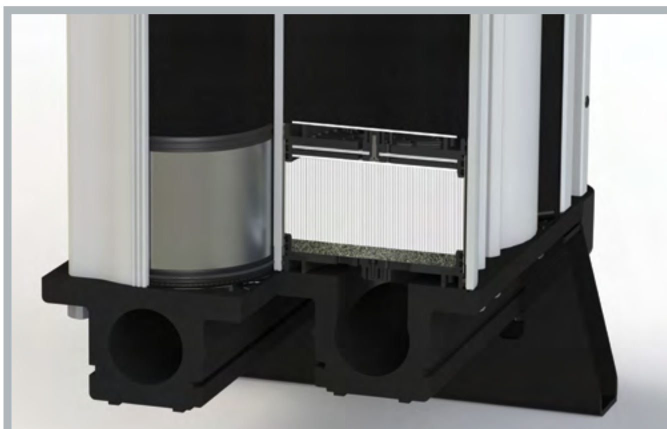

Figure 4 - Nitrogen Generator with Integrated AMT Dryer

dried to -40°F (-40°C) PDP which affords a high level of protection from water vapour to the CMS. When the columns are switched over, the columns are vented to atmosphere with all of the exhaust gas passing in a counter-current flow direction followed by a small amount of purge gas which regenerates the AMT dryer preparing the column for re-use. This eliminates the need for an upstream external dryer and its purge losses. Pressure losses across the external dryer are also eliminated which means a higher inlet pressure is possible which enables increased outlet flow to be achieved.

Due to the nature of the AMT material, its service life is in line with the CMS and does not require routine maintenance. Hence the AMT invention provides for a high level of purity of the incoming air which ensures the CMS operates at maximum efficiency since it is not unnecessarily subjected to heavy loads of water vapour.

Modular Nitrogen Generator with Integrated AMT Dryer

This revolutionary design (Figure 5) utilizes high tensile aluminium extrusions which enable light and compact products using common parts to be produced in a production process which provides consistency of design and short production times. Capacity can be readily increased to meet future demand. The common manifolds (top and bottom) provide for the compressed air to be fed into the lower manifold and Nitrogen gas to be delivered from the top manifold. Twin columns containing the AMT integral dryer, the CMS and integrated dust filter are arranged between the manifolds. The number of columns and banks determine the overall capacity. All components are common to each size apart from the manifolds; however, the unique manifold design (patents pending) allows the manifolds to be extended and additional columns added when capacity needs to be increased.

The example shown produces 1589 scfh (45 m3/hour) at 100 psig (7 bar) of Nitrogen, with a purity of 0.5% O_2 content.

Energy Savings

- Elimination of purge air from an external desiccant dryer saves about 20% of the compressor power.
- Simplification by the removal of any type of external dryer will typically save 10 psi (0.7 bar) or about 5% of compressor power.
- Maintenance costs are reduced due to the simplified system and commonality of components.
- Installation costs are reduced due to less equipment, less labour and reduced transit of product to site.
- Up to 25% energy savings are therefore possible with the use of the integrated AMT dryer technology.
- The compressor size is also reduced by up to 25%.

Figure 5 - Modular Nitrogen Generator

Conclusions

The opportunity to integrate the drying stage into the CMS column using AMT technology has produced improvements over the prior methodology such that significant operational and economic advantages are achieved. An AMT dryer module was developed to overcome the problems described and enable reliable operation over extended periods to provide the user with a lower through life cost while maintaining a high level of performance. Purge air (typically ~20%) required by external desiccant dryers is eliminated. The integration of AMT technology eliminates pressure losses of an external dryer, typically 10 psi (0.7 bar), resulting in higher inlet pressure to the generator improving Nitrogen yield. AMT has a life expectancy aligned to the CMS and does not require routine maintenance. AMT fully recovers from excessive use, even if flooded with bulk water. The total system is greatly simplified with lower initial and on-going running costs.

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Publication ref. n-psi-N1TP-01-US