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Hybrid Refrigerated/Desiccant Compressed Air Dryers

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Abstract

For those relatively few, but general large compressed air applications that need extremely dry air (down to -40°F), there are several types of desiccant dryers to do the job. In many cases, the most effective and least costly to operate will be a hybrid dryer system. The hybrid solution includes both refrigerated and desiccant systems in series. Refrigeration will typically remove 85% to 88% of the total amount of water, and the desiccant dryer is challenged with only the remaining 12% to 15% of the total water removal. As refrigeration is comparatively a very inexpensive method for dehydrating compressed air, the energy to produce a dew point of -40°F in a compressed air stream is significantly reduced when the air is first routed through a refrigeration system before being treated by a desiccant dryer.

Whether the extra low dew points are needed year round or only seasonally, this combination achieves better dew point stability and significantly reduces both operating and maintenance costs compared to other dryer types equally capable of producing dew points as low as -40°F.

The combination system permits the refrigerated dryer to be operated independently. This is advantageous because many systems with desiccant dryers only need them during cooler months. The majority of compressed air applications simply require the water vapor remaining in the air after treatment to remain in the vapor state, and a refrigerated dryer provides adequate drying during warm weather periods. If the desiccant dryer is only needed during cooler months, additional operating and maintenance cost savings are realized.

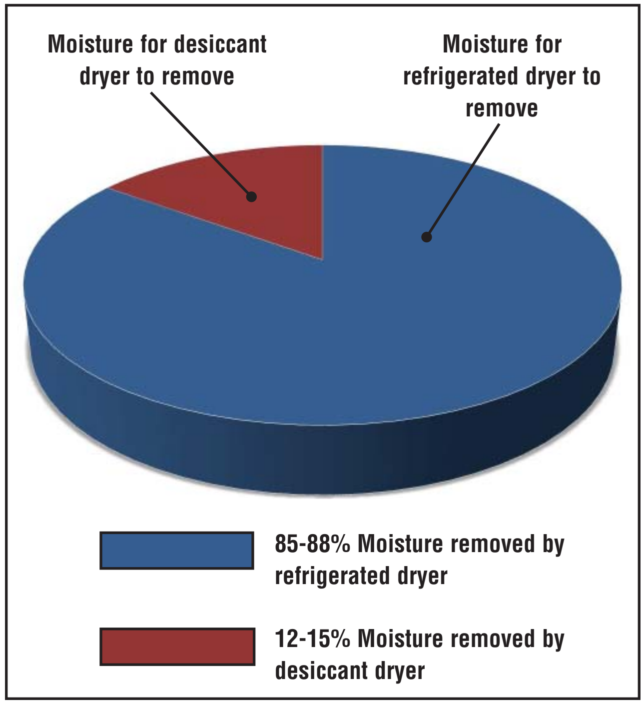

FIGURE 1: Percentage of moisture removed by the refrigerated and desiccant dryer

How a Hybrid Drying System Operates

As shown in Figure 2 on the following page, compressed air that has been through a compressor's aftercooler (typically about 100°F after cooling) enters the refrigerated dryer and passes through the primary side of the air-to-air heat exchanger (A/A HX) (1) where its temperature is reduced to about 70°F. This change in temperature condenses a significant amount of the water vapor that entered the A/A HX. Some oil vapor may also be condensed in the A/A HX.

The mixture of 70°F saturated compressed air and liquid water enters the air-to-refrigerant heat exchanger (A/R HX) (2) where the temperature of both the air and the liquid water are further reduced to about 38°F. Again the condensing of water vapor creates more liquid water, and the condensing of oil vapor creates oil aerosols.

This mixture of 38°F saturated compressed air, liquid water, and oil aerosols enters the refrigerated dryer's separator (3) where oil aerosols are coalesced and the liquid water and newly formed oil droplets are separated from the compressed air stream and can be removed from the air system by an automatic drain mechanism. The separator element also captures and retains solid particles.

The cold saturated air, reduced in oil aerosols and particulates, should be routed through an oil coalescing filter (4) prior to the desiccant dryer stage.

The cold, saturated, oil-free, and particle-free compressed air is now passed through a bed of activated alumina desiccant (5) where its dew point is reduced to -40°F and its temperature is slightly increased due to the heat released by the adsorption of water vapor being carried out of the desiccant bed by the compressed air flow. The air temperature will rise to about 41°F at the outlet of the desiccant bed.

The cold, dry, oil-free air stream passes through a particulate filter (6) where desiccant fines that are swept out of the desiccant bed by the compressed air flow are captured.

The final step of the cleaning and drying process is to route the cold, dry, oil-free and particle-free compressed air back to the refrigerated dryer and through the secondary side of the A/A HX (7). Here the hot, untreated inlet air is partially cooled while the cold, dry air from the after-filter is warmed to about 85°F (this warming does not change the dew point), and delivered to the compressed air distribution system (8).

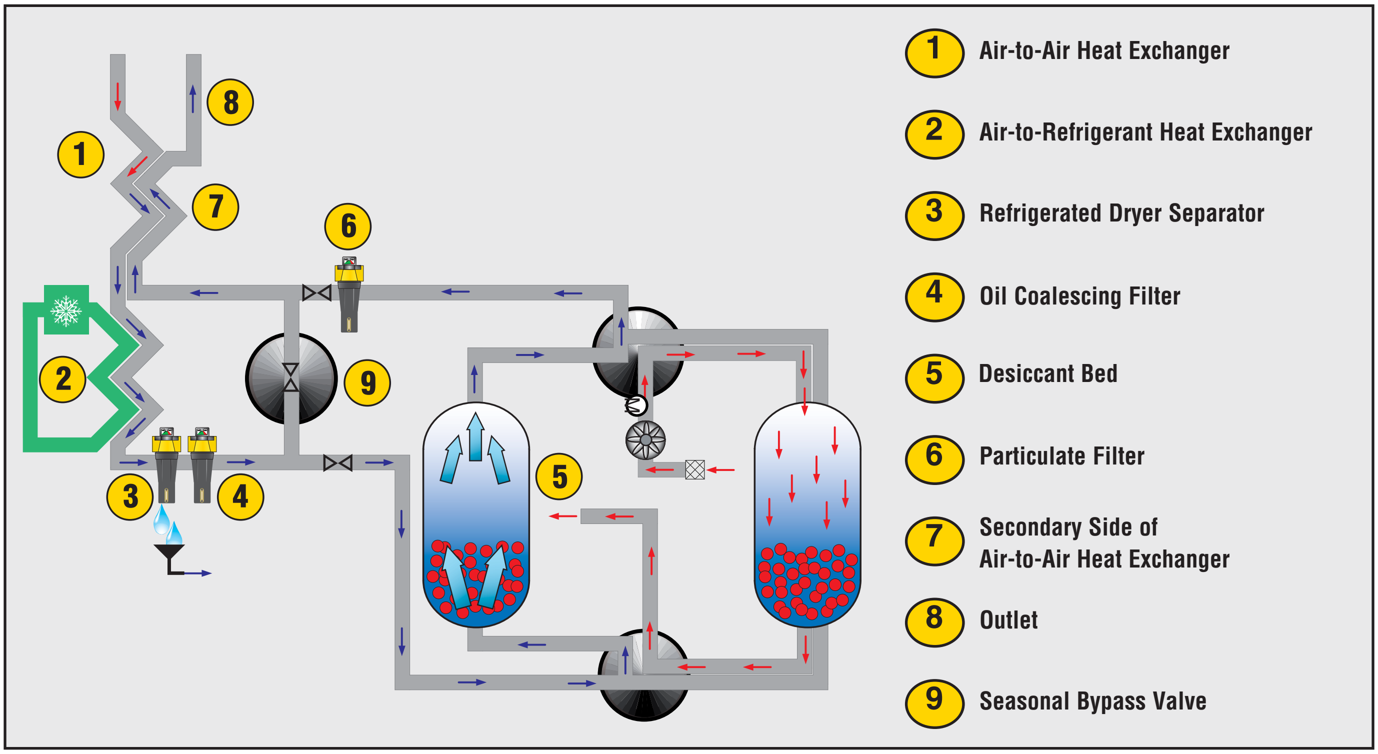

FIGURE 2: Hybrid Refrigerated/Desiccant Compressed Air Dryer operation.

Components and Requirements of a Hybrid Drying System

Refrigerated Dryer

The refrigerated dryer may have a condensing section of either the air-cooled or water-cooled variety, but the system must be designed and sized to reduce the compressed air temperature to within a range of 36°F to 40°F, with a low air temperature of 38°F or 39°F being typical.

As an air system demand typically has peak and minimum requirements, the load on an air dryer will vary. For this reason the refrigerated dryer of a hybrid system must be capable of operation that matches power consumption of the refrigeration system to the prevailing air demand. This can be accomplished with a scroll-type refrigerant compressor equipped with load and unload capability. Often called a “digital scroll” compressor, these units load and unload (rather than start and stop), circulating refrigerant through the refrigerant circuit only as needed. The risk of motor burn-out is greatly reduced with digital scroll technology as the motor of a digital scroll compressor is not routinely stopped and restarted, consequently enhancing system reliability.

As the interconnecting pipe sections from the refrigerated dryer to desiccant dryer and desiccant dryer back to refrigerated dryer are carrying cold air (38°F and 41°F respectively), both must be insulated to preserve the low air temperatures.

Desiccant Dryer

Selection of the desiccant dryer type for the hybrid system is critical. There are two basic types of desiccant dryers, being “heatless” (also known as “pressure swing”) and “heated” (of which there are several kinds).

Choosing the Right Dryer

Desiccant dryers are sometimes needed, but have higher life cycle costs than refrigerated dryers. Because energy, desiccant, and valve maintenance costs add up quickly, it is best to use a refrigerated dryer whenever possible.

When a desiccant dryer is necessary, putting a refrigerated dryer before it can save on operating costs. Using both dryers is cost effective for large systems (over 1500 cfm) or where power is expensive. It also reduces the size of the desiccant dryer needed. If the low dew point is needed seasonally, the desiccant dryer can be turned off and the refrigerated dryer will suffice.

Not all of these desiccant dryers are suitable for use in a hybrid system. For example, heatless desiccant dryers provide no energy savings capability when used in combination with a refrigerated dryer. Since the primary goal of the hybrid system is energy reduction, the blower purge type is the best choice.

It is then a “heated” type desiccant dryer that must be used and the type best suited for service in a hybrid system is the “externally heated atmospheric blower purge”, hereafter referred to simply as “blower purge”. The operation and components of a blower purge dryer will not be described in detail. It is assumed the reader is generally familiar with the components and operation of a blower purge dryer.

A long drying and regenerating cycle—typically 16 hours—is required for the blower purge dryer in a hybrid system. The long cycle is necessary to allow adequate time for both regeneration and desiccant bed cooling after regeneration is complete.

Combination systems require a long drying and regenerating cycle to eliminate the temperature spike in the compressed air (a characteristic of heated desiccant dryers) that will occur after a regenerated desiccant bed is put back on-line in drying service. The residual heat from regeneration is carried out of the bed by the compressed air stream and the outlet air temperature can rise to over 300°F, depending on the type of heated dryer.

Since a hybrid drying system routes air from the blower purge dryer to the A/A HX of the refrigerated dryer, a temperature spike in the desiccant dryer's outlet air cannot be tolerated. Hence a hybrid system must completely cool the desiccant bed after regeneration. As the desiccant bed can only be cooled with dry process air (ambient air should not be used for cooling) to prevent a temperature and dew point spike (another characteristic of heated desiccant dryers) in the outlet air, a long cycle permits a low cooling air flow rate, and further assists the cooling process by increasing the time that heat loss from the desiccant tower to the ambient air can occur.

The cooling air flow rate of a blower purge dryer in a hybrid system is 4% of the dryer's rated inlet capacity and averages only 1.1% over the drying and regenerating cycle. Only a small volume of air is required for cooling because the desiccant beds of hybrid systems are comparatively small and regeneration temperatures are comparatively low (230°F to 250°F). The low regeneration temperature for combination systems is due primarily to the low temperature (39°F) of the air entering the blower purge dryer. The cumulative effect is complete cooling of the desiccant bed that can be achieved with minimal loss of process air.

Filtration

Because oil vapor present in the atmosphere is ingested by air compressors and that oil vapor then condenses as it cools in its travel through an air system, an oil coalescing filter must be installed between the refrigerated dryer's separator and the inlet to the blower purge dryer.

FIGURE 3: Proper filtration in conjunction with the hybrid dryer is essential for ensuring proper air treatment.

This placement ensures sufficient removal of liquids upstream of the oil coalescing filter so that its maximum allowable liquid loading is not exceeded and protection for the desiccant bed from oil contamination allows the full service life of the desiccant to be realized. As the oil coalescing filter is in the cold air stream, it must be insulated.

Downstream of the blower purge dryer and upstream of the secondary side of the refrigerated dryer's A/A HX, a one micron particulate filter is placed to capture desiccant fines. One micron is adequate particulate removal as 99+% of desiccant fines exist in particle sizes greater than one micron with seven micron particles being the median size.

Without this filter, desiccant fines would pass unimpeded through the A/A HX and travel downstream to equipment installed in the compressed air distribution system. Therefore, the particle filter, more commonly referred to as the "after-filter", serves the same purpose in a hybrid system as it does with any other desiccant dryer type. As the particulate filter of the combination system is in the cold air stream, it must be insulated.

Advantages of a Hybrid Drying System

Using a refrigerated dryer in combination with a blower purge dryer yields a surprising number of benefits. As a "major" benefit in one application may be a "minor" benefit in another, the following benefits are not given in any weighted order.

Produce a consistent outlet dew point and air temperature through the full operating range.

There are no dew point or temperature spikes at any time during the drying and regenerating half-cycles.

Have longer desiccant service life than other types of desiccant dryers.

In normal operation heated dryers, such as blower purge or heated purge (often called, inaccurately, "exhaust" purge), desiccant service life of up to 2 years can be expected.

A desiccant service life of 3 to 5 years can be expected from a heatless desiccant dryer in normal operation.

In a hybrid system, a desiccant service life of 5 to 7 years can be expected.

The longer desiccant service life in combination systems results from:

- Less thermal cycling - The desiccant beds in hybrid systems are heated and cooled half as often as in other heated dryer types. The desiccant is regenerated every eight (8) hours in hybrid systems where regeneration every four (4) hours is typical of other heated dryer types.

- Magnitude of thermal cycling is reduced - The typical regeneration temperature for blower purge dryers in hybrid dryer service is 230°F to 250°F. Therefore the temperature change of the desiccant during regeneration is about 200°F (e.g., from 40°F to 240°F).

The typical regeneration temperature for heated dryers is about 400°F, with some as high as 425°F. Therefore the temperature change of the desiccant bed during regeneration can be as much as 300°F.

Also contributing to longer service life of desiccant in hybrid systems is that depressurization of the desiccant tower, in preparation for regeneration, is controlled. The tower is depressurized slowly over a period of several minutes rather than instantaneously as with heatless desiccant dryers. Rapid depressurization subjects the desiccant beds to very high air velocities, albeit for a brief period of time (but with extreme frequency for heatless dryers). Since there is ample time to accomplish regeneration with a hybrid system, depressurization can be done slowly.

Reduce the frequency of switching and check valve cycling.

As hybrid systems operate on a 16 hour cycle, 8 hours drying, 8 hours regenerating, valve actuation is initiated at 8 hour intervals. Heated dryers typically operate on an 8 hour cycle, 4 hours drying, 4 hours regenerating, and valve actuation is initiated at 4 hour intervals. The valves of a hybrid system cycle 50% less than those of a typical heated dryer.

The most common cycle time for heatless dryers is 10 minutes: 5 minutes drying, 5 minutes regenerating. Therefore, the valves of heatless dryers switch every 5 minutes. By comparison, the valves of a hybrid system cycle 99% less than those of a typical heatless dryer.

Require significantly less desiccant per scfm of rated capacity than other types of desiccant dryers.

For this example, dryers with a rated capacity of 1500 scfm are considered, though the numbers would be similar (proportional) for other flow rates.

- Heated dryer, such as heated purge or blower purge, requires:

FIGURE 4: Hybrid Refrigerated/Desiccant Compressed Air Dryers offer significant benefits for large compressed air systems requiring low dew points.

- 1260 lb desiccant per tower
- 2520 lb for replacement

- Heatless dryer requires:
  - 1030 lb desiccant per tower
  - 2060 lb for replacement

- Hybrid system requires:
  - 780 lb desiccant per tower
  - 1560 lb for replacement

Total replacement desiccant, however, is only half of the equation. The other half is replacement frequency. Consider the average quantity of replacement desiccant each dryer type requires annually:

- Heated: 2520 lb x 1 change/2 yrs = 1260 lb/yr

- Heatless: 2060 lb x 1 change/5 yrs = 412 lb/yr

- Hybrid: 1560 lb x 1 change/7 yrs = 223 lb/yr

Will produce outlet dew point exceeding design (typically -40°F) when prevailing ambient conditions are less taxing than design ambient conditions.

Design ambient dew point for combination systems is 65°F. When the ambient dew point is lower than 65°F, the outlet dew point from the hybrid system will be lower than -40°F (all other parameters being constant).

It is not uncommon for hybrid systems to produce dew points in the range of -80°F during wintertime operation, especially in areas where winters are very cold, and consequently ambient dew points are very low.

Consume significantly less power than other types of desiccant dryers.

At rated conditions and producing a -40°F pressure dew point for seven months a year with a 38°F pressure dew point for the remaining five months, a hybrid system consumes:

- 48% less power than a blower purge dryer
- 54% less power than a heated purge dryer
- 64% less power than a heatless dryer

Tolerate elevated inlet air temperatures with less performance loss than other types of heated desiccant dryers.

The lack of attention to an air compressor's aftercooler will eventually result in steadily elevating discharge air temperatures, which of course means steadily increasing water load on the air treatment. The process is normally not rapid, occurring gradually over time, but the cumulative effect of time can be marked.

The capacity of heated desiccant dryers can be severely impaired as the temperature of the inlet air to the dryer rises. A rise of only 5°F above the rated inlet air temperature (100°F to 105°F) results in a 13% decrease of their inlet flow capacity (i.e., a 1000 scfm heated dryer becomes an 870 scfm heated dryer when the inlet temperature is 105°F).

With a 10°F rise, heated dryers lose 26% of their rated capacity. At 20°F above the rated inlet air temperature the capacity loss is 45% and a 1000 scfm heated dryer now becomes a 550 scfm heated dryer.

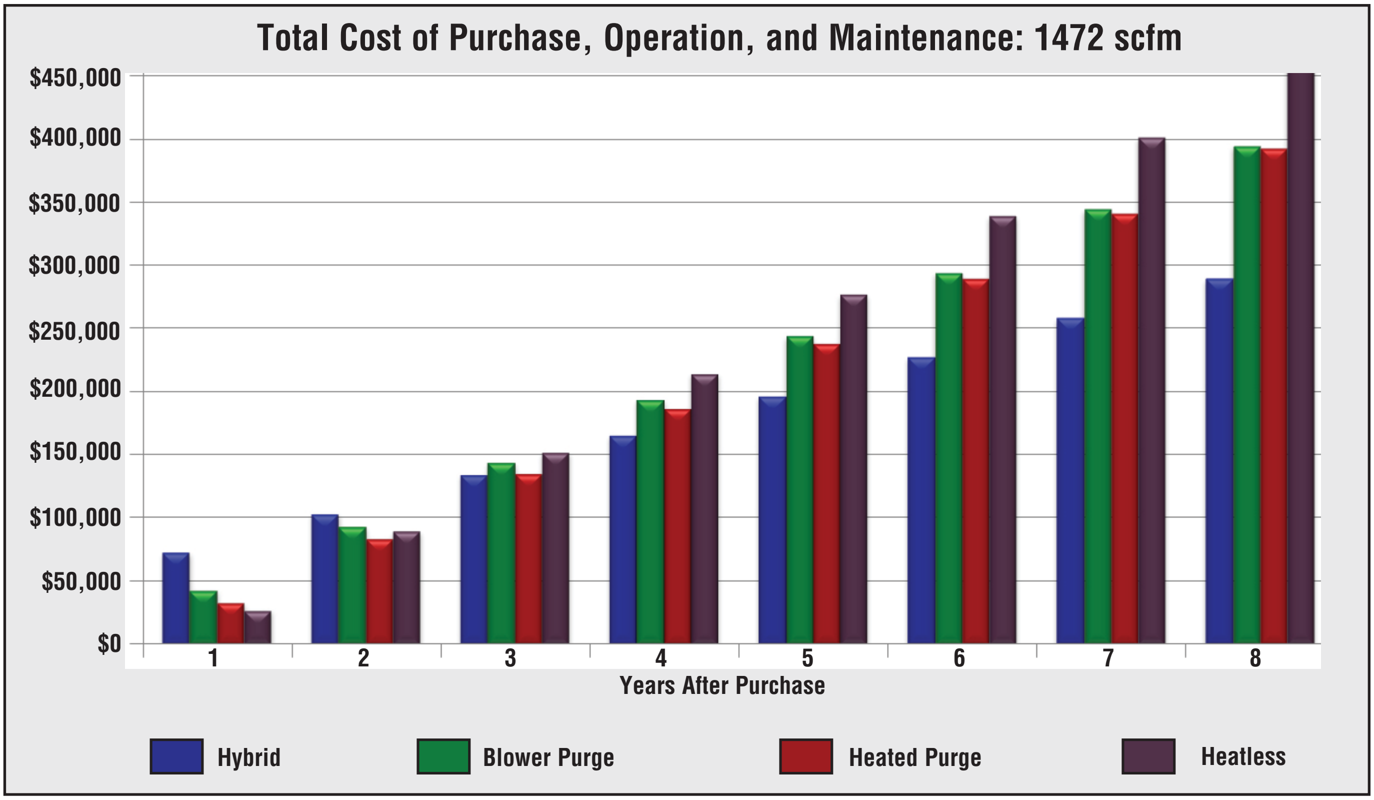

FIGURE 5: At 1472 cfm, a hybrid dryer is the most cost effective choice. It offers less than a 2-year payback.

Hybrid dryers are not as affected by inlet temperature rising above the rated condition.

It is the refrigerated dryer, rather than the blower purge dryer, in a hybrid system that will be most challenged by a rising inlet air temperature, and the effect is much less pronounced on a refrigerated dryer than it is on a heated desiccant dryer.

A 5°F rise in inlet air temperature to a refrigerated dryer may result in a slight elevation of the outlet dew point. Theoretically the dew point would rise to 41°F, but this is a tolerable condition for the hybrid system's blower purge dryer. In this case, any loss in performance may not be detectable.

If the inlet air temperature rose 10°F, this would certainly impact the capacity of the hybrid system as the refrigerated dryer would lose 18% of its rated capacity, but this is much less than the 26% loss a heated dryer would have.

If the inlet air temperature rose 20°F above the rated condition, the refrigerated dryer would lose 30% of its rated capacity, but again, this is much less than the 45% capacity loss a heated dryer would have.

The benefit of a hybrid system's greater tolerance for rising inlet air temperature is it permits more time for maintenance personnel to locate and correct the cause of the problem before air quality from the dryer deteriorates to an unacceptable level.

Produce both refrigerated (+38°F) and desiccant (-40°F) dryer dew points.

Since hybrid systems have the ability to by-pass and shut down the blower purge dryer when sub-freezing dew points are not necessary, they have some unique advantages.

- The operating cost of the blower purge dryer is eliminated during warm weather periods, further reducing the total cost of treating compressed air.
- The service life of the desiccant and after-filter elements is extended by the same amount of time the blower purge dryer can be kept off-line, reducing annual maintenance costs.
- Routine maintenance for the blower purge dryer, such as filter element replacement, valve rebuilds, even desiccant replacement, can be performed without having to schedule air system downtime.
- The need to stock routine maintenance items (such as filter elements, valve rebuild kits, and replacement desiccant) is eliminated along with the associated administrative costs of those functions. Warehouse space is also preserved.

Conclusion

A hybrid refrigerated/blower purge compressed air dryer is a flexible drying system capable of consistent performance and reliability with low operating and maintenance costs that quickly returns its initial purchase price.

About the Authors

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