CHAPTER 23

DESICCANT DEHUMIDIFICATION AND PRESSURE-DRYING EQUIPMENT

DEHUMIDIFICATION is the removal of water vapor from air, gases, or other fluids. There is no pressure limitation in this definition, and sorption dehumidification equipment has been designed and operated successfully for system pressures ranging from subatmospheric to as high as 6000 psi. In common practice, *dehumidification* usually refers to equipment operating at essentially atmospheric pressures and built to standards similar to other types of air-handling equipment. For drying gases under pressure, or liquids, the term **dryer** or **dehydrator** is normally used.

This chapter mainly covers equipment and systems that dehumidify air rather than those that dry other gases or liquids. Both liquid and solid desiccants are used; they either adsorb water on the desiccant's surface (adsorption) or chemically combine with water (absorption).

Nonregenerative equipment uses hygroscopic salts such as calcium chloride, urea, or sodium chloride. **Regenerative** systems usually use a form of silica or alumina gel, activated alumina, molecular sieves, lithium chloride salt or solution, or glycol solution. In regenerative equipment, the water removal mechanism is reversible. The choice of desiccant depends on installation requirements, equipment design, and chemical compatibility with the gas to be treated or impurities in the gas. Chapter 22 of the 2005 *ASHRAE Handbook—Fundamentals* has more information on desiccant materials and how they operate.

Some commercial applications of desiccant dehumidification include

- Keeping buildings and HVAC systems dry to prevent mold growth
- Lowering relative humidity to facilitate manufacturing and handling of hygroscopic materials
- Lowering the dew point to prevent condensation on products manufactured in low-temperature processes
- Providing protective atmospheres for heat treatment of metals
- Controlling humidity in warehouses and caves used for storage
- Preserving ships, aircraft, and industrial equipment that would otherwise deteriorate
- Maintaining a dry atmosphere in a closed space or container, such as the cargo hold of a ship or numerous static applications
- Eliminating condensation and subsequent corrosion
- Drying air to speed drying of heat-sensitive products, such as candy, seeds, and photographic film
- Drying natural gas
- Drying gases that are be liquefied
- Drying instrument and plant air
- Drying process and industrial gases
- Dehydration of liquids
- Frost-free cooling for low-temperature process areas such as brewery fermenting, aging, filtering, and storage cellars; blast freezers; and refrigerated warehouses
- Frost-free dehumidification for processes that require air at a subfreezing dew-point humidity

This chapter covers (1) the types of dehumidification equipment for liquid and solid desiccants, including high-pressure equipment; (2) performance curves; (3) variables of operation; and (4) some typical applications. Using desiccants to dry refrigerants is addressed in Chapter 6 of the 2006 *ASHRAE Handbook—Refrigeration*.

METHODS OF DEHUMIDIFICATION

Air may be dehumidified by (1) cooling it or increasing its pressure, reducing its capacity to hold moisture, or (2) removing moisture by attracting the water vapor with a liquid or solid desiccant. Frequently, systems use a combination of these methods to maximize operating efficiency and minimize installed cost.

Figure 1 illustrates three methods to dehumidify with desiccant materials or equipment. Air in the condition at Point A is dehumidified and cooled to Point B. In a liquid-desiccant unit, air is simultaneously cooled and dehumidified directly from Point A to Point B. In a solid-desiccant unit, this process can be completed by precooling and dehumidifying from Point A to Point C, then desiccating from Point C to Point E, and finally cooling to Point B. It could also be done with solid desiccant equipment by dehumidifying from Point A to Point D and then cooling from Point D to Point B.

Compression

Compressing air reduces its capacity to hold moisture. The resulting condensation reduces the air's moisture content in absolute terms,

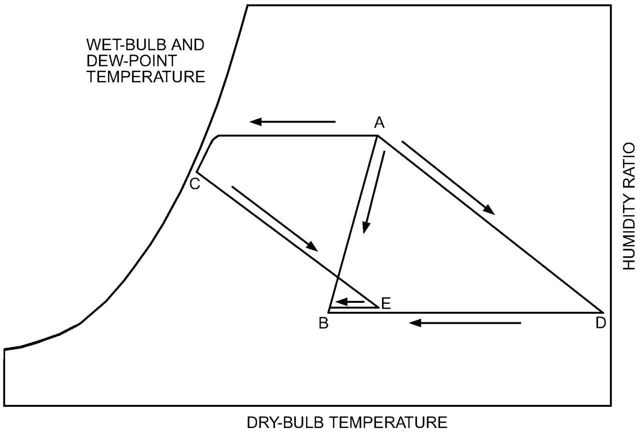


Fig. 1 Methods of Dehumidification

The preparation of this chapter is assigned to TC 8.12, Desiccant Dehumidification Equipment and Components.

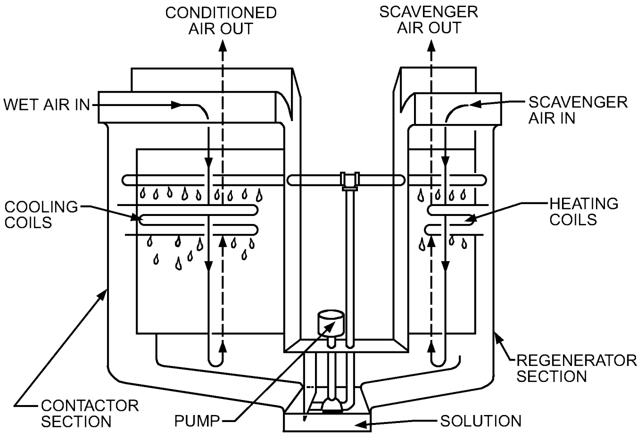


Fig. 2 Flow Diagram for Liquid-Absorbent Dehumidifier

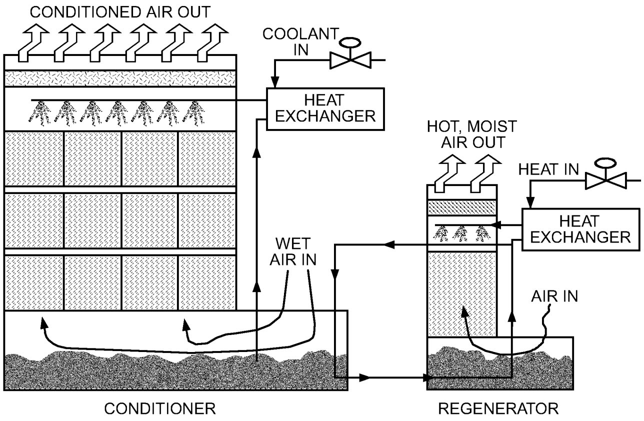


Fig. 3 Flow Diagram for Liquid-Absorbent Unit with Extended Surface Air Contact Medium

but produces a saturated condition: 100% relative humidity at elevated pressure. In atmospheric-pressure applications, this method is too expensive, but is worthwhile in pressure systems such as instrument air. Other dehumidification equipment, such as coolers or desiccant dehumidifiers, often follows the compressor to avoid problems associated with high relative humidity in compressed-air lines.

Cooling

Refrigerating air below its dew point is the most common method of dehumidification. This is advantageous when the gas is comparatively warm, has a high moisture content, and the desired outlet dew point is above 40°F. Frequently, refrigeration is combined with desiccant dehumidification to obtain an extremely low dew point at minimum cost.

Liquid Desiccants

Liquid-desiccant conditioners (absorbers) contact the air with a liquid desiccant, such as lithium chloride or glycol solution (Figures 2 and 3). The water vapor pressure of the solution is a function of its temperature and concentration. Higher concentrations and lower temperatures result in lower water vapor pressures.

A simple way to show this relationship is to graph the humidity ratio of air in equilibrium with a liquid desiccant as a function of its concentration and temperature. Figure 4 presents this relationship for lithium chloride/water solutions in equilibrium with air at 14.7 psi. The graph has the same general shape as a psychrometric chart, with the relative humidity lines replaced by desiccant concentration lines.

Liquid-desiccant conditioners typically have a high contact efficiency, so air leaves the conditioner at a temperature and humidity ratio very close to the entering temperature and equilibrium humidity ratio of the desiccant. When the conditioner is dehumidifying, moisture absorbed from the conditioned airstream dilutes the desiccant solution. The diluted solution is reconcentrated in the regenerator, where it is heated to elevate its water vapor pressure and equilibrium humidity ratio. A second airstream, usually outside air, contacts the heated solution in the regenerator; water evaporates from the desiccant solution into the air, and the solution is reconcentrated. Desiccant solution is continuously recirculated between the conditioner and regenerator to complete the cycle.

Liquid desiccants are typically a very effective antifreeze. As a result, liquid-desiccant conditioners can continuously deliver air at subfreezing temperatures without frosting or freezing problems. Lithium chloride/water solution, for example, has a eutectic point of –90°F; liquid-desiccant conditioners using this solution can cool air to temperatures as low as –65°F.

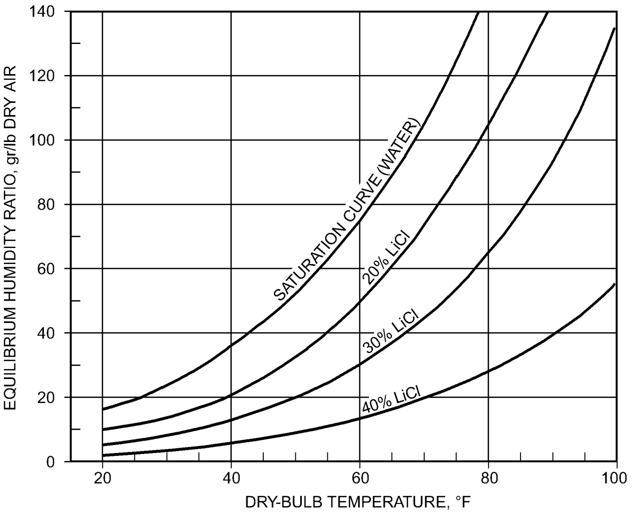


Fig. 4 Lithium Chloride Equilibrium

Solid Sorption

Solid sorption passes air through a bed of granular desiccant or through a structured packing impregnated with desiccant. Humid air passes through the desiccant, which when active has a vapor pressure below that of the humid air. This vapor pressure differential drives water vapor from the air onto the desiccant. After becoming loaded with moisture, the desiccant is reactivated (dried out) by heating, which raises the vapor pressure of the material above that of the surrounding air. With the vapor pressure differential reversed, water vapor moves from the desiccant to a second airstream called the *reactivation air*, which carries moisture away from the equipment.

DESICCANT DEHUMIDIFICATION

Both liquid and solid desiccants may be used in equipment designed for drying air and gases at atmospheric or elevated pressures. Regardless of pressure levels, basic principles remain the same, and only the desiccant towers or chambers require special design consideration.

Desiccant capacity and actual dew-point performance depend on the specific equipment used, characteristics of the various desiccants, initial temperature and moisture content of the gas to be dried, reactivation methods, etc. Factory-assembled units are available up to a capacity of about 80,000 cfm. Greater capacities can be obtained with field-erected units.

LIQUID-DESICCANT EQUIPMENT

Liquid-desiccant dehumidifiers are shown in Figures 2 and 3. In Figure 2, liquid desiccant is distributed onto a **cooling coil**, which acts as both a contact surface and a means of removing heat released when the desiccant absorbs moisture from the air. In Figure 3, liquid desiccant is distributed onto an extended heat and mass transfer surface (a **packing** material similar to that used in cooling towers and chemical reactors). The packing provides a great deal of surface for air to contact the liquid desiccant, and the heat of absorption is removed from the liquid by a heat exchanger outside the airstream. Air can be passed through the contact surface vertically or horizontally to suit the best arrangement of air system equipment.

Depending on the air and desiccant solution inlet conditions, air can be simultaneously cooled and dehumidified, heated and dehumidified, heated and humidified, or cooled and humidified. When the enthalpy of the air is to be increased in the conditioner unit, heat must be added either by preheating the air before it enters the conditioner or by heating the desiccant solution with a second heat exchanger. When the air is to be humidified, makeup water is automatically added to the desiccant solution to keep it at the desired concentration.

Moisture is absorbed from or desorbed into the air because of the difference in water vapor pressure between the air and the desiccant solution. For a given solution temperature, a higher solution concentration results in a lower water vapor pressure. For a given solution concentration, a lower solution temperature results in a lower water vapor pressure. By controlling the temperature and concentration of the desiccant solution, the conditioner unit can deliver air at a precisely controlled temperature and humidity regardless of inlet air conditions. The unit dehumidifies the air during humid weather and humidifies it during dry weather. Thus, liquid-desiccant conditioners can accurately control humidity without face-and-bypass dampers or after-humidifiers.

Heat Removal

When a liquid desiccant absorbs moisture, heat is generated. This heat of absorption consists of the latent heat of condensation of water vapor at the desiccant temperature and the heat of solution (heat of mixing) of the condensed water and the desiccant. The heat of mixing is a function of the equilibrium relative humidity of the desiccant: a lower equilibrium relative humidity produces a greater heat of mixing.

The total heat that must be absorbed by the desiccant solution consists of the (1) heat of absorption, (2) sensible heat associated with reducing the dry-bulb temperature of the air, and (3) residual heat carried to the conditioner by the warm, concentrated desiccant returning from the regenerator unit. This total heat is removed by cooling the desiccant solution in the conditioner heat exchanger (Figure 3). Any coolant can be used, including cooling tower water, ground water, seawater, chilled water or brine, and direct-expansion or flooded refrigerants.

Regenerator residual heat, generally called **regenerator heat dumpback**, can be substantially reduced by using a liquid-to-liquid heat exchanger to precool the warm, concentrated desiccant transferred to the conditioner using the cool, dilute desiccant transferred from the conditioner to the regenerator. This also improves the thermal efficiency of the regenerator, typically reducing heat input by 10 to 15%.

Regeneration

When the conditioner is dehumidifying, water is automatically removed from the liquid desiccant to maintain the desiccant at the proper concentration. Removal takes place in a separate regenerator. A small sidestream of the desiccant solution, typically 8% or less of the flow to the conditioner packing, is transferred to the regenerator unit. In the regenerator, a separate pump continuously circulates the desiccant solution through a heat exchanger and distributes it over the packed bed contactor surface. The heat exchanger heats the desiccant solution with low-pressure steam or hot water so that its water vapor pressure is substantially higher than that of the outside air. Outside air is passed through the packing, and water evaporates into it from the desiccant solution, concentrating the solution. The hot, moist air from the regenerator is discharged to the outdoors. A sidestream of concentrated solution is transferred to the conditioner to replace the sidestream of weak solution transferred from the conditioner and complete the cycle.

The regenerator's water removal capacity is controlled to match the moisture load handled by the conditioner. This is accomplished by regulating heat flow to the regenerator heat exchanger to maintain a constant desiccant solution concentration. This is most commonly done by maintaining a constant solution level in the system with a level controller, but specific-gravity or boiling-point controllers are used under some circumstances. Regenerator heat input is regulated to match the instantaneous water removal requirements, so no heat input is required if there is no moisture load on the conditioner. When the conditioner is used to humidify the air, the regenerator fan and desiccant solution pump are typically stopped to save energy.

Because the conditioner and regenerator are separate units, they can be in different locations and connected by piping. This can substantially lower ductwork cost and required mechanical space. Commonly, a single regenerator services several conditioner units (Figure 5). In the simplest control arrangement, concentrated desiccant solution is metered to each conditioner at a fixed rate. The return flow of weak solution from each conditioner is regulated to maintain a constant operating level in the conditioner. A level controller on the regenerator regulates heat flow to the regenerator solution heater to maintain a constant volume of desiccant solution, and hence a practically constant solution concentration.

The regenerator can be sized to match the dehumidification load of the conditioner unit or units. Regenerator capacity is affected by regenerator heat source temperatures (higher source temperatures increase capacity) and by desiccant concentration (higher concentrations reduce capacity). The relative humidity of air leaving the conditioner is practically constant for a given desiccant concentration, so regenerator capacity can be shown as a function of delivered air relative humidity and regenerator heat source temperature. Figure 6 is a normalized graph showing this relationship. For a given moisture load, a variety of regenerator heat sources may be used if the regenerator is sized for the heat source selected. In many cases, the greater capital cost of a larger regenerator is paid back very quickly by reduced operating cost when a lower-cost or waste-heat source (e.g., process or turbine tailsteam, jacket heat from an engine-driven generator or compressor, or refrigeration condenser heat) is used.

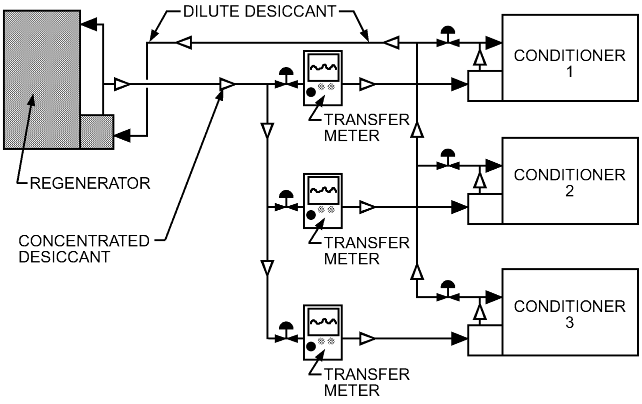


Fig. 5 Liquid Desiccant System with Multiple Conditioners

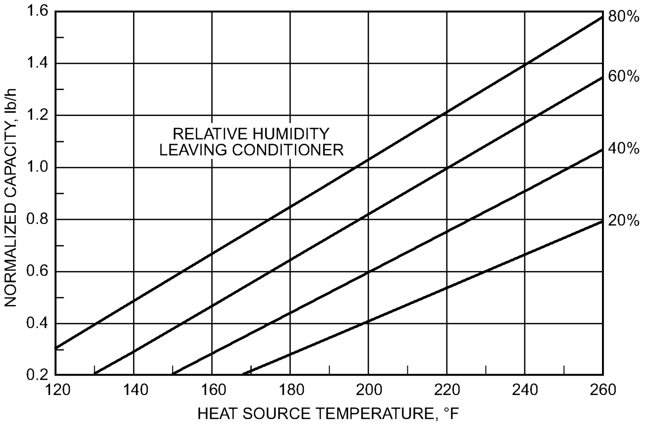


Fig. 6 Liquid Desiccant Regenerator Capacity

SOLID-SORPTION EQUIPMENT

Solid desiccants, such as silica gel, zeolites (molecular sieves), activated alumina, or hygroscopic salts, are generally used to dehumidify large volumes of moist air, and are continuously reactivated. Dry desiccants can also be used in (1) nonreactivated, disposable packages and (2) periodically reactivated desiccant cartridges.

Disposable packages of solid desiccant are often sealed into packaging for consumer electronics, pharmaceutical tablets, and military supplies. Disposable desiccant packages rely entirely on vapor diffusion to dehumidify, because air is not forced through the desiccant. This method is used only in applications where there is no anticipated moisture load at all (such as hermetically sealed packages) because the moisture absorption capacity of any nonreactivated desiccant is rapidly exceeded if a continuous moisture load enters the dehumidified space. Disposable packages generally serve as a form of insurance against unexpected, short-term leaks in small, sealed packages.

Periodically reactivated cartridges of solid desiccant are used where the expected moisture load is continuous, but very small. A common example is the breather, a tank of desiccant through which air can pass, compensating for changes in liquid volume in petroleum storage tanks or drums of hygroscopic chemicals. Air dries as it passes through the desiccant, so moisture will not contaminate the stored product. When the desiccant is saturated, the cartridge is removed and heated in an oven to restore its moisture sorption capacity. Desiccant cartridges are used where there is no requirement for a constant humidity control level and where the moisture load is likely to exceed the capacity of a small, disposable package of desiccant.

Desiccant dehumidifiers for drying liquids and gases other than air often use a variation of this reactivation technique. Two or more pressurized containers of dry desiccant are arranged in parallel, and air is forced through one container for drying, while desiccant in the other container is reactivated. These units are often called **dual-tower** or **twin-tower dehumidifiers**.

Continuous reactivation dehumidifiers are the most common type used in high-moisture-load applications such as humidity control systems for buildings and industrial processes. In these units, humid **process air** is dehumidified in one part of the desiccant bed while a different part of the bed is dried for reuse by a second airstream (**reactivation air**). The desiccant generally rotates slowly between these two airstreams, so that dry, high-capacity desiccant leaving the reactivation air is always available to remove moisture from the process air. This type of equipment is generally called a **rotary desiccant dehumidifier**. It is most commonly used in building air-handling systems, and the section on Rotary Solid-Desiccant Dehumidifiers describes its function in greater detail.

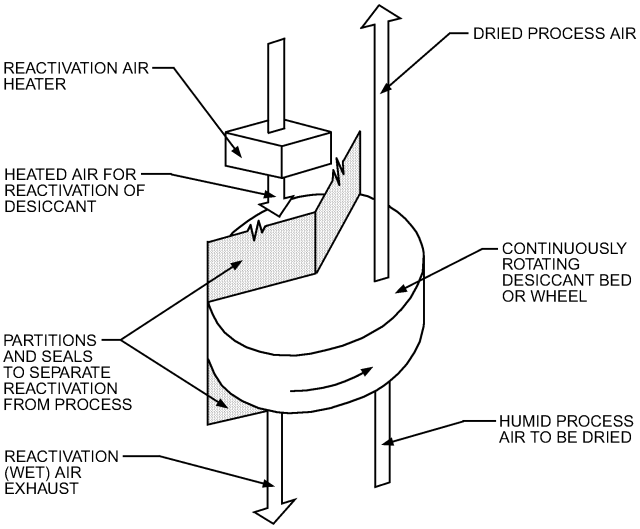


Fig. 7 Typical Rotary Dehumidification Wheel

ROTARY SOLID-DESICCANT DEHUMIDIFIERS

Operation

Figure 7 illustrates the principle of operation and arrangement of major components of a typical rotary solid-desiccant dehumidifier. The desiccant can be beads of granular material packed into a bed, or it can be finely divided and impregnated throughout a structured medium. The structured medium resembles corrugated cardboard rolled into a drum, so that air can pass freely through flutes aligned lengthwise through the drum.

In both granular and structured-medium units, the desiccant itself can be either a single material, such as silica gel, or a combination, such as dry lithium chloride mixed with zeolites. The wide range of dehumidification applications requires flexibility in selecting dessicants to minimize operating and installed costs.

In rotary desiccant dehumidifiers, more than 20 variables can affect performance. In general, equipment manufacturers fix most of these to provide predictable performance in common applications for desiccant systems. Primary variables left to the system designer to define include the following for both process and reactivation air:

- Inlet air temperature
- Moisture content
- Velocity at face of the desiccant bed

In any system, these variables change because of weather, variations in moisture load, and fluctuations in reactivation energy levels. It is useful for the system designer to understand the effect of these normal variations on dehumidifier performance.

Figures 8 to 12 show changes in process air temperature and moisture leaving a generic rotary desiccant dehumidifier as modeled by a finite difference analysis program (Worek and Zheng 1991). Commercial unit performance differs from this model because such units are generally optimized for very deep drying. However, for illustration purposes, the model accurately reflects the relationships between the key variables.

To further illustrate relationships between these variables, ASHRAE Technical Committee 8.12 developed an interactive wheel performance estimator (available on the committee's section of the ASHRAE Web site at www.ashrae.org; see Figure 13). Entering different values for moisture and temperature of process and reactivation airstreams gives the performance of a typical desiccant dehumidification wheel. This program is generic and not based on

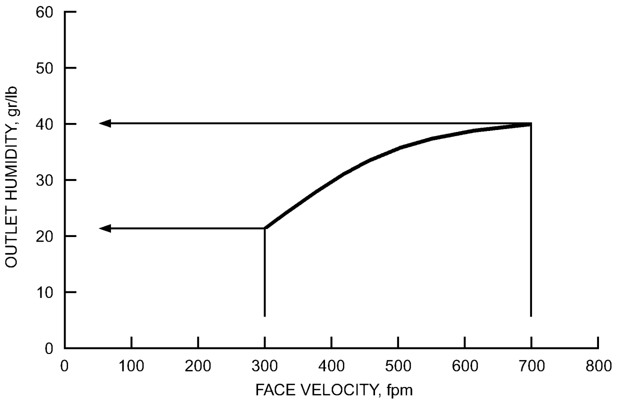


Fig. 8 Effect of Changes in Process Air Velocity on Dehumidifier Outlet Moisture

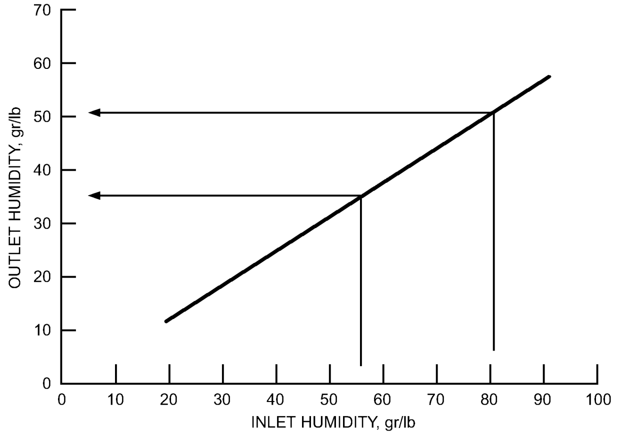


Fig. 9 Effect of Changes in Process Air Inlet Moisture on Dehumidifier Outlet Moisture

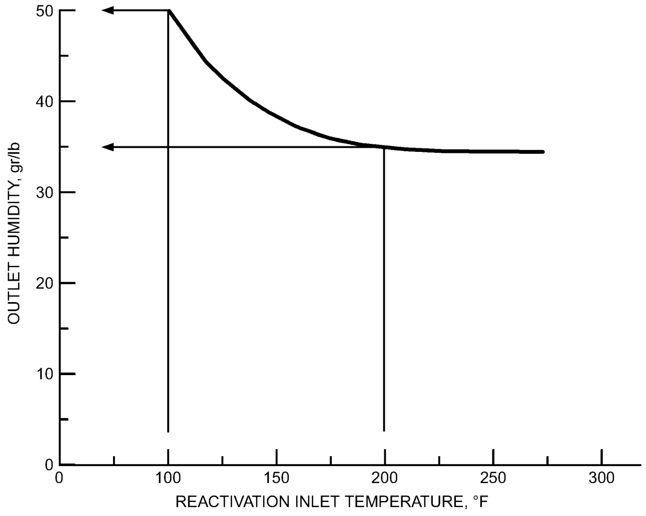


Fig. 10 Effect of Changes in Reactivation Air Inlet Temperature on Dehumidifier Outlet Moisture

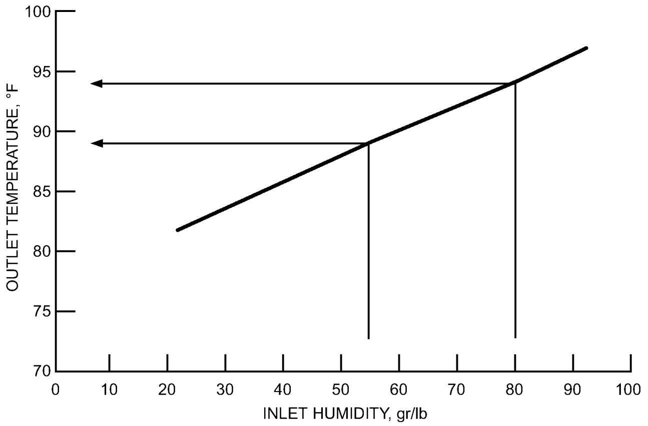


Fig. 11 Effect of Changes in Process Air Inlet Moisture on Dehumidifier Outlet Temperature

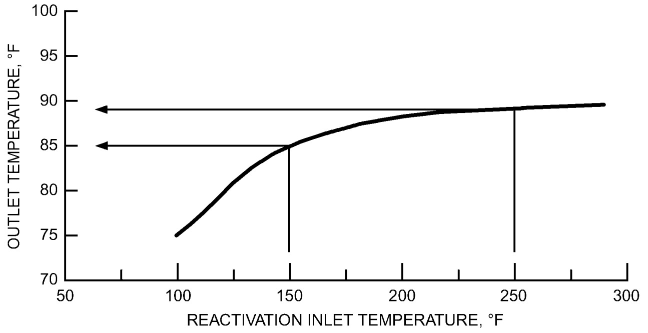


Fig. 12 Effect of Changes in Reactivation Air Inlet Temperature on Dehumidifier Outlet Temperature

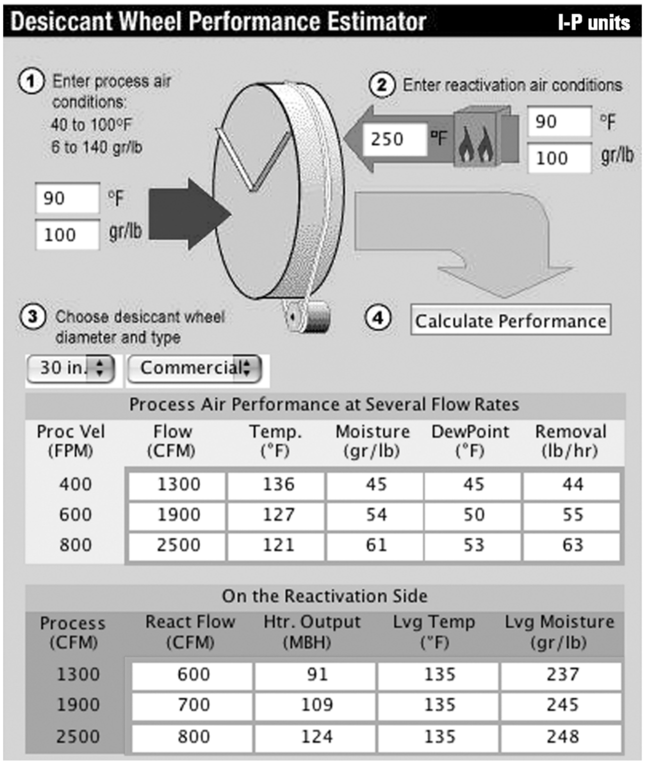
any specific equipment. Performance of units made by different manufacturers varies widely. Consequently, this estimator is useful only for education, not for design.

For example, Figure 13 shows that when the velocity through the desiccant bed increases, the process air is not as dry as it leaves the unit. But, at the same time, as that greater mass of air flows through the wheel (higher air velocity), the dehumidifier actually removes more total pounds of water per hour. This relationship explains why industrial applications, which often require low dew points, generally use lower velocities through the dehumidifier. Commercial applications, which commonly have much larger moisture loads and less need for very low dew points, usually use higher velocities through desiccant equipment.

The desiccant used for the model is silica gel; the bed is a structured, fluted medium; the bed depth is 16 in. in the direction of airflow; and the ratio of process air to reactivation air is approximately 3:1. Process air enters at normal comfort conditions of 70°F, 50% rh (56 grains per pound of dry air).

Process air velocity through the desiccant bed strongly affects leaving moisture. As shown in Figure 8, if the entering moisture is 56 gr/lb and all other variables are held constant, the outlet moisture varies from 22 gr/lb at 300 fpm to 40 gr/lb at 700 fpm. Thus, air that passes through the bed more slowly is dried more deeply. Therefore, if air must be dried very deeply, a large unit (slower air velocities) must be used.

Process air inlet moisture content affects outlet moisture: if air is more humid entering the dehumidifier, it will be more humid leaving the unit. For example, Figure 9 indicates that for an inlet humidity of 56 gr/lb, the outlet humidity will be 35 gr/lb. If inlet moisture content rises to 80 gr/lb, the outlet humidity rises to 50 gr/lb. Therefore, if constant outlet humidity is necessary, the dehumidifier needs capacity control unless the process inlet airstream does not vary in temperature or moisture throughout the year (a rare circumstance).



Process air: 90 °F, 100 gr/lb

Reactivation air: 250 °F; 90 °F, 100 gr/lb

30 in. | Commercial

Process Air Performance at Several Flow Rates

Proc Vel (FPM)	Flow (CFM)	Temp. (°F)	Moisture (gr/lb)	DewPoint (°F)	Removal (lb/hr)
400	1300	136	45	45	44
600	1900	127	54	50	55
800	2500	121	61	53	63

On the Reactivation Side

Process (CFM)	React Flow (CFM)	Htr. Output (MBH)	Lvg Temp (°F)	Lvg Moisture (gr/lb)
1300	600	91	135	237
1900	700	109	135	245
2500	800	124	135	248

Fig. 13 Interactive Desiccant Wheel Performance Estimator

Reactivation air inlet temperature changes the outlet moisture content of the process air. From 100 to 250°F, as more heat is added to the reactivation air, the desiccant dries more completely, which means that it can attract more moisture from the process air (Figure 10). If reactivation air is only heated to 100°F, process outlet moisture is 50 gr/lb, or only 6 gr/lb lower than the entering humidity. In contrast, if reactivation air is heated to 200°F, the outlet moisture is 35 gr/lb, so that almost 40% of the original moisture is removed.

This relationship has two important consequences. If the design needs dry air, it is generally more economical to use high reactivation air temperatures. Conversely, if leaving humidity from the dehumidifier need not be especially low, inexpensive, low-grade heat sources (e.g., waste heat, cogeneration heat, or rejected heat from refrigeration condensers) can be used to reactivate the desiccant.

Process air outlet temperature is higher than the inlet air temperature primarily because the heat of sorption of moisture removed from the air is converted to sensible heat. The heat of sorption includes the latent heat of condensation of the removed moisture, plus additional chemical heat, which varies depending on the desiccant type and process air outlet humidity. Also, some heat is carried over to the process air from the reactivation sector because the desiccant is warm as it enters the relatively cooler process air. Generally, 80 to 90% of the temperature rise of process air is from the heat of sorption, and the balance is from heat carried over from reactivation.

Process outlet temperature versus inlet humidity is illustrated in Figure 11. Note that as more moisture is removed (higher inlet humidity), outlet temperature rises. Air entering at room comfort conditions of 70°F, 56 gr/lb leaves the dehumidifier at 89°F. If the dehumidifier removes more moisture, such as when the inlet humidity is 80 gr/lb, outlet temperature rises to 94°F. The increase in temperature rise is roughly proportional to the increase in moisture removal.

Process outlet temperature versus reactivation air temperature is illustrated in Figure 12, which shows the effect of increasing reactivation temperature when the moisture content of the process inlet air stays constant. If the reactivation sector is heated to elevated temperatures, more moisture is removed on the process side, so the temperature rise from latent-to-sensible heat conversion is slightly greater. In this constant-moisture inlet situation, if the reactivation sector is very hot, more heat is carried from reactivation to process as the desiccant mass rotates from reactivation to process. Figure 12 shows that if reactivation air is heated to 150°F, the process air leaves the dehumidifier at 85°F. If reactivation air is heated to 250°F, the process air outlet temperature rises to 89°F. The 4°F increase in process air temperature is primarily caused by the increase in heat carried over from reactivation.

One consequence of this relationship is that desiccant equipment manufacturers constantly seek to minimize the “waste mass” in a desiccant dehumidifier, to avoid heating and cooling extra, nonfunctional material such as heavy desiccant support structures or extra desiccant that air cannot reach. Theoretically, the most efficient desiccant dehumidifier has an infinitely large effective desiccant surface combined with an infinitely low mass.

Use of Cooling

In process drying applications, desiccant dehumidifiers are sometimes used without additional cooling because the temperature increase from dehumidification helps the drying process. In semiprocess applications such as controlling frost formation in supermarkets, excess sensible cooling capacity may be present in the system as a whole, so warm air from a desiccant unit is not a major consideration. However, in most other applications for desiccant dehumidifiers, provision must be made to remove excess sensible heat from process air after dehumidification.

In a liquid-desiccant system, heat is removed by cooling the liquid desiccant itself, so process air emerges from the desiccant medium at the appropriate temperature. In a solid-desiccant system, cooling is accomplished downstream of the desiccant bed with cooling coils. The source of this cooling can affect the system’s operating economics.

In some systems, postcooling is accomplished in two stages, with cooling tower water as the primary source followed by compression or absorption cooling. Alternatively, various combinations of indirect and direct evaporative cooling equipment are used to cool the dry air leaving the desiccant unit.

In systems where the latent and sensible loads peak at different times, the sensible cooling capacity of the basic air-conditioning system is sufficient to handle the process air temperature rise without additional equipment. Systems in moderate climates with high ventilation requirements often combine high latent loads in the morning, evening, and night with high sensible loads at midday, so desiccant subsystems to handle latent loads are especially economical.

Using Units in Series

Dry-desiccant dehumidifiers are often used to provide air at low dew points. Applications requiring large volumes of air at moisture contents of 5 gr/lb (0°F dew point) are quite common and can be easily achieved by rotary desiccant units in a single pass beginning with inlet moisture contents as high as 45 gr/lb (45°F dew point). Some dry-desiccant units commonly deliver air at 2 gr/lb (–18°F dew point) without special design considerations. Where extremely low dew points must be achieved, or where air leakage inside the unit may be a concern, two desiccant dehumidifiers can be placed in series, with dry air from one unit feeding both process and reactivation air to a second unit. The second unit delivers very dry air, because there is reduced risk of moisture being carried over from reactivation to process air when dry air is used to reactivate the second unit.

Industrial Rotary Desiccant Dehumidifier Performance

Figures 8 through 12 are based on the generalized model of a desiccant dehumidifier described by Worek and Zheng (1991). The model, however, differs somewhat from commercial products.

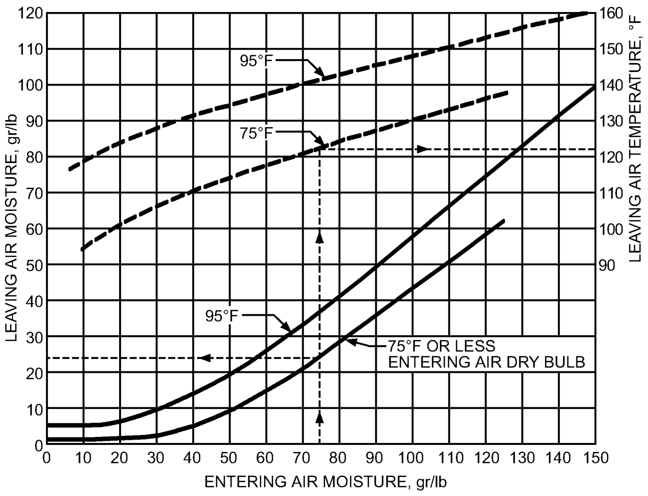


Fig. 14 Typical Performance Data for Rotary Solid Desiccant Dehumidifier

Figure 14 shows typical performance of an industrial desiccant dehumidifier.

EQUIPMENT OPERATING RECOMMENDATIONS

Desiccant equipment tends to be very durable if maintained properly, often operating at high efficiency 30 years after it was originally installed. Required maintenance is specific to the type of desiccant equipment, the application, and the installation. Each system requires a somewhat different maintenance and operational routine. The information in this section does not substitute for or supersede any recommendations of equipment manufacturers, and it is not a substitute for owners' experience with specific applications.

Process Air Filters

Clean filters are the most important item in a maintenance routine. If a solid desiccant is clogged with particulates, or if a liquid desiccant's sorption characteristics are changed by entrained particulates, the material may have to be replaced prematurely. Filters are much less expensive and much easier to change than the desiccant. Although each application is different, the desiccant usually must be replaced, replenished, or reconditioned after 5 to 10 years of operation. Without attention to filters, desiccant life can be reduced to 1 or 2 years of operation or less. Filters should be checked at least four times per year, and more frequently when airstreams are heavily laden with particulates.

The importance of filter maintenance requires that filter racks and doors on desiccant systems be freely accessible and that enough space be allowed to inspect, remove, and replace filters. Optimal design ensures that filter locations, as well as the current condition of each filter, are clearly visible to maintenance personnel.

Reactivation/Regeneration Filters

Air is filtered before entering the heater of a desiccant unit. If filters are clogged and airflow is reduced, unit performance may be reduced because there is not enough air to carry all the moisture away from the desiccant. If electrical elements or gas burners are used to heat the air, reducing airflow may damage the heaters. Thus, the previous suggestions for maintaining process air filters also apply to reactivation/regeneration filters.

Reactivation/Regeneration Ductwork

Air leaving the reactivation/regeneration section is hot and moist. When units first start up in high-moisture-load applications, the reactivation air may be nearly saturated and even contain water droplets. Thus, ductwork that carries air away from the unit should be corrosion-resistant, because condensation can occur inside the ducts, particularly if the ducts pass through unheated areas in cool weather. If heavy condensation seems probable, the ductwork should be designed with drains at low points or arranged to let condensation flow out of the duct where the air is vented to the weather. The high temperature and moisture of the leaving air may make it necessary to use dedicated ductwork, rather than combining the air with other exhaust airflows, unless the other flows have similar characteristics.

Leakage

All desiccant units produce dry air in part of the system. If humid air leaks into either the dry air ductwork or the unit itself, system efficiency is reduced. Energy is also wasted if dry air leaks out of the distribution duct connections. Therefore, duct connections for desiccant systems should be sealed tightly. In applications requiring very low dew points (below 10°F), the ductwork and desiccant system are almost always tested for leaks at air pressures above those expected during normal operation. In applications at higher dew points, similar leak testing is considered good practice and is recommended by many equipment manufacturers.

Because desiccant equipment tends to be durably constructed, workers often drill holes in the dehumidifier unit casing to provide support for piping, ductwork, or instruments. Such holes eventually leak air, desiccant, or both. Designers should provide other means of support for external components so contractors do not puncture the system unnecessarily.

Contractors installing desiccant systems should be aware that any holes made in the system must be sealed tightly using both mechanical means and sealant compounds. Sealants must be selected for long life at the working temperatures of the application and of the casing walls that have been punctured. For example, reactivation/regeneration sections often operate in a range from a cold winter ambient of –40°F to a heated temperature as high as 300°F. Process sections may operate in a range of –40°F at the inlet to 150°F at the outlet.

Airflow Indication and Control

As explained in the section on Rotary Solid-Desiccant Dehumidifiers, performance depends on how quickly air passes through the desiccant; changes in air velocity affect performance. Thus, it is important to quantify the airflow rate through both the process and reactivation/regeneration parts of the unit. Unless both airflows are known, it is impossible to determine whether the unit is operating properly. In addition, if velocity exceeds the maximum design value, the air may carry desiccant particles or droplets out of the unit and into the supply air ductwork. Thus, manufacturers often provide airflow gages on larger equipment so the owner can be certain the unit is operating within the intended design parameters.

Smaller equipment is not always provided with airflow indicators because precise performance may be less critical in applications such as small storage rooms. However, in any system using large equipment, or if performance is critical in smaller systems, unit airflow should be quantified and clearly indicated, so operating personnel can compare current flow rates through the system with design values.

Many desiccant units are equipped with manual or automatic flow control dampers to control the airflow rate. If these are not provided with the unit, they should be installed elsewhere in the system. Airflows for process and reactivation/regeneration must be correctly set after all ductwork and external components are attached, but before the system is put into use.

Commissioning

Heat and moisture on the dry-air side of desiccant equipment is balanced equally by the heat and moisture on the regeneration/

reactivation side. To confirm that a solid-desiccant system is operating as designed, the commissioning technician must measure airflow, temperature, and moisture on each side to calculate a mass balance. In liquid systems, these six measurements are taken on the process-air side. On the regenerator side, the liquid temperature is read in the sump and at the spray head to confirm the regenerator's heat transfer rate at peak-load conditions.

If the dehumidification unit does not provide the means, the system should be designed to facilitate taking the readings that are essential to commissioning and troubleshooting. Provisions must be made to measure flow rates, temperatures, and moisture levels of airstreams as they enter and leave the desiccant. For liquid systems, provisions must be made for measuring the solution temperature and concentration at different points in the system. Four precautions for taking these readings at different points in a desiccant system follow.

Airflow. Airflow instruments measure the actual volumetric flow rate, which must be converted to standard flow rate to calculate mass flow. Because temperatures in a desiccant system are often well above or below standard temperature, these corrections are essential.

Air temperature. Most airstreams in a desiccant system have temperatures between 0 and 300°F, but temperature can be widely varied and stratified as air leaves the desiccant in solid-desiccant systems. Air temperature readings must be averaged across the duct for accurate calculations. Readings taken after a fan tend to be more uniform, but corrections must be made for heat added by the fan itself.

Process air moisture leaving dry desiccant. In solid-desiccant equipment, air leaving the desiccant bed or wheel is both warm and dry: usually below 20% rh, often below 10%, and occasionally below 2%. Most low-cost instruments have limited accuracy below 15% rh, and all but the most costly instruments have an error of ±2% rh. Consequently, to measure relative humidities near 2%, technicians use very accurate instruments such as manual dew cups or automated optical dew-point hygrometers. ASHRAE *Standard* 41.6 describes these instruments and procedures for their proper use. When circumstances do not allow the use of dew-point instruments, other methods may be necessary. For example, an air sample may need to be cooled to produce a higher, more easily measured relative humidity.

Low humidity readings can be difficult to take with wet-bulb thermometers because the wet wick dries out very quickly, sometimes before the true wet-bulb reading is reached. Also, when the wet-bulb temperature is below the freezing point of water, readings take much longer, which may allow the wick to dry out, particularly in solid-desiccant systems where there may be considerable heat in the air leaving the desiccant. Therefore, wicks must be monitored for wetness. Many technicians avoid wet-bulb readings in air leaving a solid-desiccant bed, partly for these reasons, and partly because of the difficulty and time required to obtain average readings across the whole bed.

Like air temperature, air moisture level leaving a solid-desiccant bed varies considerably; if taken close to the bed, readings must be averaged to obtain a true value for the whole air mass.

When very low dew points are expected, the commissioning technician should be especially aware of limitations of the air-sampling system and the sensor. Even the most accurate sensors require more time to come to equilibrium at low dew points than at moderate moisture levels. For example, at dew points below –20°F, the sensor and air sample tubing may take many hours rather than a few minutes to equilibrate with the air being measured. Time required to come to equilibrium also depends on how much moisture is on the sensor before it is placed into the dry airstream. For example, taking a reading in the reactivation/regeneration outlet essentially saturates the sensor, so it will take much longer than normal to equilibrate with the low relative humidity of the process leaving air.

Reactivation/regeneration air moisture leaving desiccant. Air leaving the reactivation/regeneration side of the desiccant is warm and close to saturation. If the humidity measurement sensor is at ambient temperature, moisture may condense on its surface, distorting the reading. It is good practice to warm the sensor (e.g., by taking the moisture reading in the warm, dry air of the process-leaving airstream) before reading moisture in reactivation air. If a wet-bulb instrument is used, water for the wet bulb must be at or above the dry-bulb temperature of the air, or the instrument will read lower than the true wet-bulb temperature of the air.

Owners' and Operators' Perspectives

Designers and new owners are strongly advised to consult other equipment owners and the manufacturer's service department early in design to gain the useful perspective of direct operating experience (Harriman 2003).

APPLICATIONS FOR ATMOSPHERIC-PRESSURE DEHUMIDIFICATION

Preservation of Materials in Storage

Special moisture-sensitive materials are sometimes kept in dehumidified warehouses for long-term storage. Tests by the Bureau of Supplies and Accounts of the U.S. Navy concluded that 40% rh is a safe level to control deterioration of materials. Others have indicated that 60% rh is low enough to control microbiological attack. With storage at 40% rh, no undesirable effects on metals or rubber compounds have been noted. Some organic materials such as sisal, hemp, and paper may lose flexibility and strength, but they recover these characteristics when moisture is regained.

Commercial storage relies on similar equipment for applications that include beer fermentation rooms, meat storage, and penicillin processing, as well as storage of machine tools, candy, food products, furs, furniture, seeds, paper stock, and chemicals. For recommended conditions of temperature and humidity, refer to the food refrigeration section (Chapters 17 to 29) of the 2006 *ASHRAE Handbook—Refrigeration*.

Process Dehumidification

Requirements for dehumidification in industrial processes are many and varied. Some of these processes are as follows:

- Metallurgical processes, in conjunction with controlled-atmosphere annealing of metals
- Conveying hygroscopic materials
- Film drying
- Manufacturing candy, chocolate, and chewing gum
- Manufacturing drugs and chemicals
- Manufacturing plastic materials
- Manufacturing laminated glass
- Packaging moisture-sensitive products
- Assembling motors and transformers
- Solid propellant mixing
- Manufacturing electronic components, such as transistors and microwave components

For information about the effect of low-dew-point air on drying, refer to Chapters 18, 20, 23, and 28 of the 2007 *ASHRAE Handbook—HVAC Applications*.

Ventilation Air Dehumidification

Over a full year, ventilation air loads a cooling system with much more moisture than heat. Except in desert and high-altitude regions, ventilation moisture loads in the United States exceed sensible loads by at least 3:1, and often by as much as 5:1 (Harriman et al. 1997). Consequently, desiccant systems are used to dehumidify ventilation air before it enters the main air-conditioning system.

Drying ventilation air has gained importance because building codes mandate larger amounts of ventilation air than in the past, in an effort to improve indoor air quality. Large amounts of humid ventilation air carry enough moisture to upset the operation of high-efficiency cooling equipment, which is generally designed to remove more sensible heat than moisture (Kosar et al. 1998). Removing excess moisture from the ventilation air with a ventilation dehumidification system improves both humidity control and cooling system effectiveness. For example, field tests suggest that when the environment is kept dry, occupants prefer warmer temperatures, which in turn saves cooling operational costs (Fischer and Bayer 2003). Also, cooling equipment is often oversized to remove ventilation-generated moisture. Predrying with a desiccant system may reduce the building's construction cost, if excess cooling capacity is removed from the design (Spears and Judge 1997).

Figures 15, 16, and 17 show the relative importance of moisture load from ventilation, how a commercial building can use a desiccant system to remove that load, and how such a system is applied in the field (Harriman et al. 2001).

Ventilation dehumidification is most cost-effective for buildings with high ventilation airflow rather than high sensible loads from internal heat or from heat transmitted through the building envelope. As a result, this approach is most common in densely occupied buildings such as schools, theaters, elder care facilities, large-scale retail buildings, and restaurants (Harriman 2003).

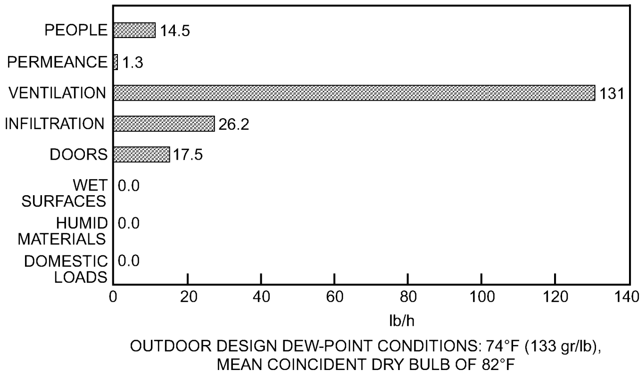
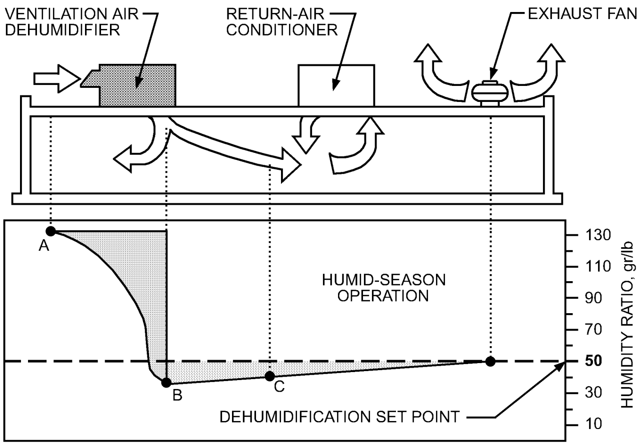


Fig. 15 Typical Peak Moisture Loads for Medium-Sized Retai Store in Atlanta, Georgia
(Harriman et al. 2001)



A. OUTSIDE AIR
Hot and humid in summertime, it must be cooled and dehumidified.
B. VENTILATION DEHUMIDIFIER
Dries incoming air to a condition below the desired humidity set point.
C. DRY VENTILATION AIR
Removes moisture loads generated inside building.

Fig. 16 Predrying Ventilation Air to Dehumidify a Commercial Building
(Harriman et al. 2001)

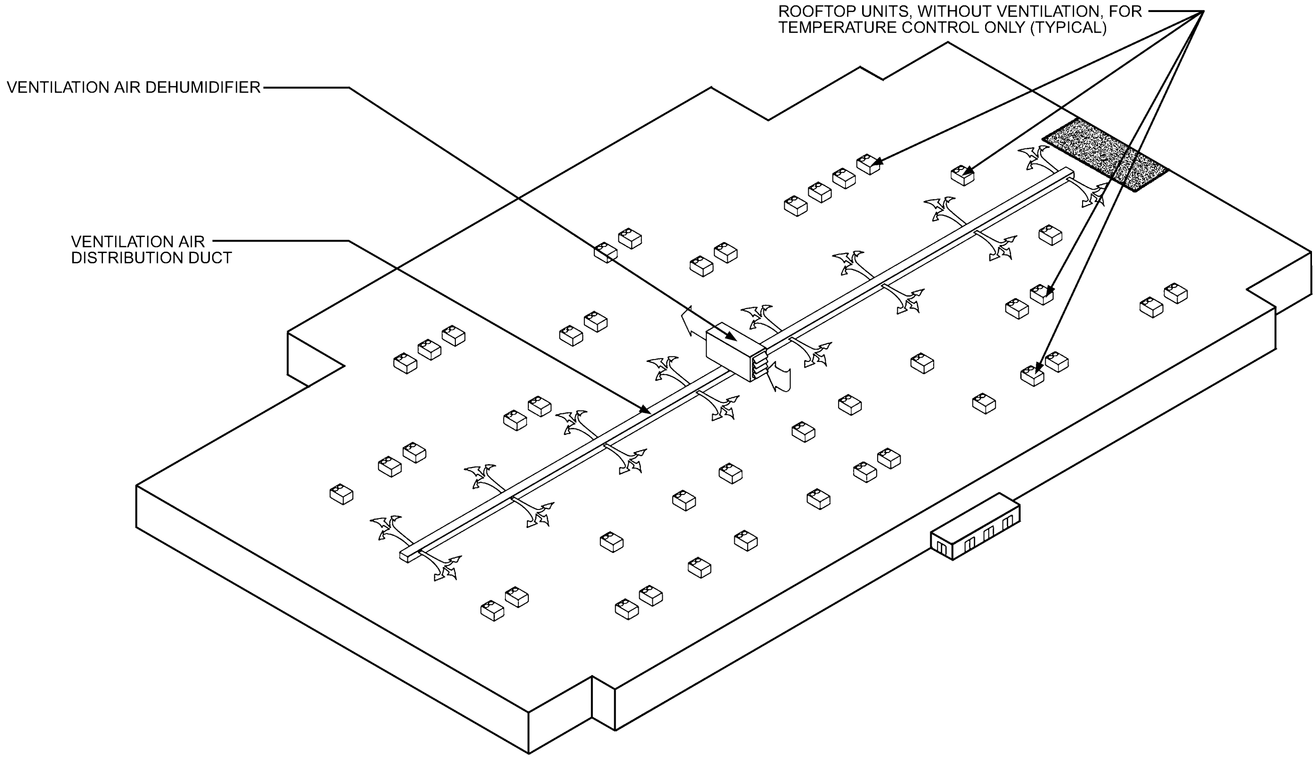


Fig. 17 Typical Rooftop Arrangement for Drying Ventilation Air Centrally, Removing Moisture Load from Cooling Units
(Harriman et al. 2001)

Condensation Prevention

Many applications require moisture control to prevent condensation. Airborne moisture condenses on cold cargo in a ship's hold when it reaches a moist climate. Moisture condenses on a ship when the moist air in its cargo hold is cooled by the hull and deck plates as the ship passes from a warm to a cold climate.

A similar problem occurs when aircraft descend from high, cold altitudes into a high dew point at ground level. Desiccant dehumidifiers are used to prevent condensation inside the airframe and avionics that leads to structural corrosion and failure of electronic components.

In pumping stations and sewage lift stations, moisture condenses on piping, especially in the spring when the weather warms and water in the pipes is still cold. Dehumidification is also used to prevent airborne moisture from dripping into oil and gasoline tanks and open fermentation tanks.

Electronic equipment is often cooled by refrigeration, and dehumidifiers are required to prevent internal condensation of moisture. Electronic and instrument compartments in missiles are purged with low-dew-point air before launching to prevent malfunctioning caused by condensation.

Waveguides and radomes are also usually dehumidified, as are telephone exchanges and relay stations. For proper operation of their components, missile and radar sites depend largely on prevention of condensation on interior surfaces.

Dry Air-Conditioning Systems

Cooling-based air-conditioning systems remove moisture from air by condensing it onto cooling coils, producing saturated air at a lower absolute moisture content. In many circumstances, however, there is a benefit to using a desiccant dehumidifier to remove the latent load from the system, avoiding problems caused by condensation, frost, and high relative humidity in air distribution systems.

For example, low-temperature product display cases in supermarkets operate less efficiently when humidity in the store is high because condensate freezes on the cooling coils, increasing operating cost. Desiccant dehumidifiers remove moisture from the air, using rejected heat from refrigeration condensers to reduce the cost of desiccant reactivation. Combining desiccants and conventional cooling can lower installation and operating costs (Calton 1985). For information on the effect of humidity on refrigerated display cases, see Chapter 46 of the 2006 *ASHRAE Handbook—Refrigeration* and Chapter 2 of the 2007 *ASHRAE Handbook—HVAC Applications*.

Air conditioning in hospitals, nursing homes, and other medical facilities is particularly sensitive to biological contamination in condensate drain pans, filters, and porous insulation inside ductwork. These systems often benefit from drying ventilation air with a desiccant dehumidifier before final cooling. Condensate does not form on cooling coils or drain pans, and filters and duct lining stay dry so that mold and mildew cannot grow inside the system. Refer to ASHRAE *Standard* 62.1 for guidance concerning maximum relative humidity in air distribution systems. Chapter 7 of the 2007 *ASHRAE Handbook—HVAC Applications* has information on ventilation of health care facilities.

Hotels and large condominium buildings historically suffer from severe mold and mildew problems caused by excessive moisture in the building structure. Desiccant dehumidifiers are sometimes used to dry ventilation air so it can act as a sponge to remove moisture from walls, ceilings, and furnishings (AHMA 1991). See Chapter 5 of the 2007 *ASHRAE Handbook—HVAC Applications* for more information on ventilating hotels and similar structures.

Like supermarkets, ice rinks have large exposed cold surfaces that condense and freeze moisture in the air, particularly during spring and summer. Desiccant dehumidifiers remove excess humidity from air above the rink surface, preventing fog and improving both the ice surface and operating economics of the refrigeration plant. For recommended temperature and humidity for ice rinks, see Chapter 35 of the 2006 *ASHRAE Handbook—Refrigeration*.

Indoor Air Quality Contaminant Control

Desiccant sorption is not restricted to water vapor. Both liquid and solid desiccants collect both water and large organic molecules at the same time (Hines et al. 1993). As a result, desiccant systems can be used to remove volatile organic compound (VOC) emissions from building air systems.

In addition to preventing growth of mold, mildew, and bacteria by keeping buildings dry, desiccant systems can supplement filters to remove bacteria from the air itself. This is particularly useful for hospitals, medical facilities, and related biomedical manufacturing facilities where airborne microorganisms can cause costly problems. The usefulness of certain liquid and solid desiccants in such systems stems from their ability to either kill microorganisms or avoid sustaining their growth (Battelle 1971; SUNY Buffalo School of Medicine 1988).

Testing

Many test procedures require dehumidification with sorption equipment. Frequently, other means of dehumidification may be used with sorbent units, but the low moisture content required can be obtained only by liquid or solid sorbents. Some typical testing applications are as follows:

- Wind tunnels
- Spectroscopy rooms
- Paper and textile testing
- Bacteriological and plant growth rooms
- Dry boxes
- Environmental rooms and chambers

DESICCANT DRYING AT ELEVATED PRESSURE

The same sorption principles that pertain to atmospheric dehumidification apply to drying high-pressure air and process or other gases. The sorbents described previously can be used with equal effectiveness.

EQUIPMENT

Absorption

Solid absorption systems use a calcium chloride desiccant, generally in a single-tower unit that requires periodic replacement of the desiccant that is dissolved by the absorbed moisture. Normally, inlet air or gas temperature does not exceed 90 to 100°F saturated. The rate of desiccant replacement is proportional to the moisture in the inlet process flow. A dew-point depression of 20 to 40°F at pressure can be obtained when the system is operated in the range of 60 to 100°F saturated entering temperature and 100 psig operating pressure. At lower pressures, the ability to remove moisture decreases in proportion to absolute pressure. Such units do not require a power source for operation because the desiccant is not regenerated. However, additional desiccant must be added to the system periodically.

Adsorption

Drying with an adsorptive desiccant such as silica gel, activated alumina, or a molecular sieve usually incorporates regeneration equipment, so the desiccant can be reactivated and reused. These desiccants can be readily reactivated by heat, purging with dry gas, or both. Depending on the desiccant selected, dew-point performance expected is in the range of –40 to –100°F measured at the operating pressure with inlet conditions of 90 to 100°F saturated and

100 psig. Figure 18 shows typical performance using activated alumina or silica gel desiccant.

Equipment design may vary considerably in detail, but most basic adsorption units use twin-tower construction for continuous operation, with an internal or external heat source, with air or process gas as the reactivation purge for liberating moisture adsorbed previously. A single adsorbent bed may be used for intermittent drying requirements. Adsorption units are generally constructed in the same manner as atmospheric-pressure units, except that the vessels are suitable for the operating pressure. Units have been operated successfully at pressures as high as 6000 psig.

Prior compression or cooling (by water, brine, or refrigeration) to below the dew point of the gas to be dried reduces the total moisture load on the sorbent, permitting the use of smaller drying units. The cost of compression, cooling, or both must be balanced against the cost of a larger adsorption unit.

The many different dryer designs can be grouped into the following basic types:

Heat-reactivated, purge dryers. Normally operating on 4 h (or longer) adsorption periods, these dryers are generally designed with heaters embedded in the desiccant. They use a small portion of dried process gas as a purge to remove the moisture liberated during reactivation heating. (See Figure 19.)

Heatless dryers. These dryers operate on a short adsorption period (usually 60 to 300 s). Depressurizing gas in the desiccant tower lowers the vapor pressure, so adsorbed moisture is liberated from the desiccant and removed by a high purge rate of the dried process gas. Using an ejector reduces the purge gas requirements.

Convection dryers. These dryers usually operate on 4 h (or longer) adsorption periods and are designed with an external heater and cooler as the reactivation system. Some designs circulate reactivation process gas through the system by a blower; others divert some or all of the process gas flow through the reactivation system before adsorption. Both heating and cooling are by convection.

Radiation dryers. Also operating on 4 h (or longer) adsorption periods, radiation dryers are designed with an external heater and blower to force heated atmospheric air through the desiccant tower for reactivation. Desiccant tower cooling is by radiation to atmosphere.

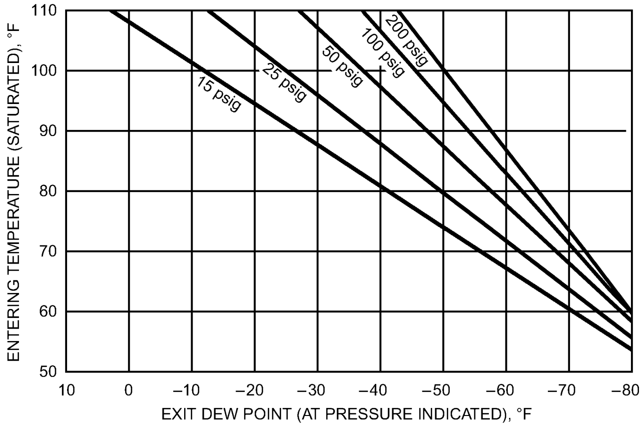


Fig. 18 Typical Performance Data for Solid Desiccant Dryers at Elevated Pressures

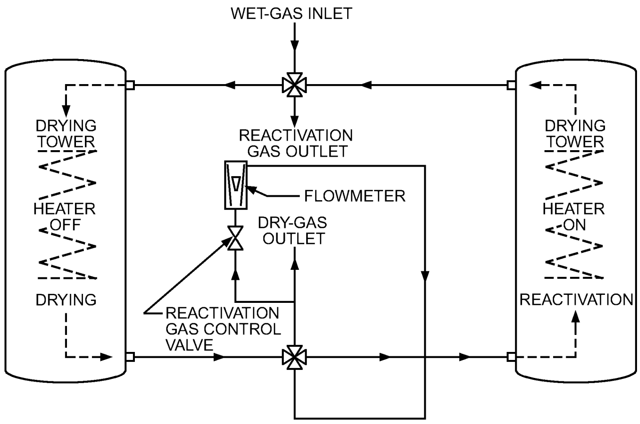


Fig. 19 Typical Adsorption Dryer for Elevated Pressures

APPLICATIONS

Material Preservation

Generally, materials in storage are preserved at atmospheric pressure, but a few materials are stored at elevated pressures, especially when the dried medium is an inert gas. These materials deteriorate when subjected to high relative humidity or oxygen content in the surrounding medium. Drying high-pressure air, subsequently reduced to 3.5 to 10 psig, has been used most effectively in pressurizing coaxial cables to eliminate electrical shorts caused by moisture infiltration. This same principle, at somewhat lower pressures, is also used in waveguides and radomes to prevent moisture film on the envelope.

Process Drying of Air and Other Gases

Drying instrument air to a dew point of –40°F, particularly where air lines are outdoors or exposed to temperatures below the dew point of air leaving the aftercooler, prevents condensation or freeze-up in instrument control lines.

To prevent condensation and freezing, it is necessary to dry plant air used for pneumatically operated valves, tools, and other equipment where piping is exposed to low ambient temperatures. Additionally, dry air prevents rusting of the air lines, which produces abrasive impurities, causing excessive wear on tools.

Industrial gases or fuels such as natural gas are dried. For example, fuels (including natural gas) are cleaned and dried before storage underground to ensure that valves and transmission lines do not freeze from condensed moisture during extraordinarily cold weather, when the gas is most needed. Propane must also be clean and dry to prevent ice accumulation. Other gases, such as bottled oxygen, nitrogen, hydrogen, and acetylene, must have a high degree of dryness. In liquid oxygen and ozone manufacturing, the air supplied to the process must be clean and dry.

Drying air or inert gas for conveying hygroscopic materials in a liquid or solid state ensures continuous, trouble-free plant operation. Normally, gases for this purpose are dried to a –40°F dew point. Purging and blanketing operations in the petrochemical industry depend on using dry inert gas for reducing problems such as explosive hazards and the reaction of chemicals with moisture or oxygen.

Equipment Testing

Dry, high-pressure air is used extensively for testing refrigeration condensing units to ensure tightness of components and to prevent moisture infiltration. Similarly, dry inert gas is used in testing copper tubing and coils to prevent corrosion or oxidation. Manufacture and assembly of solid-state circuits and other electronic components require exclusion of all moisture, and final testing in dry boxes must be carried out in moisture-free atmospheres. Simulation of dry high-altitude atmospheres for testing aircraft and missile components in wind tunnels requires extremely low dew-point conditions.

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ADDITIONAL INFORMATION

ASHRAE Technical Committee 8.12 posts updated and additional information regarding desiccant equipment and systems on the committee's subsection of the ASHRAE Web site, located at www.ashrae.org.

Related Commercial Resources