

percent relative humidity. This single curve can normally be used for temperatures ranging from 0 F to approximately 180 F. Fig. 7 contains equilibrium data for several common desiccants plotted on the relative humidity basis. Silica gel and alumina gel are so-called *high-capacity* desiccants because of their large equilibrium capacities at high relative humidities. It should be remembered, however, that the capacities given in Figs. 6 and 7 are equilibrium values and should not be used for the design of dynamic systems. Under certain operating conditions, low-capacity desiccants actually outperform high-capacity desiccants.

The process of adsorption by solid desiccants is reversible. If the vapor pressure of the adsorbed water becomes greater than the partial pressure of the vapor in the surrounding atmosphere, water will be released by the adsorbent. In most cases, this desorption is accomplished by the application of heat to drive off the adsorbate. Reactivation temperatures for common desiccants are generally within the range 200 to 500 F. Since no physical or chemical change occurs to the adsorbent in this process, it is again ready to extract water from a wet gas after the so-called *reactivation*. It is this property of reversibility which makes adsorption an economical process. Most solid adsorbents are able to operate for thousands of adsorption-reativation cycles.

It is not necessary to apply heat to reactivate solid desiccants, since these materials will come to equilibrium with the relative humidity of the gas stream with which they are in contact. The new *heatless dryers* use this system for reactivation. After the adsorbent becomes wet in the drying operation, a portion of the dried gas is expanded and used for reactivation. This expanded gas will have a very low relative humidity and moisture will be removed from the desiccant in order to approach a new equilibrium. This type of reactivation is usually restricted to units operating at pressures greater than 60 psig. A suitable vacuum can also be used to reactivate solid adsorbents.

In order to be satisfactory for commercial dehumidification purposes, an adsorbent should have the following characteristics:

1. High adsorptive capacity.
2. Chemical stability, resisting contamination from impurities.
3. Physical ruggedness to resist breakdown from handling and use.
4. Capability of reactivation at temperatures generally obtainable.
5. Heat stability at reactivation temperatures.
6. Relatively high density to avoid excessive bulk.
7. Reasonable cost.

A number of adsorbents are available for use in solid adsorption systems, including activated aluminas and bauxites, silica gels, and aluminosilicates marketed under various trade names. The reader is referred to the various manufacturers for detailed information regarding performance of the various desiccants.

SOLID ADSORPTION SYSTEMS

Dehumidification by a solid desiccant such as silica gel or activated alumina may be performed under either static or dynamic operation. In the static method, there is no forced circulation of the gas to be dried into, or through, the desiccant. Instead, the air immediately surrounding the adsorbent is initially dried and subsequently, through convection and diffusion, water vapor from spaces and objects farther away pass into the air surrounding the desiccant and then to the desiccant where it is adsorbed. Since considerable time may be required for the air and the desiccant to establish equilibrium, this type of dehumidification is best suited for small

containers. This method was used extensively by the armed services during World War II to preserve overseas shipments and domestic storage. Some foods sensitive to humidity, such as potato chips, are now packaged with a small container of solid adsorbent to retain freshness.

On the other hand, dynamic dehumidification is operated with forced passage of the air being treated through the desiccant bed. This method is used in installations such as dehumidified warehouses and ships of the "Mothball Fleet," where large volumes of air must be dried.

The only requisites for a dynamic dehumidifier are a desiccant bed, a fan to force the humid air through this bed, and a heater or other means to periodically reactivate the adsorbent. As the air passes into the activated desiccant, it surrenders a certain amount of its water vapor. The rate of moisture pickup and the humidity condition of the leaving air are functions of a great many variables, some of which will be discussed later. The ratio of the amount of water adsorbed by the desiccant in a given time to the amount of water vapor in the air entering the desiccant bed during that time is known as *adsorption efficiency*. A characteristic of adsorbents in dynamic use is that this adsorption efficiency remains constant and at a relatively high level from the beginning of an adsorption cycle until some later point in the cycle at which time the efficiency begins to drop. This point is known as the *breakpoint*, and the amount of water adsorbed on the desiccant at this point is known as the *breakpoint capacity*. In the ideal case the breakpoint capacity would coincide with the equilibrium capacity. In actual operation, however, breakpoint capacity can be a small proportion of the equilibrium capacity, depending on operating conditions. For isothermal operation with low flow rates and deep beds, breakpoint capacity will approach equilibrium capacity. High inlet temperature and humidity, small bed depths, and high flow rates will all tend to decrease the breakpoint capacity. Although additional drying can be effected beyond the breakpoint, good commercial practice requires that the desiccant be regenerated at or near this point. Adsorption carried beyond the breakpoint continues at an increasingly slower rate until the adsorbent is completely saturated. This point is known as *completion*.

When regeneration of the adsorbent is desired, the heater is energized and the direction of air flow through the bed is usually reversed. The dry-bulb temperature of the effluent air rises rapidly at first, and then virtually levels off for a period of time. This period of level or slowly increasing temperature represents the period during which the major portion of the heat input is being used to boil off the adsorbed water. This temperature pattern continues until most of the water contained in or on the desiccant is released. When the latent heat requirements begin to diminish, the heat input goes into sensible heat gain to the passing air stream. This is reflected in a rather sharp increase in the dry-bulb temperature of the effluent air. This period, measured from the beginning of desorption, has been designated *temperature-rise time*. Although additional regeneration (at a slower rate) can be attained by continuing the heat addition process beyond the temperature-rise time, once again commercial practice calls for reactivation to be ended near this point unless very dry effluent air is required in the following adsorption cycle. Regeneration past this point until the adsorbent is in moisture equilibrium with the air stream is known as *complete desorption* or *desorption to completion*. The energy expended in the heater per unit weight of water desorbed for any given time is called *economy of desorption* and usually is expressed in kilowatt hours per pound of water desorbed.

During the process of adsorption there is a liberation of heat which results in an elevation of the effluent air tempera-

Dehumidification By Sorbent Materials

ture. This heat is equivalent to the latent heat of vaporization of the adsorbed liquid plus an added quantity known as the *heat of wetting*, which is defined as the heat developed when the liquid and the solid surface contact one another. The heat of wetting is relatively large when adsorbing the first water molecules on a freshly reactivated desiccant and tapers off to a very low value as the desiccant approaches saturation. As the adsorbed vapor condenses, the latent heat is converted to sensible. All of the released heat, known cumulatively as the *heat of adsorption*, is dissipated into the desiccant, the enclosure, and the passing air stream. In comfort air conditioning it is often necessary to cool the effluent air prior to its introduction to the conditioned space, but in most other dehumidification applications this heat is not objectionable, in which case no provisions are made for its removal. An operation of this type is called *adiabatic*; meaning that the released heat is taken up for the most part by the passing air stream, that the adsorbent chamber is insulated, and that no attempt is made to cool either the adsorbent or the effluent air. Although ordinary air-conditioning dehumidification only approaches the adiabatic process, it is called *adiabatic* to differentiate it from isothermal adsorption in which the bed is cooled by cooling coils. Even then only part of the heat of adsorption can be removed. Under true adiabatic conditions at atmospheric pressure, temperature in the desiccant bed can rise as high as 245 F when drying air of high moisture content.*

As would be expected, the useful concentration of the adsorbent will be quite low for this type of operation and, consequently, the volumetric heat capacity of the adsorbent will be the controlling factor for design.

Some of the many variables that influence the results of a dynamic dehumidification operation are as follows:

- A. Variables concerning the desiccant bed:
 1. Type of desiccant.
 2. Dry weight of desiccant.
 3. Particle size.
 4. Bulk density.
 5. Shape of bed.
 6. Area of bed normal to gas flow.
 7. Depth of bed.
 8. Packing of the desiccant in the bed.
 9. Pressure drop through bed.
- B. Variables concerning the gas to be dried:
 1. Flow rate.
 2. Temperature.
 3. Moisture content.
 4. Pressure.
 5. Contact time between gas and adsorbent; a function of inlet face velocity and bed depth.
- C. Variables concerning reactivation:
 1. Reactivation temperature.
 2. Rate and magnitude of heat supply.
 3. Heat storage capacity of the bed.
 4. Temperature gradient of the bed.
 5. Amount of insulation.
 6. Amount of sweep gas.
- D. Miscellaneous:
 1. Cycle time.
 2. Leakage from the apparatus.

Solid adsorption dehumidifiers are usually of the stationary dual-bed type in which one bed is adsorbing while the other is being reactivated. Some air or gas flow should be provided during the reactivation cycle to sweep out the moisture which is released by the heat. Fig. 8 shows a schematic flow diagram for a typical dual-bed dehumidification unit using heat for reactivation. Moist air is passing through Bed A from top to bottom while Bed B is being reactivated. When the effluent air from Bed A is no longer dry, the flow to the two towers is switched so that Bed B goes on the drying cycle while Bed A is reactivated. Cycle time is normally specified for the unit

by the manufacturer and is controlled by a timer. Larger units may have adjustable time cycles that can be changed for various operating conditions. Still other units are operated from either manual or automatic readings of the effluent moisture content.

Many variations in the simple design given in Fig. 8 are available from the various manufacturers of dual-bed units. Valves may be one-way, two-way or four-way. Flow of air may be up or down in either the drying or the reactivation cycle. Beds may be vertical, horizontal or radial, the latter to give a larger cross-sectional area for large volumes of air to be dried. Reactivation can be by steam, electricity, or gas, or by the newer heatless methods previously mentioned. Some manufacturers install cooling coils in the adsorbent beds to

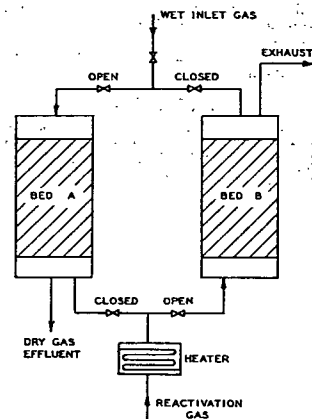


Fig. 8 Typical Dual-Bed Dehumidification Unit

remove some of the heat of adsorption while others divide the adsorbent beds and install coolers between the sections to accomplish this purpose. Beds may be relatively shallow for partial drying, or deep for complete drying.

Relatively low dew points can be obtained in a closed room with a machine having a thin desiccant bed by recirculating the room air through the machine a number of times, progressively lowering the room dew point as increasingly drier air enters the machine. The machine capacity must be greater than the internal moisture load and the infiltration of moisture from external sources. Deep desiccant beds are used when extreme dryness is required in one pass through the dehumidifier, and the air is not recirculated. Beds as deep as 15 ft have been used in some large units. Such beds can produce effluent dew points below -100 F in continuous operation. Typical performance data for dry desiccant units will be found in Chapter 85 of the 1964 Guide And Data Book.

SORPTION DEHUMIDIFIERS FOR ELEVATED PRESSURES

The same sorption principles which pertain to low-pressure (approximately atmospheric) dehumidification apply to drying of high-pressure air, process, or other gases. The