humidity ratio of the mixture of outdoor and recirculated air and the dehumidifier performance data can be used to calculate the humidity ratio of the air leaving the dehumidifier. The difference between the humidity ratio of the air in the room and that of the dehumidified air entering the room represents the effective dehumidification per pound of air. The rate of internal moisture gain in grains per minute, divided by the effective dehumidification in grains per pound of air, equals the air quantity required in pounds per minute. The following typical example using arbitrary values shows a general method of determining the dehumidifying requirements. Sensible heat determination considerations are discussed in other chapters, and are purposely omitted here.

Example 1: A sorption dehumidifier is to be used to maintain indoor conditions of 73 F and 20 percent relative humidity, i.e., 24.1 grains per pound of dry air, 30 F dew point, in a room 20 ft x 30 ft x 10 ft high, having a total wall, ceiling, and floor surface area of 2200 sq ft. Outdoor design conditions are 72 F dew point (118.4 grains per pound).

Internal sources of moisture are: 4 occupants; an open natural gas burner using 15 cu ft of natural gas per hour; an open top water tank, having an area of 2 sq ft exposed surface, in which water is maintained at 87 F, with air movement over the water surface being 100 fpm. Determine the quantity and condition of the dehumidified air to be supplied to the room.

Solution: The internal moisture gain consists of items 1 to 5.

		Grains per Minute
1. From occupants:	$4 \times 1800/60 =$	120
1800 grains per person per hour is obtained from Fig. 7 of Chapter 10 of the 1961 GUIDE AND DATA Book, by interpolation between curves *C* and *D*.		
2. From burned gas:	$15 \times 650/60 =$	162
1 cu ft natural gas produces approximately 650 grains of moisture.		
3. From exposed water surface:	$2 \times 20 =$	40
Evaporation from water surface is assumed to be 20 grains per (minute) (square foot) at 87 F water with air movement of 100 fpm.		
4. From infiltration:	$\frac{6000}{60 \times 13.56} \times (118.4 - 24.1) =$	696
One air change, 6000 cu ft, assumed per hour (see Chapter 24 of the 1961 GUIDE AND DATA BOOK).		
5. Moisture transmitted through room surface:	$\frac{2200}{60} \times 3 \times (0.783 - 0.176) =$	67
Permeability assumed to be 3 grains per (square foot) (hour) (inch Hg vapor-pressure difference on two sides of wall).		
Total moisture gain from internal sources		1085

Let q be the air delivered to the room, pounds per minute. Let it be assumed for this problem that 85 percent of the air is recirculated and 15 percent is outdoor air. Enough air must be supplied to replace leakage from the system or to satisfy normal ventilating requirements for the occupants of the room as given in Chapter 10 of the 1961 GUIDE AND DATA BOOK, whichever is greater. The amount is estimated from experience or obtained by test.

The humidity ratio of the mixture of recirculated and outdoor air entering the dehumidifier is then:

$$\frac{0.85q(24.1) + 0.15q(118.4)}{0.85q + 0.15q} = 38.3 \text{ grains per pound entering dehumidifier.}$$

From the manufacturer's performance data for the dehumidifier to be used it is determined that with 38.3 grains per pound of entering air the leaving condition is 6.5 grains per pound.

Effective dehumidification in the room is 24.1 − 6.5 or 17.6 grains per pound of supply air.

$$\text{Then } q = \frac{1085 \text{ grains per minute}}{17.6 \text{ grains per pound}} = 61.6 \text{ lb air per minute}$$

minimum that must be supplied to the room to maintain 30 F dew point.

Note that this value represents the minimum requirement for the arbitrary conditions set forth and that in practice, safety margins should be added to the outdoor air percentage value and to the calculated internal moisture gain.

APPLICATIONS FOR ATMOSPHERIC PRESSURE DRYING

Preservation of Materials in Storage

The annual cost of corrosion damage in the United States has been estimated to be between $5 and 6 billion, while that for all forms of deterioration excluding foods amounts to upwards of $12 billion annually. A significant amount of this loss could be saved by moisture control with sorption dehumidifiers. The Armed Forces utilize to some extent dehumidified warehouses for special moisture-sensitive materials in long term storage. The success of the U. S. Navy *Operation Mothball* in preservation of the inactive fleet is well known. Tests by the Bureau of Supplies and Accounts of the Navy Department concluded that 40 percent relative humidity would be an adequately safe level in large warehouses under relatively stable temperature conditions. These relative humidity maximums are selected to control deterioration of materials. Others have indicated that 60 percent rh is low enough to control microbiological attack. With storage below 30 to 40 percent relative humidity, no undesirable effects on metals or rubber type compounds have been noted.

Some organic materials such as sisal, hemp, and paper may lose flexibility and strength, but regain these characteristics with the regain of moisture content.

Preservation of materials by dehumidification is effectively accomplished on shipboard, warehouses and caves by the use of sorption equipment. Commercial storage operations also rely on similar equipment for applications which include beer fermentation rooms, meat storage and penicillin processing, as well as storage of machine tools, candy, food products, furs, furniture, seed, paper stock, and chemicals.

Reference should be made to Chapters 23, 46, and 50 for recommended conditions of temperature and humidity for storage of various materials.

Process Dehumidification

The requirements for dehumidification in industrial processes are many and varied. Some of these processes are:

1. Metallurgical processes, in conjunction with the controlled atmosphere annealing of metals.
2. Conveying of hygroscopic materials.
3. Film drying (see Chapter 30).
4. Candy, chocolate, and chewing gum manufacturing (see Chapter 33).
5. Manufacturing of drugs and chemicals.
6. Manufacture of plastic materials.
7. Manufacture of laminated glass.
8. Packaging of moisture-sensitive products.
9. Assembly of motors and transformers.
10. Solid propellent mixing rooms.
11. Manufacturing of electronic components such as transistors and micro-wave components.

In the heat treating operation for annealing of wire and strip in steel mill operations, low moisture content of the nitrogen and hydrogen gases in the range of −40 to −100 F is required. The presence of moisture would result in discoloration and possible surface corrosion.

In the powder granulation of vitamin concentrates, a minute

quantity of moisture *will prevent proper compression* to tablet form. Dryer temperatures over 145 F cannot be utilized as they destroy the enzymes of the product. The problem is further aggravated by the fact that at 100 F, the dryer temperature determined as best suited to and safest for the product, sufficient moisture is not removed on humid summer days. Complete shutdown on these days may frequently result. Application of a sorbent dehumidifier to automatically and continuously extract all excess moisture will provide steady, year-round production at operating speeds and temperatures. In the production of certain vitamin concentrates, extracts from fruits and vegetables are dried and blended while in powder form. The blend is compressed into tablets and packaged for shipment. Drying is accomplished with a batch-type tunnel dryer. The blended powder granulations, in trays, are placed on racks in the dryer, and hot dry air at approximately 100 F is circulated throughout. Excess moisture must be extracted from the powders to assure satisfactory compression in the tabletting machines. The moisture content of the powders before drying is 30 percent, while after drying, it is only 5 to 6 percent. One complete cycle of operation takes approximately 24 hr. Without chemical dehumidification, it might take 48 hr, even under favorable conditions.

Satisfactory yeast drying requires the slow, even removal of moisture at pre-determined rates. Otherwise the delicate outer shells of these living organisms might be ruptured, destroying their use. Economic operation of the dryer itself necessitates a constant substantial production rate. For these reasons, sorption dehumidifiers will assure product quality and production rates and permit year round satisfactory operation. Yeast, in order to grow, must have energy and nitrogen sources. The propagation of yeast begins in the laboratory with the isolation and controlled growth from a single pure yeast culture. After growth through planned fermentation, the yeast is mechanically separated and is used for additional laboratory fermentation or for seeding the final trade fermenters. After fermentation, the batch is put into centrifugal separators which concentrate the yeast to a cream of about 16 percent solids. For active dry yeast production, this cream is next filtered. The resulting compressed yeast is then dried, ground, vacuum packaged, and placed in refrigerated storage until shipment.

Water vapor trapped in *sealed refrigeration systems* can cause erratic operation of the refrigerator due to the freezing of the moisture at the place of refrigerant expansion. It also speeds chemical reactions leading to the breakdown of the refrigerant and the oil. Prevention of this water vapor entrapment begins with the basic equipment manufacturer. The oil and refrigerant must be dry so that moisture will not be added when the unit is charged. The parts which make up a refrigeration system must be dry when they are assembled. These parts must then be quickly sealed to prevent the reintroduction of moisture. For further information, see Chapter 59 of the 1961 GUIDE AND DATA BOOK.

Condensation Prevention

Many applications require moisture control to prevent condensation. Cold cargo in a *ship's hold* will cause cargo sweat when the ship reaches moist climates and ship sweat will occur when the moist atmosphere in a cargo hold is cooled by the hull and deck plates, when the ship goes from a warm to a cold climate.

In *pumping stations* and *sewage lift stations*, the piping will cause condensation especially in the spring when the weather warms and water in the pipes is still cold.

Dehumidification is also used to prevent moisture from the air *to drip into oil and gasoline tanks* and into open beer 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 prior to launching to prevent malfunctioning due to condensation.

Wave guides and radomes are also usually dehumidified, as are also telephone exchanges and relay stations.

The *D.E.W. Line installations* with regard to our national security, depend to a large extent for the proper operation of their components on the prevention of condensate on interior surfaces.

Independent Humidity Control in Air-Conditioned Spaces

Comfort air conditioning generally requires the maintenance of summer temperatures between 75 and 80 F and relative humidities of 45 to 55 percent. While these can normally be obtained most economically with refrigeration systems, there are numerous cases in which the latent heat load is larger than the cooling load where the use of sorption systems in conjunction with refrigeration will give the optimum results. Examples of this are assembly halls, restaurants, night clubs, fallout shelters, and other places of assembly where the internal latent heat load is high. There are also large buildings and hotels located in high humidity areas which depend on dehumidification systems for proper comfort air conditioning.

In general, installations involving the use of panel cooling require the circulation of a relatively highly dehumidified air for the maintenance of ventilation requirements and the prevention of condensation on the panel surfaces (see Chapter 3). There also may be some need for dehumidification in areas that are heated by panel surfaces where insulation is good and water load is high. An example of this might be laundry and cooking areas in the home.

There are sometimes instances where a given space must be held at a lower humidity than is available from an existing air-conditioning system. An example would be a special treatment room for some very hygroscopic material. A dehumidifier, independent from the main air-conditioning system, would be used to handle this load.

Testing

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

1. Wind tunnels.
2. Spectroscopy rooms.
3. Paper and textile testing (see Chapters 25 and 26).
4. Bacteriological and plant growth rooms.
5. Dry boxes.
6. Environmental rooms and chambers (see Chapter 61).

Many of the aerodynamic tests carried out in *wind tunnels* are possible only because high altitude moisture conditions are readily simulated by the use of sorbent dryers. Fogging conditions which would otherwise occur would interfere with observations and photography of the test sections being analyzed. The sorbent dehumidifiers for supersonic and sonic wind tunnels are some of the largest in existence. At one wind tunnel installation, over 2,000,000 cfm of air is dried to a dew point of less than −40 F by using more than 2,000,000 lb of solid desiccant. In spectroscopy rooms, the control of