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# **Testing of Novel Desiccant Materials and Dehumidifier Matrices for Desiccant Cooling Applications**

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## Testing of Novel Desiccant Materials and Dehumidifier Matrices for Desiccant Cooling Applications

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### ABSTRACT

This paper presents the results of testing of desiccant materials and dehumidifier matrices for desiccant cooling and dehumidification applications. In testing desiccant materials, we used a gravimetric technique to measure the moisture capacity of four desiccant materials. These materials were microporous silica gel powder, macroporous silica gel powder, polystyrene sulfonic acid sodium salt, and a silica-gel/epoxy composite. The microporous silica gel powder had the most desirable moisture capacity properties of the four materials tested for desiccant cooling applications. The polystyrene sulfonic acid sodium salt showed some promise. Our testing of dehumidifier matrices included measuring the pressure drop and heat- and mass-transfer rate characteristics of a silica-gel/corrugated dehumidifier matrix under conditions typical of desiccant cooling systems. The matrix is a section of a commercial dehumidifier. The transient dehumidification capacity of the matrix was calculated from the tests and compared with previously tested matrices.

### INTRODUCTION

Solid desiccant cooling and dehumidification systems have received considerable attention in the past several years as alternatives or supplements to conventional vapor compression machines for air conditioning of buildings and spaces that have high latent loads. A desiccant cooling system involves passing humid (and warm) air through a desiccant dehumidifier for drying and through a cooler for sensible cooling to provide conditioned air. The desiccant becomes saturated with water and needs to be regenerated with hot air provided by an energy source (e.g., sun, natural gas, waste heat, or electricity).

The cost, efficiency, and durability of a desiccant cooling/dehumidification system depend on those of the components used in the system. The desiccant dehumidifier is a major component in the system. After several years of research, it is well understood that the performance of a desiccant dehumidifier depends strongly on the properties of its desiccant and the geometry of the matrix (Collier 1989). Usually, microporous silica gel has been used as the research baseline desiccant for solar-regenerated desiccant cooling applications (Penney and Maclaine-cross 1985). Lithium chloride impregnated wheels, commercially available dehumidifiers, have been used in desiccant cooling systems (Cargocaire 1986). Advanced dehumidifiers for desiccant cooling applications should have parallel passage geometries, such as parallel plate or corrugated (sine-passage), to be compact and efficient with low pressure drops (Penney and Maclaine-cross 1985).

In the past several years we have experimentally quantified the performance of several desiccant materials and dehumidifier matrices for cooling applications (e.g., Pesaran 1987; Pesaran et al. 1988). The matrices tested were microporous silica gel/parallel passage, microbead silica gel/parallel passage, microbead silica

gel/staggered parallel strip, and lithium chloride/corrugated (sine-passage). Recently we tested a silica gel/corrugated matrix and compared the results with previously tested matrices. In all these matrices, which can be a section of a dehumidifier, the desiccant material is coated or impregnated on the walls of the matrix. The matrix walls form parallel air passages for low pressure drop flow. The first three dehumidifier matrices are research prototypes; the corrugated matrices are sections of commercially available dehumidifiers.

The purpose of our effort is to improve state-of-the-art dehumidifier performance, while collaborating with industry on cost and reliability issues so that a (solar) cooling system becomes a viable, cost-effective alternative. This paper describes the basic measurements needed for characterization of materials and matrices for desiccant cooling/dehumidification applications. We briefly describe desiccant materials and the dehumidifier matrix tested, experimental methods, experimental results, and future thrusts.

## DESICCANT MATERIAL TESTING AND RESULTS

### Test Apparatus

The sorption test apparatus (Figure 1) has been used to test the sorption performance (moisture capacity and mass-transfer rate) of desiccant materials under isothermal conditions (Pesaran et al. 1988). Test cells containing desiccant materials are exposed to an adsorption or desorption air flow to simulate near-actual operating conditions. Bone-dry air enters a mass flow meter and then flows through a humidifier to obtain the desired level of humidity. The conditioned air then passes through a test cell, which is immersed in a constant-temperature water bath. The dry weight of the desiccant in the test cell is known. The inlet and the outlet air to and from the desiccant are monitored with two dew-point hygrometers. When the air and desiccant reach equilibrium with each other, the test cell is removed and weighed to determine any weight changes due to moisture desorption or adsorption. This gives the sorption capacity of the desiccant at a desired humidity. The mass-transfer rate data are obtained by recording the outlet air humidity from the desiccant as a function of time.

### Results and Discussion

Four desiccant materials were tested: a silica-gel/epoxy composite, microporous silica gel powder, macroporous silica gel powder, and a polymer: polystyrene sulfonic acid sodium salt. The last three were in powder form with particle sizes ranging from 0.00008 to 0.0008 in (2 to 20  $\mu\text{m}$ ). To contain these powders in a test cell with air flowing through it, we fabricated a special test cell that had 0.00002 to 0.00028 in (0.5 to 7  $\mu\text{m}$ ) sintered filter plugs on both ends. A photograph of the cell is shown in Figure 2.

The silica-gel/epoxy composite was prepared by mixing microporous silica gel particles in epoxy. The idea was to fabricate a composite made from a suitable desiccant and a bonding material that can be easily and cost-effectively manufactured (perhaps ultimately injection molded) into a high-performance dehumidifier geometry. The sample was fabricated by an aircraft blade manufacturer in solid form. We were able to machine a piece of it into thickness of 0.04 in (1 mm) with length of 4.0 in (100 mm) and width of 0.8 in (20 mm), the required size for our test cell.

This thin sheet was placed into our parallel passage test cell. The isotherm of the sample was obtained at 86 F (30°C) and is shown in Figure 3. The isotherm of virgin silica gel (grade 40) is also shown in this figure for comparison. As one can see, the

composite has only 30% moisture capacity of the baseline virgin silica gel. We also found that the rate of diffusion (adsorption) into the composite was two to three times lower than for silica gel. Therefore, this composite did not pass the performance screening criteria previously identified (Czanderna and Thomas 1987; Collier et al. 1986; Jurinak 1982) for advanced desiccants. From the outset, we were a bit apprehensive about using an epoxy, but the low-cost, moldable concept using an easily adapted commercial process seemed to be a worthwhile long shot. Other methods to embed silica gel or other desiccants should be pursued using similar techniques.

It should be noted that performance screening criteria for a good desiccant for cooling applications are:

1. An isotherm shape similar to type 1 moderate (Collier et al. 1986). See Figure 4 for the typical shape of such an isotherm. The shape of the isotherm affects adsorption and desorption wave fronts in a dehumidifier and thus dehumidifier and desiccant cooling system performance.
2. Rapid adsorption and desorption rates, as fast as in silica gel. Thus moisture diffusivity in silica gel is a base line.
3. Low heat capacity, similar to silica gel.
4. Low heat of adsorption--at most 30% higher than its latent heat of condensation.
5. Low thermal conductivity.
6. Capacity change of at least 10% by weight between 5% and 60% relative humidity. Note that the large capacities are not nearly as important as one might think.

The microporous silica gel powder is a silica gel with average pore size of 22 Å, similar to regular density silica gel we have identified as the research baseline for advanced desiccant dehumidifiers for cooling applications. We feel that the powder silica gel can be embedded into a substrate (e.g., a plastic film) and then formed into a cost-effective dehumidifier. The results of the sorption testing of this powder at 86 F (30°C) are also shown in Figure 3. The isotherm of microporous silica gel powder is very similar to grade 40, as expected. The microporous silica gel powder is suitable for dehumidifiers for cooling applications. Its advantage over, for example, grade 40 is its form, which can be used in thin substrate films in conjunction with proven fabrication methods of low-cost, high-performance dehumidifiers.

The macroporous silica gel powder is a silica gel with average pore size of 70 Å. The isotherm of this material at 86 F (30°C) obtained at the sorption test apparatus is shown in Figure 3. Macroporous silica gel powder has less than 10% moisture adsorption capacity below 70% relative humidity. The operating range of a desiccant cooling system is usually less than 70% RH. The macroporous silica gel powder is not suitable for desiccant cooling systems, but it can be used for unique very high humidity applications because of its high moisture capacity at high humidities.

Polystyrene sulfonic acid sodium salt is a polymer that was identified as one of the leading candidate desiccant polymers for desiccant cooling applications because of its favorable sorption performance behavior (Czanderna and Thomas 1987). This finding was based on testing of a 10- $\mu$ m-thick lab-prepared film of this polymer in a quartz-crystal microbalance. Scale-up to larger samples under flowthrough conditions was needed to further evaluate its potential. We tested the material in powder form with larger

particles and larger weight. The results of testing of the commercial grade of this polymer in powder form are shown in Figure 3. The sorption capacity of polystyrene sulfonic acid sodium salt is 10%-30% lower than the sorption capacity of microporous silica gel in the mid range of humidity (10%-70%). Since we expect that the manufacturing technique of grafting a polymerized desiccant to a structural polymer into an acceptable dehumidifier is more cost-effective and perhaps more reliable than manufacturing of silica gel particles into a dehumidifier, this lower capacity may not be important. To fully evaluate the potential application of this material for our applications, the next step is to work with an industrial partner to evaluate cost to manufacture versus performance trade-offs for the polymer and silica gel. Our advanced desiccant material research team is chemically modifying this and other polymers to improve their sorption performance properties (Czanderna 1988).

## DEHUMIDIFIER MATRIX TESTING AND RESULTS

### Test Apparatus

The desiccant heat- and mass-transfer test apparatus (Figure 5) has been used to test different prototype dehumidifier matrices (Pesaran 1987). A matrix contains a desiccant material, with or without a substrate, formed into a particular geometry. In this apparatus, the pressure drop, heat- and mass-transfer rate data, and dehumidification capacity of a promising dehumidifier matrix are obtained under adiabatic conditions. The apparatus consists of an air heater, a steam injector, a variable speed fan, a test section, and instrumentation to control and measure air flow rate, air temperatures, pressure drops, and dew-point temperatures.

The experimental procedure consists of obtaining adiabatic step transient response and pressure-drop characteristics of the dehumidifier test matrix. Each step transient test basically consists of three parts: matrix conditioning, process air preparation, and transient response. After the matrix is installed in the test section, it is insulated to simulate adiabatic conditions. The dehumidifier matrix is conditioned to a desired uniform state (temperature and desiccant water content) by passing conditioned air through the matrix. Then the air is bypassed, and the matrix is sealed by closing the butterfly valves on both sides. The process airstream is brought up to a new state (temperature and/or humidity) while passing through the bypass. Finally, when the process airstream reaches the desired humidity, temperature, and flow rate, it is abruptly introduced to the matrix, and the transient response of the matrix is obtained by recording the outlet air temperature and dew-point temperature (humidity) as a function of time. The pressure drop across the test matrix as a function of mass flow rate is measured when equilibrium is reached.

The dehumidifier matrix recently tested was provided by a dehumidifier wheel manufacturer. The matrix contains silica gel reinforced with many inorganic fibers and is formed in the corrugated (sine-passage) shape. A prototypical section of the dehumidifier was cut to fit snugly into the heat- and mass-transfer test apparatus test section. Figure 6 shows a photograph of this matrix. Table 1 summarizes the physical dimensions of the test article.

### Results and Discussion

The pressure drop across the test matrix was measured as a function of flow rate when the matrix was in (temperature and humidity) equilibrium with the air stream. The results of these tests are presented in Figure 7. The pressure drop increases linearly with increase of flow rate, an indication that the flow is laminar in the passages. The

experimental results were compared with predictions of the fully developed laminar flow theory, and it was found that the measured hydraulic diameter agrees quite well with the experimentally obtained hydraulic diameter. The pressure drop of a different sine-passage matrix, containing lithium chloride, from a different manufacturer, tested last year (Pesaran et al. 1988) is also presented in Figure 7 for comparison. The pressure drops are similar because the hydraulic diameters of both matrices are close to each other (0.059 in [1.5 mm] for the silica gel matrix versus 0.063 in [1.6 mm] for the lithium chloride matrix). Note that the pressure drop is an indication of how much fan energy is required to pass a certain air flow rate across a matrix.

A series of adiabatic step transient tests (adsorption and desorption) was performed on the matrix. Breakthrough data, i.e., the outlet air temperature and humidity from the test matrix as a function of time, were obtained until equilibrium is reached. Table 2 summarizes the nominal initial and inlet conditions of the matrix. Figures 8 and 9 are typical results of these tests.

We have obtained the amount of moisture that can be adsorbed (or desorbed) as a function of time by integrating from the breakthrough data the mass flow rate times the absolute humidity. This integration, when compared to the initial conditions, results in the total mass of moisture adsorbed or desorbed in the matrix as a function of time. Figure 10 shows the amount of moisture adsorbed (Figure 10a) or desorbed (Figure 10b) by the matrix during adsorption and desorption tests corresponding to the ones shown in Figures 8 and 9. Figure 10a compares the transient dehumidification (or regeneration in the case of Figure 10b) capacity of this matrix (A) with those of three other test matrices (B, C, and D) normalized on a per unit matrix volume (pounds [kilograms]) of water exchanged per cubic foot [cubic metre] of matrix. The conditions of tests for the four matrices were similar: a mass flow rate of 0.051 lb/s (0.023 kg/s) for matrices A, B, and C and 0.040 lb/s (0.018 kg/s) for matrix D; adsorption temperature of 86 F (30°C); regeneration temperatures of 158 -176 F (70°-80°C); and an absolute humidity of 0.015 lb/lb (g/g).

Here, we have not presented the details of the matrices of B, C, and D, such as type of desiccant used, configuration, hydraulic diameter, desiccant mass, volume, etc. Some of the results and specifications are of a proprietary nature and cannot be revealed at this time. Our intent in this paper is to present how desiccant materials and matrices can be tested and how they can be compared against each other.

Figure 9 shows that in the first 4 min of each test, the sorption capacity of the silica-gel/sine-passage matrix (A) is very similar to that of matrix B. At longer times, the sorption capacity of matrix B is higher than that of this silica-gel matrix (A). From this observation one can conclude that with an adsorption-regeneration cycle time below 4 min the dehumidification capacity of the two matrices is about the same. The adsorption-desorption cycle time corresponds to the rotational speed of a dehumidifier wheel. It appears that the two dehumidifiers have similar dehumidification capacity at high rotational speeds. Matrices A and B have higher dehumidification capacities than matrices C and D.

Further analyses of the tests along with system simulation models should be performed to verify these observations. The issue of reliability and wheel maintenance for either configuration needs to be systematically evaluated from field installations by owners. Using these matrix test data, in conjunction with mathematical dehumidifier models, performance of dehumidifiers containing these materials under various operating conditions could be determined.

## CONCLUSIONS

The sorption capacity of four desiccant materials was obtained in a sorption test apparatus. We believe that the microporous silica gel powder should be considered for further studies for dehumidification applications and, in particular, new manufacturing methods. Commercial grade of a polymer, polystyrene sulfonic acid sodium salt, also showed promise. The pressure drop and heat- and mass-transfer rate data of a silica-gel/corrugated test dehumidifier matrix were obtained in a heat- and mass-transfer test apparatus. Preliminary comparisons of its transient dehumidification capacity with matrices previously tested showed that the matrix is comparable with other matrices at short times corresponding to high adsorption-regeneration cycle times. Further analyses of the test data and system simulation using the experimental data are needed to verify this observation. It seems that significant cost breakthroughs can occur utilizing new manufacturing techniques. The key is to have high mass-transfer performance with little maintenance in a properly designed system. We expect that these breakthroughs are just around the corner.

## REFERENCES

- Cargocaire Engineering Company. 1986. Superaire cuts supermarket cost by cutting frost. Leaflet. Amesbury, MA: Cargocaire.
- Collier, R.K. 1989. "Desiccant properties and their effect on cooling system performance." ASHRAE Transactions, Vol. 95, Part 1.
- Collier, R.K.; Cale, T.C.; and Lavan, Z. 1986. Advanced desiccant materials assessment. FRI-8610181. Chicago, IL: Gas Research Institute.
- Czanderna, A.W. 1988. Polymers as advanced materials for desiccant applications. SERI/PR-255-3308. Golden, CO: Solar Energy Research Institute.
- Czanderna, A.W.; and Thomas, T.M. 1987. Advanced desiccant materials research. SERI/PR-255-3102. Golden, CO: Solar Energy Research Institute. Also "A quartz-crystal microbalance apparatus for water sorption by polymers." Journal of Vacuum Science Technology, Vol. A5, No. 4, pp. 2412-2416.
- Jurinak, J. 1982. Open-cycle solid desiccant cooling—component models and system simulations. Ph.D. thesis. Madison: University of Wisconsin.
- Penney, T.R.; and Maclaine-cross, I.L. 1985. "Promising advances in desiccant cooling." Presented at DOE Solar Buildings Conference, Washington, DC, 18-20 March, 1985. Also SERI/TP-252-2683. Golden, CO: Solar Energy Research Institute.
- Pesaran, A.A. 1987. "Adiabatic air dehumidification in laminar flow desiccant matrices." Presented at ASME Winter Annual Meeting, Boston, MA.
- Pesaran, A.A.; Parsons, B.K.; and Parsons, J.M. 1988. Experimental and analytical studies of parallel-passage desiccant dehumidifiers. SERI/TR-254-3286. Golden, CO: Solar Energy Research Institute.



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TABLE 1

## Physical Characteristics of the Silica-gel/Corrugated Test Matrix

|  |                       |                         |
|--|-----------------------|-------------------------|
| <u>Overall dimensions</u>                |                       |                         |
| Height                                   | 6.25 in               | (0.159 m)               |
| Width                                    | 6.50 in               | (0.165 m)               |
| Length                                   | 7.88 in               | (0.200 m)               |
| Frontal area                             | 40.63 in <sup>2</sup> | (0.026 m <sup>2</sup> ) |
| <u>Single passage dimensions (means)</u> |                       |                         |
| Height, divider to divider               | 0.0647 in             | (1.64 mm)               |
| Width, maximum channel                   | 0.0817 in             | (2.08 mm)               |
| Height, passage gap                      | 0.0587 in             | (1.64 mm)               |
| Divider wall thickness                   | 0.0085 in             | (0.22 mm)               |
| Channel wall thickness                   | 0.0079 in             | (0.22 mm)               |
| Mass                                     | 2.818 lb              | (1.278 kg)              |
| Active desiccant fraction                | 0.75                  |                         |

TABLE 2

## Summary of Conditions of Transient Heat- and Mass-Transfer Tests of the Silica-gel/Corrugated Test Matrix

| Test Number | Initial Air Temperature (°C) | Initial Air Humidity (g/kg) | Inlet Air Temperature (°C) | Inlet Air Humidity (g/kg) | Inlet Air Flow Rate (g/s) |
|-------------|------------------------------|-----------------------------|----------------------------|---------------------------|---------------------------|
| 69-Adsorb   | 79.6                         | 15.1                        | 31.0                       | 15.1                      | 23.2                      |
| 70-Desorb   | 30.1                         | 14.9                        | 69.9                       | 15.1                      | 23.2                      |
| 71-Adsorb   | 79.8                         | 15.0                        | 30.4                       | 15.0                      | 30.5                      |
| 72-Desorb   | 29.8                         | 14.9                        | 73.1                       | 15.0                      | 30.1                      |
| 73-Adsorb   | 80.0                         | 12.2                        | 32.0                       | 12.1                      | 22.9                      |
| 74-Desorb   | 30.1                         | 12.0                        | 73.3                       | 11.9                      | 23.2                      |
| 75-Adsorb   | 79.7                         | 15.0                        | 31.7                       | 15.0                      | 15.0                      |
| 76-Desorb   | 30.0                         | 15.1                        | 68.6                       | 15.0                      | 15.6                      |
| 77-Adsorb   | 79.9                         | 12.0                        | 32.8                       | 12.0                      | 15.2                      |
| 78-Desorb   | 29.9                         | 12.1                        | 66.9                       | 11.9                      | 15.5                      |
| 79-Adsorb   | 80.0                         | 12.0                        | 32.2                       | 12.0                      | 30.1                      |
| 80-Desorb   | 29.9                         | 11.8                        | 70.5                       | 12.0                      | 30.3                      |
| 82-Adsorb   | 79.8                         | 15.4                        | 30.5                       | 15.6                      | 30.2                      |
| 83-Desorb   | 29.9                         | 15.0                        | 71.1                       | 15.1                      | 30.3                      |
| 84-Adsorb   | 79.9                         | 11.8                        | 30.5                       | 12.0                      | 15.0                      |
| 85-Desorb   | 29.9                         | 11.9                        | 70.7                       | 12.1                      | 15.2                      |
| 86-Adsorb   | 94.8                         | 15.1                        | 31.2                       | 15.0                      | 23.3                      |
| 87-Desorb   | 29.8                         | 14.9                        | 88.1                       | 15.1                      | 22.9                      |
| 88-Adsorb   | 96.4                         | 15.3                        | 33.2                       | 15.1                      | 30.1                      |
| 89-Desorb   | 29.8                         | 14.8                        | 86.6                       | 14.9                      | 30.0                      |

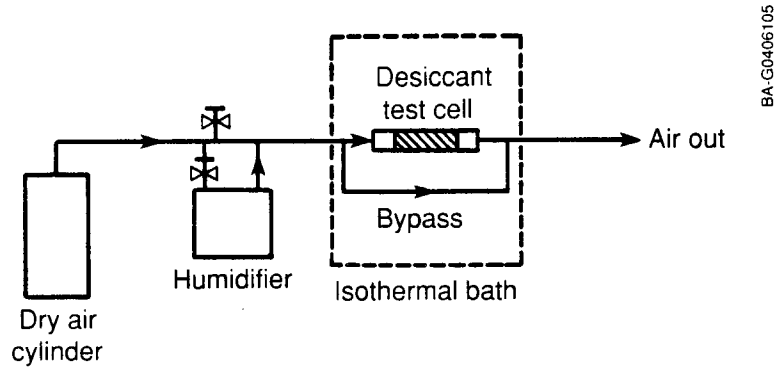


Figure 1. Schematic of sorption test apparatus

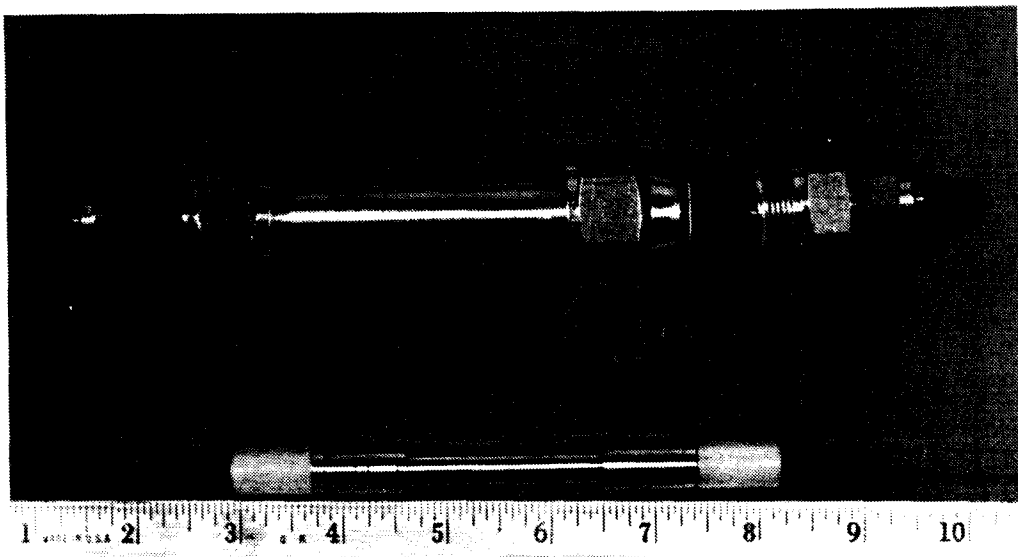


Figure 2. Photograph of packed bed test cell for testing powders

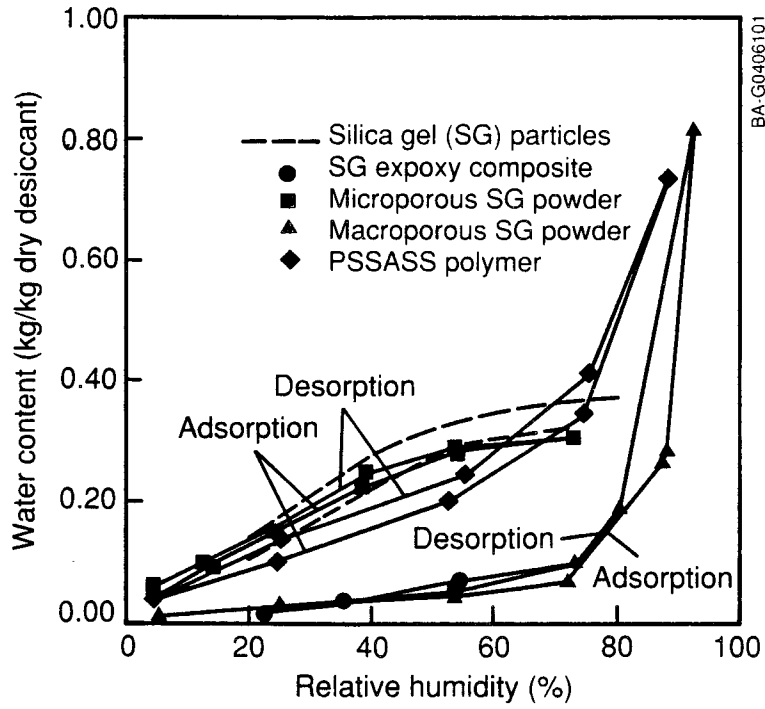


Figure 3. Adsorption isotherms of desiccant materials at 30°C

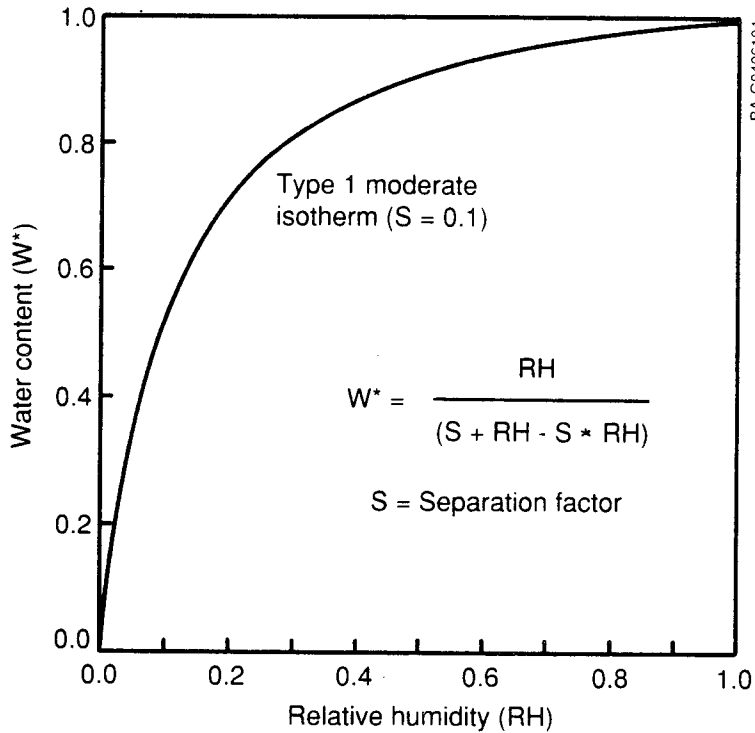


Figure 4. Adsorption isotherm shape of an "optimal" desiccant defined by Collier et al. (1986) (for a desiccant cooling system ventilation cycle using staged regeneration and 160°C regeneration temperature)

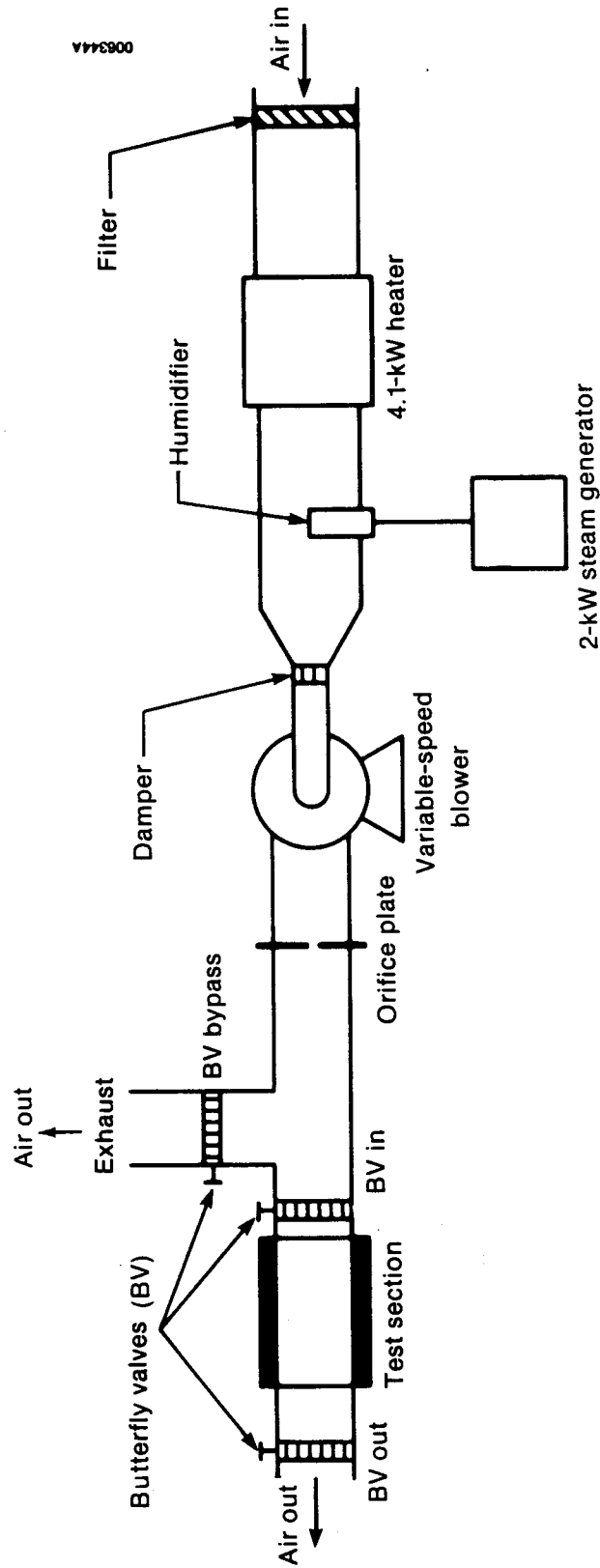


Figure 5. Schematic of the heat and mass transfer test apparatus

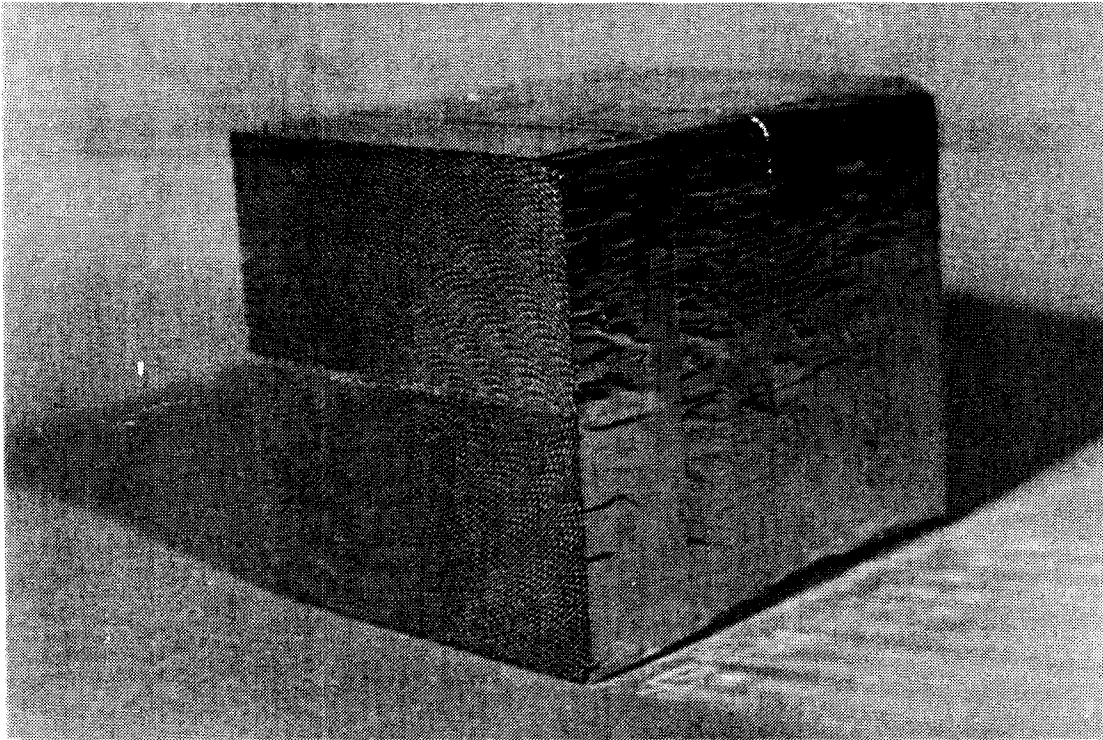


Figure 6a. Photograph of silica gel/corrugated test matrix

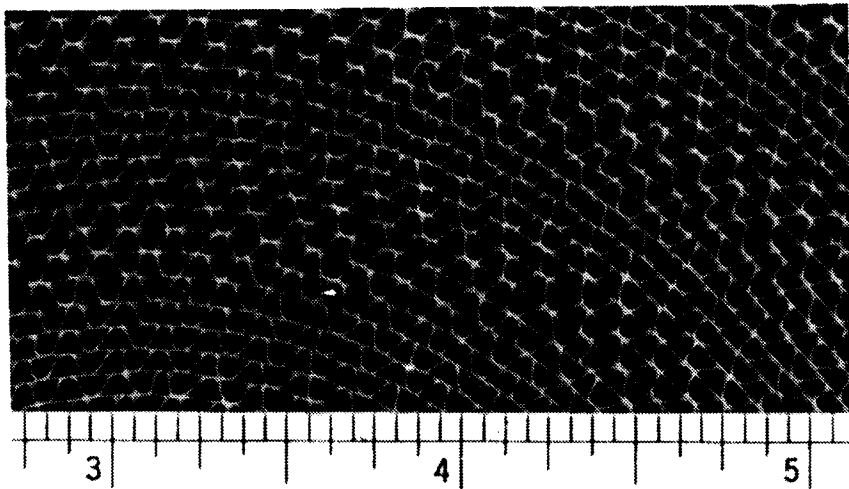


Figure 6b. Photograph of the face of the silica gel/corrugated test matrix

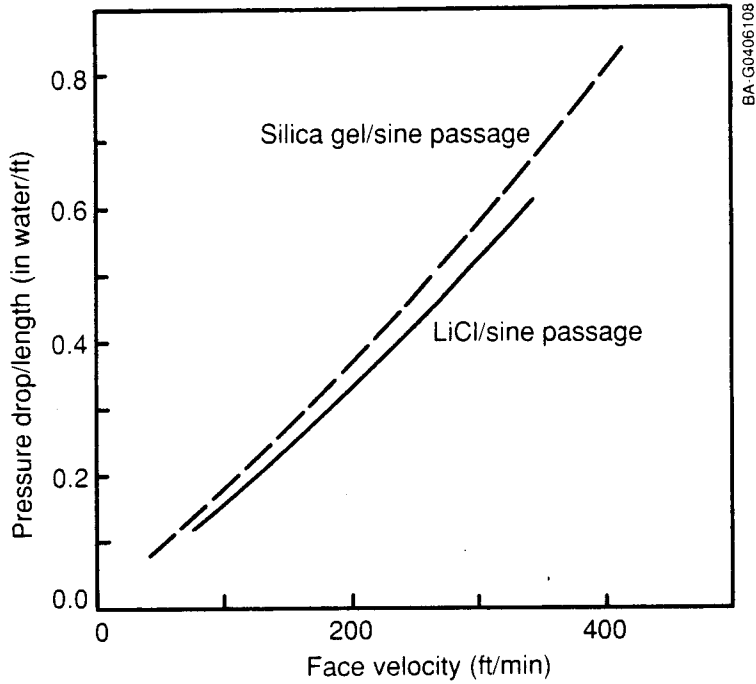


Figure 7. Pressure drop across two dehumidifier test matrices

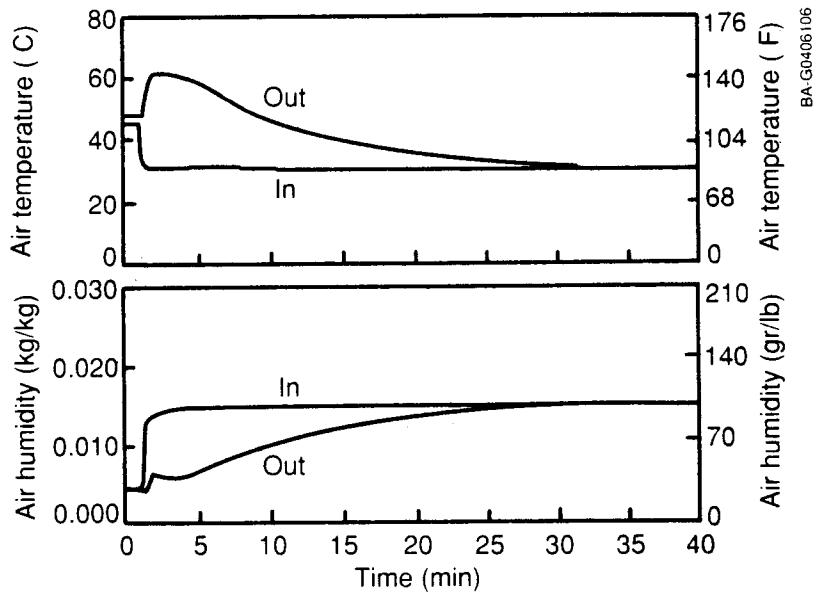


Figure 8. Results of transient response experiment for the silica gel/corrugated test matrix (adsorption run)

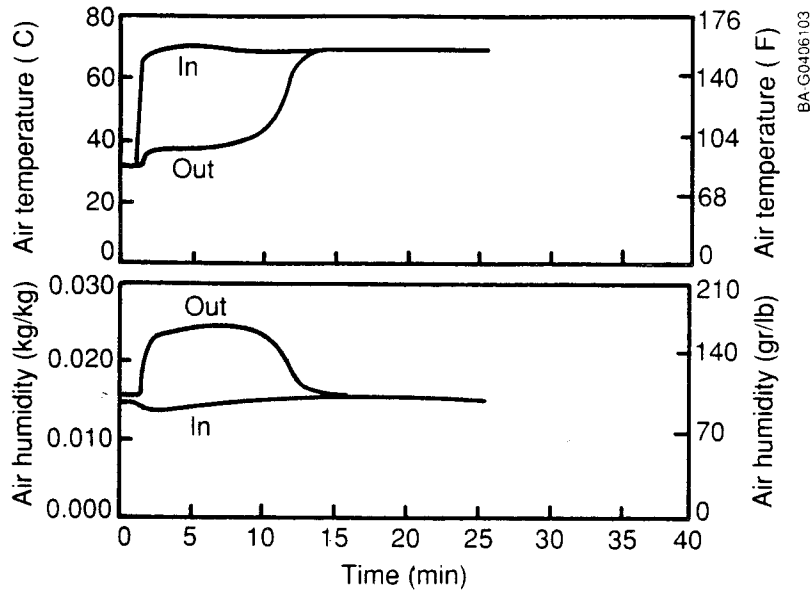


Figure 9. Results of transient response experiment for the silica gel/corrugated test matrix (desorption run)

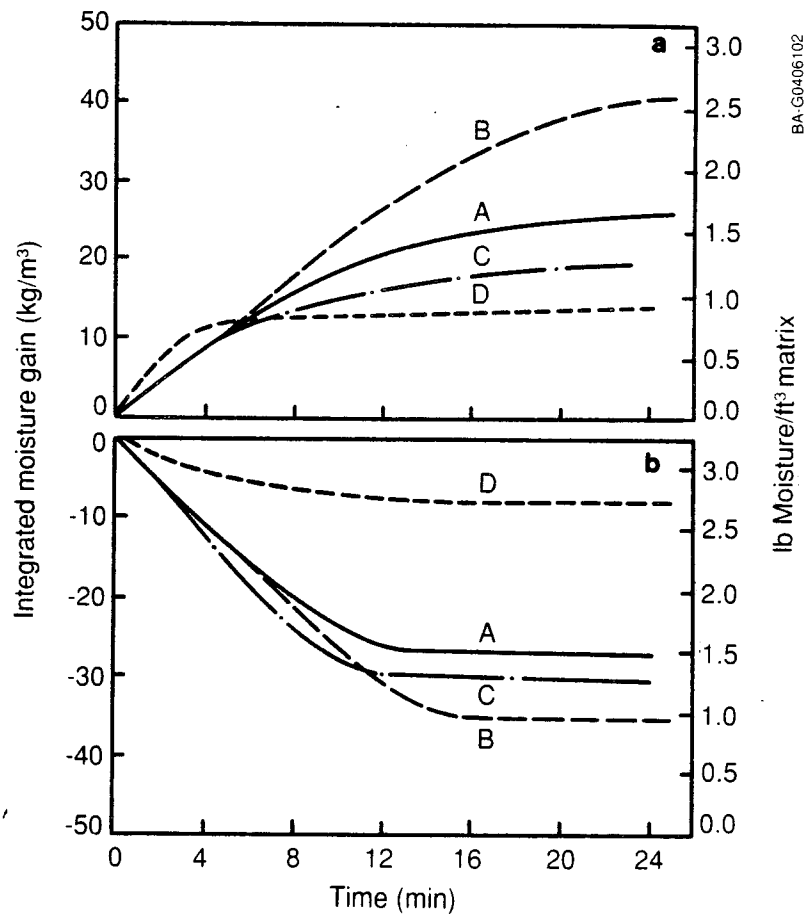


Figure 10. Transient dehumidification capacity of four test matrices; a: adsorption, b: desorption