EXPERIMENTS ON SORPTION CHARACTERISTICS OF SOLID DESICCANT

MATERIALS FOR SOLAR DESICCANT COOLING SYSTEMS

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ABSTRACT

A test facility for measuring the sorption proper-
ties of candidate solid desiccant materials under
dynamic conditions as well as equilibrium conditions,
those experienced during desiccant dehumidifier opera-
tion, was constructed and tested. The theory of per-
turbation chromatography was initially used to measure
the equilibrium properties of a desiccant/water-vapor
system for the first time.   Silica gel, molecular
sieve, and gamma-manganese dioxide were tested. The
equilibrium capacity estimated by the perturbation
chromatography was lower than those available in liter-
ature, which suggests that perturbation chromatography
may not be applicable to desiccant/water-vapor sys-
tems. The perturbation chromatography was replaced
with a gravimetric technique, and satisfactory results
were obtained for a water-vapor/molecular-sieve system.

NOMENCLATURE

C	H_2O gas-phase concentration $(kmol/m^3)$
C_s	H_2O sorbed-phase concentration $(kmol/m^3)$
d	average particle diameter (m)
M_w	molecular weight of H_2O (kg/kmol)
m	mass of dry desiccant (kg)
n	number of kilomoles of H_2O
P	total pressure (torr)
$\dot{Q}$	volumetric flow rate (m^3/s)
RH	relative humidity
T	temperature (^oC)
t	time (s)
u	gas velocity (m/s)
V	free gas volume (m^3)
V_s	sorbed volume (m^3)
V_R	retention volume (m^3)

W	desiccant water content (kg H_2O/kg dry desiccant)
x	spatial coordinate along axis of flow (m)

GREEK SYMBOLS

Δt	retention time difference between test cell and bypass (s)

SUPERSCRIPTS

*	isotopic tracer (D_2O)
He	helium

SUBSCRIPTS

bp	bypass
lit	calculated from literature
tc	test cell

INTRODUCTION

Solid desiccant cooling systems, which can take
advantage of solar energy, have received considerable
attention as an alternative to standard vapor compres-
sion systems for air conditioning. The system process
involves drying an air stream by passing it through a
desiccant bed and an evaporative cooler to provide the
air conditioning. The desiccant in the dehumidifier is
regenerated with hot air provided by energy obtained
from either a gas burner or solar collectors (1,2).
The greatest potential for improving system per-
formance lies in the development of advanced, highly
effective dehumidifiers. The performance of the dehu-
midifier is limited by the sorption capacity, sorption
properties, and long-term stability of the desiccant
under cyclic operation conditions. The sorption pro-
cesses in the desiccant bed are the passage of a
thermal and a mass transfer wave with different
diffusivities.

There are large amounts of water vapor equilibrium data on common industrial desiccants, however most of them are not updated, and considerable scatter exists in the equilibrium isotherms in the literature; e.g., ±15% scatter for silica gel, the most common desiccant used for solar application (3). Rojas (4), Hubard (5), and Jury and Edwards (6) obtained equilibrium data on silica-gel/water-vapor using a gravimetric technique. High heat of adsorption and low mass transfer diffusiveness of silica gel limits the performance of the dehumidifier. A composite of silica gel and manganese dioxide is believed to have lower heat of adsorption and higher mass transfer diffusivities (7,8). Fraioli (8) measured the equilibrium properties of various forms of manganese dioxide using the gravimetric technique. Molecular sieve is a desiccant often used in dehumidifiers regenerated by gas burners (1). The water vapor equilibrium capacity of molecular sieve was measured using the gravimetric method (9).

In gravimetry a small sample of desiccant is suspended from a microbalance in a chamber and exposed to the process air; direct measurement of the sample gives the water content of the desiccant as a function of time. One can measure the equilibrium capacity of the desiccant (i.e., water content per mass of dry desiccant) when there is no change in the mass of the sample with time (4,10). Although gravimetric techniques can be highly accurate, they are not feasible for obtaining dynamic data (i.e., weight change as a function of time) for a simulated dehumidifier geometry.

Another method used for obtaining equilibrium capacity is perturbation chromatography. This method is reliable for an adsorbate-adsorbent system such as hydrocarbons and zeolite (11,12). However, to my knowledge, this method has not been applied to a water vapor/desiccant system; this study is the first. In perturbation chromatography the process air stream flows into a test cell that contains the desiccant material, the air stream interacts with the desiccant, and the concentration of the outlet air stream is monitored as a function of time. When the inlet and outlet water vapor concentrations are the same; i.e., the desiccant has reached equilibrium, a small amount of isotopic tracer (heavy water, D_2O) is injected into the desiccant. Then, one can calculate the equilibrium capacity of the desiccant from travel time of the isotopic tracer through the desiccant.

Although chromatographic techniques are not as direct as the gravimetric techniques the former requires more data reduction and is generally not as accurate in determining equilibrium capacity. However, the test cell can be built using the chromatographic methods to simulate a section of the dehumidifier, and parametric studies can then be conducted to evaluate the effect that the dehumidifier geometry and desiccant bonding method has on the dynamic and equilibrium sorption properties. This was the reason why the chromatograph technique was initially selected for this study.

However, the chromatograph method did not provide reliable equilibrium data. Therefore, we replaced this method with the gravimetric technique, using specially designed test cells that could be removed from the system easily and weighed. In this method a process air stream flows into a desiccant test cell that simulates a section of an actual dehumidifier. The outlet water vapor concentration is monitored as a function of time (as in the chromatograph technique). When the inlet and outlet concentrations are the same, the test cell is removed from the system and weighed using a precision balance. The test cell is then placed back in the system, and the process is repeated several times until there is no detectable change in the weight of the

desiccant. This modified method has the advantage of the gravimetric method (i.e., direct measurement, reasonable accuracy) and chromatography technique (i.e., simulation of a section of dehumidifier).

The purpose of the study was to develop a test facility to measure the sorption characteristics of candidate solid desiccant materials under equilibrium and dynamic conditions, different geometrical configurations, a broad range of process air stream conditions (20°-90°C, 10%-90% relative humidity), and characteristics of desiccant dehumidifier operation. This paper focuses on the equilibrium results.

This study summarizes the theory of perturbation chromatography and its application in determining sorption properties and describes the present test facility and the test cells of various dehumidifier geometries. Equilibrium capacities calculated by the perturbation chromatography and the modified gravimetry are also presented. The results of the experiments conducted on silica gel, molecular sieve, and gamma-manganese dioxide are discussed.

THEORY OF PERTURBATION CHROMATOGRAPHY

The following derivation is similar to those of Pitts and Czanderna (14). Consider air with water vapor concentration $C(x,t)$ eluting through a test cell containing a desiccant of dry mass m and water content $W(x,t)$. By continuity the change in water concentration in a section of the test cell is given by the net flux into that section, or

$$\frac{\partial n}{\partial t} + V \frac{\partial(Cu)}{\partial x} = 0 , \qquad (1)$$

where n is the total number of moles of H_2O molecules in the section. Because $n = C_s V_s + CV$, then by substitution in Eq. (1) we have

$$V_s \frac{\partial C_s}{\partial C} \frac{\partial C}{\partial t} + V \frac{\partial C}{\partial t} + CV \frac{\partial u}{\partial x} + uV \frac{\partial C}{\partial x} = 0 . \qquad (2)$$

Assuming that the process stream velocity in the test cell u is constant, then $\partial u/\partial x = 0$, and Eq. (2) can be written as

$$\frac{\partial C}{\partial t} + \frac{u}{1 + \frac{V_s}{V} \frac{\partial C_s}{\partial C}} \frac{\partial C}{\partial x} = 0 .$$

Since C is a conserved quantity, the Lagrangian derivative is zero, so we can write the velocity of a perturbation in C as

$$\left(\frac{dx}{dt}\right)_C = \frac{u}{1 + \frac{V_s}{V} \frac{\partial C_s}{\partial C}} . \qquad (3)$$

Defining the retention volume V_R as

$$\frac{V_R}{u} = \frac{V}{\left(\frac{dx}{dt}\right)_C} ,$$

and substituting in Eq. (3) and rearranging gives us·

$$V_R = V + V_s \frac{\partial C_s}{\partial C} . \qquad (4)$$

If an isotopic perturbation is introduced into the test cell and its related variables are labeled with an asterisk, then Eq. (4) becomes

$$V_R^* = V^* + V_s \frac{\partial C_s^*}{\partial C^*} . \qquad (5)$$

Assuming that the sorption process does not distinguish between the labeled and unlabeled water molecules, then

$$\frac{C_s^*}{C^*} = \frac{C_s}{C} \quad \text{and} \quad \frac{\partial C_s^*}{\partial C^*} = \frac{C_s}{C} . \qquad (6a,b)$$

Substituting this into Eq. (5) yields

$$V_R^* = V + V_s \frac{C_s}{C} .$$

Using the desiccant water content ($W = V_s C_s M_w/m$) in the above equation gives

$$W = (V_R^* - V) \frac{M_w C}{m} . \qquad (7)$$

In a real experiment V_R^* cannot be measured directly because there is dead volume or volume between the test cell and detectors that is not filled with desiccant. The chromatograph described here uses the bypass method to correct for the dead volume.

The bypass (a short length of empty tubing) and the test cell are attached to a switching valve. We can determine the retention volume by measuring the time it takes the isotopic perturbation to propagate through the test cell and through the bypass:

$$V_R^* = V_{R,tc}^* - V_{R,bp}^* = \dot{Q}_{tc} t_{tc}^* - \dot{Q}_{bp} t_{bp}^* .$$

The free gas volume V can be measured by passing a non-reactive gas such as helium through the test cell and bypass, thus

$$V = \dot{Q}_{tc} t_{tc}^{He} - \dot{Q}_{bp} t_{bp}^{He} ;$$

therefore, the desiccant water content becomes

$$W = \left[\dot{Q}_{tc}(t_{tc}^* - t_{tc}^{He}) - \dot{Q}_{bp}(t_{bp}^* - t_{bp}^{He}) \right] \frac{M_w C}{m} . \qquad (8)$$

The pressure drop in the bypass can be made approximately the same as in the test cell by a valve, so $\dot{Q}_{bp} \sim \dot{Q}_{tc}$. Equation 8 can be written as

$$W = \dot{Q}_{tc} \left[\Delta t^* - \Delta t^{He} \right] \frac{M_w C}{m} \qquad (9)$$

where

$$\Delta t^* = t_{tc}^* - t_{bp}^*$$

$$\Delta t^{He} = t_{tc}^{He} - t_{bp}^{He} .$$

Measuring retention time at one temperature and concentration yields one point on an equilibrium isotherm and is equivalent to measuring the mass gained by a fixed sample of desiccant suspended from a micro-balance and exposed to the same air stream conditions.

CHROMATOGRAPH EXPERIMENTAL SET-UP AND PROCEDURE

A gas chromatographic sorption apparatus to characterize the sorption properties of desiccants was originally designed and constructed by Pitts et al. (14). The apparatus was modified for this study to control the water vapor concentration better. A diagram of the modified experimental set-up is given in Fig. 1.

Set-up

The gas reservoir consists of one or more cylinders of compressed, "bone-dry" air (less than 3-ppm water content). The air enters a mass flow controller
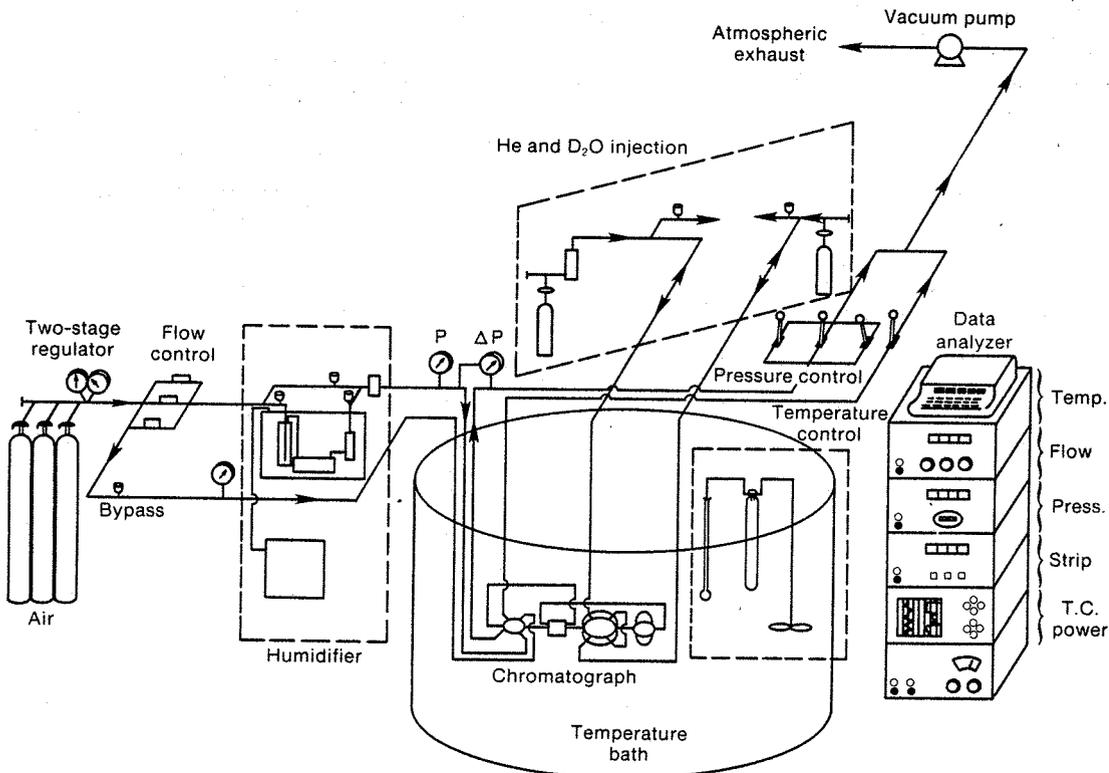

Figure 1. Diagram of the Experiment Set-Up

that measures and controls the air mass flow rate over a range of 10 to 500 cm^3/min and feeds the gas into a humidifier to obtain the desired level of water vapor concentration in the process stream. In the humidifier dry air bubbles through deionized water in a bubbler immersed in an isothermal bath. The saturated air then passes to a dew point hygrometer sensor that measures and monitors the inlet dew point temperature. The absolute pressure is monitored by a pressure transducer at this point, and the gas stream is fed into the test cell in the chromatograph loop, which is immersed in a constant-temperature deionized water bath. Samples of isotopic tracer (D_2O), air, and nonadsorbing gas (helium) can be injected into the desiccant test cell via a 10-port switching valve. The bath can be raised or lowered by a hydraulic scissor jack.

The chromatograph loop consists of a thermal conductivity detector, switching valves, two D_2O or He sample loops, a bypass loop, and the test cell containing a desiccant. The thermal conductivity detector is used to measure the relative thermal conductivity of the effluent air stream from the test cell to inlet process stream. The output of the detector, which is in millivolts, can be converted to water vapor concentration using calibration curves (11). The thermal conductivity detectors have a very fast response time and are very sensitive to concentration changes. Injection of D_2O or He through the test cell or bypass changes the thermal conductivity detector so it can be used for obtaining retention times and, thus, the equilibrium capacity of the desiccant.

The flow enters the first loop of a thermal conductivity detector, then goes to a switching valve for the injection of D_2O or helium. Next, the flow passes through another switching valve that contains the desiccant test cell and the bypass loop. The stream emerges from the test cell or bypass and passes through the second loop of the thermal conductivity detector. At this point the pressure drop across the chromatograph loop is measured using a differential pressure transducer. Then, the process stream passes through needle valves to control pressure, then through a vacuum pump, and finally to the outside.

Procedure

Preparation. The dry weight of the desiccant material in a test cell was obtained before the experiments by passing bone-dry air at 100°C and 1 atm through the desiccant for at least 24 hours and then by direct weight measurements. The process air stream conditions such as temperature, pressure, humidity ratio, and flow

rate were brought up to the desired operating values while the air flowed through bypass (bp).

Breakthrough Part. Once all operating parameters were set and equilibrated, the process air stream was switched into the test cell, and the breakthrough data were obtained by measuring the thermal conductivity outputs as a function of time. The outputs are converted to water vapor concentrations. When the outlet concentration from the test cell reaches the inlet concentration, the desiccant is in equilibrium with the process air.

Equilibrium Part. In the equilibrium part of the experiments the equilibrium water content of the desiccant was determined by measuring retention times of D_2O and He. After equilibrium was obtained a small amount of D_2O vapor or He was injected to the test cell using a switching valve.

The thermal conductivity detector was monitored until a variation in output was recorded; this gave the time at which the perturbation of D_2O reached the thermal conductivity detector after passing through the test cell and interacting with the desiccant. The same measurement was made in the bypass section to correct for all the piping length outside the test cell. These steps were repeated with helium gas to obtain a measure of the free gas volume in the desiccant.

DESCRIPTION OF TEST CELLS

Two different configurations of test cells were initially constructed for sorption studies: packed bed and parallel passage. We used the packed-bed test cell to obtain equilibrium data of the desiccant materials and to compare the data with published values. The packed-bed experimental data can be used as a reference base for results obtained with the parallel-passage geometry to find the effect of adhesive and filling materials on adsorption capacity.

The parallel passage test cell simulates one of the channels of the Solar Energy Research Institute (SERI) parallel-passage dehumidifier (15), which has the largest heat transfer to pressure drop ratio among the available dehumidifier geometries. The relevant parameters of the test cells used in this study are summarized in Table 1.

Material. The desiccant materials used in this study were silica gel molecular sieve and gamma-MnO_2. Silica gel has been recommended in solar desiccant cooling applications because of its high moisture recycling capacity in the temperature range available from solar collectors (1). We used a regular density

Table 1. Test Cell Parameters

Test Cell	A	B	C	D	E
Geometry	Packed bed	Packed bed	Parallel passage	Packed bed	Packed bed
Material	Silica gel	Molecular sieve	Silica gel	Molecular sieve	Gamma-MnO_2
Mass, dry desiccant ($\times 10^3$ kg)	0.2334	0.4517	0.6277	0.2235	0.2163
Particle size ($\times 10^3$ m)	0.3	1.0	0.3	1.0	0.15
Cross section ($\times 10^3$ m)	circle, 2.16	circle, 2.16	rectangle 20 × 0.95	circle, 4.44	circle, 4.44
Length ($\times 10^2$ m)	10.78	10.0	10.0	2.5	2.0
Technique	chromatography	chromatography	chromatography	gravimetry	gravimetry

silica gel from W. R. Grace with a mesh size of 45-60 ($d \approx 0.3$ mm) and a type 4A molecular sieve from Linde with a mesh size of 12-16 ($d \approx 1.0$ mm). This material has well established properties and was used as a reference for checking the reliability of the experimental procedure. Gamma-MnO_2 was provided by Argonne National Laboratory and had an average particle size of 0.15 mm.

Packed-Bed Test Cells. The first packed-bed test cell designed for perturbation chromatography was made of 1/8-inch (outside diameter) stainless tubing with a 0.02-in. wall thickness and packed with small particles of desiccant material. The packing length was about 0.1 m, and glass wool plugs were used to support the particles.

The second packed-bed test cell made for the gravimetric technique was a lightweight, stainless steel tube that could easily be inserted and extracted from stainless steel housing and easily weighed. The tube was 5 cm long with an inner diameter of 0.444 cm and contained desiccant particles confined between two glass wool plugs. For more details see Zangrando et al. (16).

Parallel-Passage Test Cell. The SERI parallel passage dehumidifier (15) is composed of parallel channels of double-sided polyester tapes on which fine particles of silica gel are impregnated. To simulate this configuration in the chromatograph loop, we fabricated a test cell from two polycarbonate sheets machined so that when they are fastened together, a parallel passage inside the two sheets is formed. Appropriate sizes of double-sided polyester tape were glued to the walls of the passage. Fine particles of silica gel were sprinkled onto the Mylar tape to form one layer of silica gel particles. The width of the passage is 0.02 m with a height of 1.7×10^{-3} m. The actual flow passage depends on channel height, the thickness of the polester tape, and particle size.

PERTURBATION CHROMATOGRAPHY RESULTS AND DISCUSSION

We obtained equilibrium results; i.e., desiccant water content versus air water vapor concentration, using isotope injection at the end of the breakthrough experiments. Table 2 shows the results of the equilibrium tests on silica gel and molecular sieve using the isotope perturbation chromatography. We found that

Δt^{He}, the time difference between passing helium through the test cell and the bypass column, is usually much less than Δt^*, the time difference between passing D_2O through the test cell and the bypass column. Therefore, Δt^{He} is ignored in comparison with Δt^* in calculating water contents [using Eq. (9)] and is not reported in Table 2. The equilibrium water content calculated in this study is compared with literature data shown as W_{lit} in Table 2.

We chose the gravimetric results of Rojas (4) on silica-gel/water-vapor to compare with the experimental results. Rojas data are close to the other published data (3). As seen in Table 2, the experimental equilibrium water contents are consistently lower than the published ones. Therefore the equilibrium results calculated in Table 2 using perturbation chromatography are erroneously obtained. The error in the experimental measurement does not account for the discrepancies.

To find the possible sources of error, we calculated the expected Δt^* from Eq. (9) based on literature data, which are reported in Table 2 as Δt^*_{lit}. The time difference Δt^* is consistently lower than Δt^*_{lit}, which suggests that the isotope peaks exit from the test cell faster than expected. This suggests that the residence time of D_2O in the desiccant is shorter than it is supposed to be, according to Eq. (9). We investigated the validity of assumptions made in the derivation of Eq. (9) suspecting that the weakest assumption can be the one presented as Eq. (6).

The principal assumption in isotopic perturbation presented as Eq. (6) is that "assuming that the adsorption process does not distinguish between the labeled and unlabeled water molecules, then . . ." The assumption that is implicit and not stated is that "isotopic exchange is rapid and complete through the mass of unlabeled, preadsorbed H_2O in time of D_2O perturbation exposure." Both of these statements are part of the basic assumption on which the method is derived, but the second statement may not be valid in reality.

The work at the Argonne National Laboratory (7) showed that certain features of the Type IV isotherm exhibited by water on silica gel can be interpreted as capillary-bound water held in the pore-blocked periphery of the individual particles. The water can be introduced into the interior of the particle until the

Table 2. Summary of Chromatrography Equilibrium Experiments

Exp. No.	P_{tc} (torr)	T_{tc} (°C)	$\overset{\circ}{Q}_{tc}$ (10^3 m³/s)	RH (%)	Δt^* (s)	W (kg/kg)	W_{lit} (kg/kg)	Δt^*_{lit} (s)
Test Cell A (silica gel)								
1A	761	30	1.87	27.56	1176	0.0786	0.149	2233
2A	772	30	1.84	37.50	750	0.067	0.193	2150
3A	760	30	1.88	51.20	1017	0.127	0.250	2000
Test Cell B (silica gel)								
1B	713	30	6.35	30.0	1116	0.109	0.160	1638
2B	759	30	6.27	29.6	1089	0.099	0.159	1749
3B	765	30	6.27	64.76	324	0.065	0.300	1495
4B	768	30	6.27	53.93	324	0.052	0.261	1626
Test Cell C (molecular sieve)								
1C	760	25.0	1.84	65.3	1023	0.062	0.220	3630
2C	760	25.0	1.83	38.9	1200	0.044	0.183	4990

meniscial balance is reestablished. The capillary-bound water is extremely localized (immobile adsorption), and, thus, the diffusion of D_2O into the interior of the microporous particle is not easily achieved. In other words, D_2O is restricted from free exchange into the interior of the particle, so the second part of the earlier basic assumption is not valid. The D_2O molecules interact with only the outer layers of adsorbed H_2O and do not penetrate far enough into the interior of the particle. Therefore, the residence time of D_2O molecules in the particles is shorter than the residence time when D_2O molecules penetrate completely into the interior of the particles. This is confirmed by the experimental measurement of Δt^*, which is smaller than Δt^*_{lit} (see Table 2).

This discussion presents one possible reason why our experimental determination of silica gel water content was unreliable, and why isotopic perturbation chromatography may be unreliable for determining silica gel water content.

Equilibrium results on molecular sieve using chromatography technique are also lower than those of manufacturer's data (see Table 2), possibly for the same reasons mentioned for silica gel. The perturbation chromatography may be used if one corrects for the effect of diffusion in the desiccant particles. More investigation of the theory and experimental procedure are required to understand the processes that may lead to successful use of the technique.

MODIFIED METHOD FOR OBTAINING EQUILIBRIUM DATA

To obtain the equilibrium and dynamic data, we modified the experimental procedure since the isotope perturbation chromatography did not provide reliable equilibrium data. We replaced the fixed test cell (A or B) with an easily removed test cell (D or E). The rest of the set-up was unchanged. We modified the experimental procedure only to obtain equilibrium data and left the preparation and breakthrough parts the same. At the end of breakthrough part the process air was bypassed, and we removed the test cell (D or E) from the set-up. The inner tube containing the desiccant was weighed with a precision balance while both ends were capped to prevent any interaction of the desiccant with the ambient air. The tube was remounted in the set-up, and the process air was readmitted to the test cell. After several hours we removed the test cell and weighed the desiccant to check for any weight changes. We repeated this procedure until there was no weight change within the accuracy of the balance (±0.0001 g). The final weight was used to calculate the water content of the desiccant. The experimental results of this method for molecular sieve and gamma-MnO_2 are given in Table 3. The manufacturer's data (9) on molecular sieve is also shown in Table 3 for comparison with the present experimental data, which is about 4%-13% less than the manufacturer's data. This is because the reactivation conditions in each case were different.

The molecular sieve in this study was reactivated with dry air at 1 atm and 100°C, and the manufacturer's sample was reactivated at 10^{-6} atm and 350°C. This implies that our desiccant was not as dry as the manufacturer's desiccant to begin with. We expected the experimental equilibrium data to be lower than those shown in the manufacturer's data. Nevertheless, the agreement between the two data confirm the reliability of the experimental method.

Gamma-MnO_2 is a laboratory-made desiccant (8), and no data were found on its water vapor equilibrium capacities. From Tables 2 and 3 we can see that gamma-MnO_2 has a much lower adsorption capacity than silica

Table 3. Summary of Gravimetry Equilibrium Experiments

Exp. No.	P_{tc} (torr)	T_{tc} (°C)	RH (%)	W (kg/kg)	W_{lit} (kg/kg)
Test Cell D (molecular sieve)					
1D	763.2	25.0	89.2	0.2110	0.225
2D	766.2	28.1	73.8	0.1955	0.223
3D	756.6	28.1	56.9	0.1883	0.220
4D	760.2	28.1	36.9	0.1816	0.216
5D	758.6	28.1	35.3	0.1812	0.215
Test Cell E (gamma-MnO_2)					
1E	757.5	20.0	36.1	0.014	—
2E	760.6	20.0	53.7	0.017	—
3E	758.1	20.0	84.1	0.032	—
4E	760.1	20.0	85.5	0.035	—
5E	760.5	20.0	90.9	0.036	—
6E	760.0	20.0	51.4	0.019	—
7E	761.7	40.0	11.6	0.0069	—
8E	761.0	40.0	17.16	0.0092	—
9E	760.1	40.0	29.60	0.0197	—

gel or molecular sieve, so it is not a suitable desiccant to be used in a solar desiccant cooling system. Researchers at Argonne National Laboratory (8) believe that composites of MnO_2/silica gel may have better adsorption rate characteristics than silica gel alone because of the tunnel crystalline structure of MnO_2. However, our preliminary rate measurements show that gamma-MnO_2 and silica gel have comparable rate characteristics. Thus, a composite of gamma-MnO_2/silica-gel will not have better rate characteristics than silica gel. The composite will have a lower adsorption capacity than silica gel, so it is not as suitable as silica gel alone. Thus, gamma-MnO_2 is not recommended for making silica gel composites. Other forms of MnO_2 may have a better chance.

CONCLUSIONS

We assembled a test facility to analyze the dynamic mass transfer process and equilibrium capacity of desiccant materials. This facility can operate under a broad range of process air stream conditions with various desiccant materials in different geometries. Silica gel was tested in two different dehumidifier configurations, packed bed and parallel passage, while molecular sieve and gamma-MnO_2 were tested in a packed-bed configuration.

First, perturbation chromatography was applied to measure sorption capacities, which showed a large discrepancy between the equilibrium experimental results and published data. This decrepancy was attributed to either the experimental procedure or the invalidity of one of the basic assumptions in the theory of isotopic perturbation chromatography for a desiccant/water-vapor system.

We modified the experimental set-up and procedure and replaced the isotope perturbation method with a gravimetric method. The experimental results with this method on molecular sieve was in fair agreement with manufacturer's data, which indicates the reliability of the second experimental approach. Water-vapor equilibrium data on gamma-MnO_2 was obtained that showed a much lower adsorption capacity compared with silica gel and

molecular sieve. The new method can be used to measure the adsorption capacity of any desiccant material.

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