Desiccant Contamination Research: Report on the Desiccant Contamination Test Facility

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PREFACE

In keeping with the national energy policy goal of fostering an adequate supply of energy at a reasonable cost, the U.S. Department of Energy (DOE) supports a variety of programs to promote a balanced and mixed energy resource system. The mission of the DOE Solar Buildings Research and Development Program is to support this goal, by providing for the development of solar technology alternatives for the buildings sector. It is the goal of the Program to establish a proven technology base to allow industry to develop solar products and designs for buildings which are economically competitive and can contribute significantly to building energy supplies nationally. Toward this end, the program sponsors research activities related to increasing the efficiency, reducing the cost, and improving the long term durability of passive and active solar systems for building water and space heating, cooling, and daylighting applications. These activities are conducted in four major areas: Advanced Passive Solar Materials Components and Systems Research, Collector Technology Research, Cooling Systems Research, and Systems Analysis and Applications Research.

Advanced Passive Solar Materials Components and Systems Research—This activity area includes work on new aperture materials for controlling solar heat gains, and for enhancing the use of daylight for building interior lighting purposes. It also encompasses work on low-cost thermal storage materials that have high thermal storage capacity and can be integrated with conventional building elements, and work on materials and methods to transport thermal energy efficiently between any building exterior surface and the building interior by nonmechanical means.

Cooling Systems Research—This activity area involves research on high performance dehumidifiers and chillers that can operate efficiently with the variable thermal outputs and delivery temperatures associated with solar collectors. It also includes work on advanced passive cooling techniques.

Systems Analysis and Applications Research—This activity area encompasses experimental testing, analysis, and evaluation of solar heating, cooling, and daylighting systems for residential and nonresidential buildings. This involves system integration studies, the development of design and analysis tools, and the establishment of overall cost, performance, and durability targets for various technology for system options.

This report describes the work conducted to improve the durability of solid desiccant dehumidifiers by investigating the causes of degradation of desiccant materials from airborne contaminants and thermal cycling. The performance of a dehumidifier strongly depends on the physical properties and durability of the desiccant material. To make durable and reliable dehumidifiers, an understanding is needed of how and to what degree the performance of a dehumidifier is affected by desiccant degradation.

This report, an account of work under Cooling Systems Research, documents the efforts to design and fabricate a test facility to investigate desiccant contamination based on industry and academia recommendations. It also discusses the experimental techniques needed for obtaining high-quality data and presents plans for next year. Researchers of the Mechanical and Industrial Technology Division performed this work at the Solar Energy Research Institute in FY 1988 for DOE's Office of Solar Heat Technologies.

The assistance of Centennial Engineering Inc., Behrent Engineering Company, Meyer-Weddle Company, Fidus Instrument Corporation, and SERI's Facilities Branch, particularly B. McCoy, is greatly appreciated.

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SUMMARY

The objective of this project is to fabricate a test facility to investigate the impact of desiccant contamination from airborne pollutants on the sorption properties of desiccant materials. The results will be used to estimate the impact of desiccant degradation on the performance of solar desiccant cooling systems. This report focuses only on the effort to build the desiccant contamination test facility. The experimental results are documented in FY 1989/1990 reports.

In FY 1987, we designed a desiccant contamination test facility based on the recommendations of the desiccant Materials Contamination Workshop hosted by DOE in June 1987 and on general experimental requirements for desiccant cooling applications. We also took into consideration the use of our existing experimental facilities, quality of data, and cost of fabrication and operation.

The facility is designed to expose desiccant samples in a test cell to air charged with airborne contaminants (cigarette smoke was the first contaminant of choice). In a second test cell, similar desiccant samples are exposed to pollutant-free air, i.e., no exposure to pollutants. The samples are also subjected to thermal and moisture cycles that desiccant materials experience during actual operation of desiccant dehumidifiers. The samples can be removed periodically to measure their sorption properties. Any difference between the samples processed with clean or polluted air is attributed to contamination and thermal cycling.

A local engineering firm, Centennial Engineering Inc., assisted us in detailed engineering design (mechanical and electrical) and cost estimation of the facility. In FY 1988, Centennial's initial engineering drawings of the desiccant contamination test facility were revised after internal and external reviews. The external reviews were provided by the DOE Solar Cooling Program Peer Review conducted at SERI on February 17, 1988. The internal reviews were provided by the SERI desiccant team and members of the SERI Facilities Branch. After incorporating these reviews in the engineering design of the facility, Centennial provided final mechanical and electrical drawings and design of the facility.

In October 1988, following a competitive procurement process, we contracted with a local engineering firm, Meyer-Weddle Company, to fabricate the facility based on the final design. The mechanical and electrical fabrication, started in November 1988, was completed in January 1989.

In addition to designing and fabricating the facility and contaminating desiccant materials, we contacted several manufacturers of smoking machines for fabrication of a fresh cigarette smoke generator. Based on its expertise and qualifications, we contracted with Fidus Instrument Corporation to build a smoking machine for our unique application. The machine will generate cigarette smoke at a rate of six cigarettes per hour for 24 hours in one day. The design and fabrication began in the first week of December 1988. Fidus delivered and installed the smoking machine in March 1989.

To control, monitor, and record the operating parameters of the test facility, we assembled hardware and software for a data-acquisition system. The system was made operational by May 1989. A gas chromatograph is in place to measure the concentration of the gaseous pollutants in the test cells.

We have also identified the experimental procedure to obtain high-quality data. After the desiccant samples are exposed intermittently to clean and polluted air, they are removed from the test cells at predetermined intervals for measurement of their sorption properties. These sorption properties include the moisture capacity and rate, measured by a gravimetric technique in the SERI sorption test facility; the elemental composition and oxidation states of surface components on the internal surfaces of desiccants, measured by SERI surface analysis equipment (e.g., x-ray photoelectron spectroscopy and scanning electron microscopy); and surface area, pore volume, and pore size distribution of desiccants, measured

using the micrometric techniques of commercial laboratories. The components adsorbed into the internal surfaces of desiccants will be analyzed using residual gas analyzers. Gas chromatography and nitrogen cold finger techniques will be used to analyze the components present in the airstreams.

The contamination experiments were started in mid-August 1989 and were completed in July 1990. We prepared a draft report documenting the interim findings of the contamination experiments in January 1989, as part of FY 1989 activities and later in December 1990 as part of FY 1990 activities.

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1.0 INTRODUCTION

1.1 Background

Open-cycle desiccant cooling and dehumidification systems have received considerable attention from public and private organizations in the past several years. They are considered alternatives or supplements to conventional vapor compression machines for air conditioning of buildings and spaces with high latent loads. The desiccant material in a dehumidifier removes the moisture from the process air to be dried. The desiccant is regenerated later with air heated by an energy source: the sun, natural gas, or electricity.

The cost, efficiency, and reliability (or durability) of a desiccant cooling system depend on its components. A desiccant dehumidifier is a major component in the system. After several years of research and development, the cost, efficiency, and size of solid desiccant dehumidifiers have improved by a factor of two, and further improvements are being pursued through cooperation with industry. The reliability of desiccant dehumidifiers is also of concern, particularly the degradation of the desiccant material.

In FY 1984, the ASHRAE SP-48 committee review of DOE's Active Heating and Cooling FY 1984-1988 Research Plan noted strong concern regarding the historical problems with contamination of desiccant beds in field operation. Desiccant degradation has been observed in industrial applications in which the process stream contains high concentrations of harsh pollutants. However, the degradation may be less for commercial and residential air conditioning applications in which the concentration level of pollutants may be quite low, especially for ventilation cycle systems.

In any case, there are limited quantitative data in the open literature on the effects of contaminants on desiccants for cooling applications. In a literature search (Pesaran et al. 1986), only two pertinent investigations on desiccant contamination were found: Farouk, Brusewitz, and Bloome (1980) found that the rate of moisture adsorption of three desiccants (molecular sieves, alumina, and silica gel) was reduced by the presence of 5% dust, typically found in agricultural grain-processing areas. However, they found that dust particles did not affect the equilibrium moisture capacity of the desiccants. Moseman and Bird (1982) carried out experiments for desiccant dehydration of natural gas and found that, after only 284 regenerations, the silica gel capacity dropped by almost 20%. Pesaran et al. (1986) also established methods to measure sorption degradation of contaminated solid desiccants (using a gravimetric technique) and to determine the identity and nature of the contaminants (using a surface analysis technique). To date, no results from a controlled desiccant contamination experiment for air-conditioning applications have been published.

In FY 1987, in order to address the issue of desiccant contamination, we started an in-depth engineering investigation. We found that although most desiccant investigators believe contamination will not be a problem, few if any quantitative data exist on the subject in the open literature. To address the problem of desiccant contamination, we proposed a roadmap (Figure 1-1). In June 1987, we presented the results of our literature and analytical studies to the participants of the Desiccant Materials Contamination Workshop hosted by DOE in Washington, D.C. The participants were from academia, industry, and public organizations. The major recommendations of the workshop were that controlled contamination experiments and base-case and worst-case experiments are needed.

In the base case, desiccants are cycled between absorption and regeneration temperatures with clean humid air. In the worst case, desiccants are cycled between two temperatures with humid air that is charged with cigarette smoke (probably the worst pollutant in a residential environment). In each case, after defined periods of testing (up to 10 months) the desiccants are removed and their sorption properties measured.

Figure 1-1. Roadmap to the problem of desiccant contamination

The differences between the virgin (a sample not thermally cycled or exposed to ambient air), base-case, and worst-case samples provide data on degradation caused by thermal cycling and contaminants. Pesaran (1987) presented the results of the workshop and the preliminary analysis.

Based on a preliminary system performance study, we found that desiccant degradation may have a significant impact (up to 40% reduction) on a desiccant cooling system's performance (Pesaran and Parsons 1987). Performance reduction was dependent on the hypothesis for desiccant degradation over time. Experimental data are needed to evaluate realistic degradation effects.

Using the workshop recommendations, general experimental requirements for desiccant cooling applications, our existing experimental facilities, quality of data, and cost issues, we decided to design and fabricate a desiccant contamination test facility (Pesaran and Parsons 1987). We proposed a conceptual design and contracted with Centennial Engineering to assist us in a detailed mechanical and electrical design and cost estimation of the facility. The 1987 Solar Cooling Peer Review concurred with our approach and our proposed conceptual design. Comments from the peer review about the analysis methods and facility design were carefully studied, and action was taken to incorporate them. Appendix A provides the viewgraphs of our presentation at this review meeting and contains information on the investigation we performed in FY 1987.

1.2 Purpose of This Project

The overall (long-term) objective of this research is to improve the durability and reliability of desiccant dehumidifiers for solar cooling applications. To achieve this objective, experimental data are needed to quantify the impact of airborne pollutants on desiccant materials in dehumidifiers.

The specific objective of this project was to fabricate a test facility to investigate the impact of contamination from airborne pollutants on the sorption properties of desiccant materials. The results from the experiments done in the facility can be used to estimate the impact of desiccant degradation on the performance of solar desiccant cooling systems. In this report we present the final design of the facility; instrumentation, experimental operation, and required material measurements; and future activities.

2.0 DESCRIPTION OF THE DESICCANT CONTAMINATION TEST FACILITY

2.1 Background

The recommendations of the DOE 1987 Desiccant Materials Contamination Workshop (Pesaran 1987) were the basis for the final design of the desiccant contamination test facility. As discussed in Section 1.0, two types of experiments were recommended:

- Base Case** in which a desiccant is cycled between absorption and regeneration temperatures with clean humid air.
- Worst Case** in which the desiccant is cycled between the absorption and regeneration temperatures with humid air that is charged with cigarette smoke (probably the worst pollutant in a residential environment).

In each case, after predetermined periods of testing, the desiccant is removed and its sorption properties are measured. The differences among the virgin, clean, and contaminated samples provide data on degradation from thermal cycling and contamination. Testing should be done for a sufficient period of time, at least 10 months. Fresh cigarette smoke was recommended by the workshop participants as the worst pollutant because it has both gaseous and particulate constituents which may be harmful to desiccants. Cigarette smoke is a "soup" of many components found as indoor air pollutants; see Appendix A for the composition of the smoke. After the initial screening it was suggested that indoor contaminants such as cooking oils also be used as the pollution source. We decided to conduct these preliminary experiments to see if even in the worst case measurable degradation exists.

In addition to the workshop recommendations, we considered other requirements for the needed experiments (Pesaran and Parsons 1987). These include data useful for solar desiccant cooling applications, cost effectiveness, quality of data, and conclusiveness of results. Considering the operating conditions for a typical solar cooling application, the following experimental conditions are required:

Adsorption temperature:	30° C to 40° C
Regeneration temperature:	65° C to 95° C
Air humidity ratio:	0.010 to 0.016 kg water/kg dry air
Cycle between adsorption and regeneration:	1 to 10 minutes
Air face velocity:	0.4 to 1.5 m/s

Also, the pollutant concentrations should be typical of those found in residential and commercial buildings. The maximum smoke concentration was found to be 6 mg/m³ of total particulate matter. In addition, multiple desiccant samples were needed for testing different desiccants.

The purpose of the desiccant contamination experiment is to degrade desiccant samples under typical solar desiccant conditions (stated above), in a controlled manner, so that the time history of degradation is known. Measurements to quantify degradation in sorption properties can be done elsewhere.

We compared the above requirements with the existing experimental facilities at SERI and elsewhere and could not find an experimental apparatus that met all the requirements and would provide satisfactory results (Pesaran and Parsons 1987). We decided to fabricate a desiccant contamination test facility based on our requirements. We identified the specifications of the facility as follows:

- Two fixed test cells, each containing 64 desiccant samples: one test cell for base-case experiments and the other for worst-case experiments
- Two air streams at either adsorption or regeneration temperatures for each test cell
- Air flow rate of each air stream set at 20 cfm (9.5 L/s)
- Multiple desiccant samples
- Average regeneration temperature at 85°C
- Average adsorption temperature at 35°C
- Average air humidity at 0.014 kg water/kg dry air
- Filtered ambient air for base case
- Cigarette smoke at burn rate of six cigarettes per hour for worst case
- 24 hours per day operation for at least 10 months.

Based on these specifications we designed a test facility. Centennial Engineering prepared the detailed mechanical and electrical engineering design and cost breakdown of the facility. We presented the results of our FY 1987 efforts to the 1987 Solar Cooling Peer Review in February 1987. They concurred with the conceptual design of our proposed test facility. They also provided a few comments that were incorporated into the final design of the facility. For example, they suggested testing several different desiccant samples. To accommodate this, we increased the number of sample holders in each test cell to 100 from 64. The initial design was reviewed internally by the SERI desiccant team and members of the SERI Facilities Branch to assure proper, dependable, and safe operation of the facility. After incorporating these reviews, the design was finalized and Centennial provided final mechanical and electrical design drawings.

In October 1988, following a competitive procurement process, we contracted with a local engineering firm, Meyer-Wedde Company, to fabricate the facility based on the final design. The electrical and mechanical fabrication began in November 1988 and was completed in January 1989.

In the following sections we discuss descriptions of the test facility, test cells, instrumentation and control, and the smoking machine.

2.2 Components and Configuration

The desiccant contamination test facility consists of two test cells containing 100 sample holders, two heaters, air filters, a humidifier, a smoking machine, and an air blower. Instrumentation is provided to measure the air flow rates, air temperature, pressure, and air humidity at several locations. The components are connected via 3-in., 2-in., or 1.5-in. galvanized steel pipes with screwed fittings. All the components of the facility are cleaned with appropriate solvents to make them oil and particulate free. The internal areas of the facility were purged with cleaning foam after completion of the fabrication.

Figure 2-1 is a schematic of the facility, and Figure 2-2 shows its detailed flow sheet. Ambient air enters through a silencer air filter to remove particulate matter. A steam humidifier (Model VPC-2, manufactured by DRI-STEEM) injects water vapor into the air stream to bring the air humidity to a desired level (typically 0.014 kg water/kg dry air). The 208-V, single-phase humidifier generates a maximum of 2.6 kg/hr steam and has a time-proportional module for stand-alone control via feedback from a dewpoint hygrometer.

After steam is injected, the air flow rate is measured by a flowmeter. The humid air then branches into two lines. Each line contains a flowmeter, an electrically actuated butterfly valve, and a feedback control mechanism to provide about 20 cfm of air in each line.

Figure 2-1. Schematic of desiccant contamination test facility

Figure 2-2. Desiccant contamination test facility flow sheet

			DESIGNED BY SERI			SOLAR ENERGY RESEARCH INSTITUTE	DESICCANT CONTAMINATION
			DRAWN BY W BOWERS			15003 DENVER WEST PARKWAY	TEST FACILITY
			CHECKED BY			GOLDEN, CO 80401-3393	FLOW SHEET
RONER	J.B.	J.M.	APPROVED BY				M-2
DOOD	SERI	SERI	SCALE NONE				REV
	BY APPR						

Line 1 (the lower line in Figures 2-1 and 2-2) contains a 500-W heater and a clean test cell for base-case experiments. The 500-W heater (Model 3282, manufactured by Chromalox) warms up the air to adsorption temperatures of 30°C to 45°C. Line 2 (the top line in Figures 2-1 and 2-2) contains a 2000-W heater, a smoking machine, and a contaminated test cell for worst-case experiments. The 2000-W heater (Model 3285, manufactured by Chromalox) heats up the air to a regeneration temperature of 75°C to 95°C. Both heaters are 120 V and single phase and are supplied with thermostats to control air temperature. The heaters also have high temperature switches which automatically turn off in case of low air velocity through the heaters or a malfunction in the control mechanism.

The heaters are connected to test cells and the smoking machine via 1.5-in. pipe sections and 10 electrically actuated globe valves (series 200-L, manufactured by Magnatrol). By opening and closing these globe valves, the air stream going through each test cell is either warm (for adsorption) or hot (for regeneration).

As can be seen from Figure 2-3, when the globe valves 1, 4, 5, 8, and 9 are open and the remaining valves are closed, air heated by the 2000-W heater (to regeneration temperatures) passes through the contaminated test cell. In this configuration, warm air produced by the 500-W heater passes through the clean test cell for moisture adsorption by the desiccant samples. In another configuration (Figure 2-4), the globe valves 1, 4, 5, 8, and 9 are closed and the remaining valves are open. In this configuration, warm air from the 500-W heater is directed toward the contaminated test cell for the adsorption process, and hot air from the 2000-W heater passes through the clean test cell for regeneration. In both figures, the flow paths are shown with solid lines and the closed pipes are shown with dashed lines. The valves are turned on or off with a repeat cycle timer (Series DA 100 Miniflex, manufactured by Eagle Signal Industrial Controls) to simulate the cycle time between adsorption and regeneration for dehumidifiers.

It is important to note that the regeneration and adsorption air streams pass through the desiccant samples in opposite (i.e., countercurrent) directions, a condition similar to that in operation of fixed and rotary dehumidifiers. A detailed analysis (Pesaran 1988) showed that a parallel-flow configuration results in a desiccant temperature and moisture content that are not typical of those encountered in the operation of typical dehumidifiers. The facility was designed to simulate the countercurrent conditions in spite of its added complexity.

Air streams leaving the test cells merge together into one stream which passes through a filter, for removing cigarette particles, before entering a blower (Model 22 URAI, manufactured by Roots-Dresser). The blower (230 V, 3 phase and 1 hp) draws the ambient air through the components and then discharges it to the existing building exhaust air duct. The air from the facility is finally discharged to the outside of the building via the building ventilation system.

Although use of three- or four-way valves would have reduced the number of pipe sections and crossovers, we selected two-way valves because they are more reliable, available, and inexpensive. These valves are normally closed. In case of power failure, all the valves will be automatically closed to stop smoke from reaching the clean test cell.

Figure 2-5 shows the general arrangement, including the plan and elevation of the test facility. The facility is located near the west wall of the desiccant cooling laboratory at the SERI Field Test Laboratory Building (FTLB), as shown in Figure 2-6. A photograph of the facility is shown in Figure 2-7.

Figure 2-3. Flow diagram of desiccant contamination test facility during clean test cell adsorption (contamination test cell regeneration) cycle. No flow through dashed line.

Figure 2-4. Flow diagram of desiccant contamination test facility during contamination test cell adsorption (clean test cell regeneration) cycle. No flow through dashed line.

Figure 2-5. Desiccant contamination test facility general arrangement—plans and elevations

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1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 26

ELECTRICAL CONNECTIONS FOR THE KVA BREAKER SHALL BE PLACED UNDER AND ABOVE THE BREAKER FOR THE FOLLOWING: ALL PHASES, UNO, TWO AND THREE. EACH WIRE WITH CORRESPONDING FITTINGS. FINAL BRANCH CIRCUIT CONNECTIONS SHALL BE MADE UP TO THE CHAIR, BE PLACED UNDER AND ABOVE EACH BREAKER. SPACING WIRE FOR EACH P.N.

1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 26

[illegible]

10. *Journal of the American Medical Association*, 2000; 284: 1039-1044.

1. TRANSFORMER SUPPLY TO WATER PUMP FROM
MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE FROM
MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
2. LIGHTS AND HEATING AND AIR CONDITIONING
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
3. TELEPHONE AND TELETYPE AND DATA EQUIPMENT
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
4. LOCAL MACHINE ROOM
5. DATA NEW OVERHEAD LINES, TRANSFORMER, SWAY
ARMED, 220V, 60 HZ, 3 PHASE, 4 WIRE FROM
RAILWAY SECTION, 220V, 60 HZ, 3 PHASE, 4 WIRE
6. ALL TRANSFORMER EQUIPMENT TO BE IN THE
EXISTING OVERHEAD LINES FROM RAILWAY
7. EXISTING 220V, 60 HZ, 3 PHASE, 4 WIRE
FROM NEW BUS TO THE MAIN BUS
8. MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
9. DATA NEW OVERHEAD LINES FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
TO THE EXISTING BUILDING FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
10. EXISTING 220V, 60 HZ, 3 PHASE, 4 WIRE
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE
FROM MAIN BUS, 220V, 60 HZ, 3 PHASE, 4 WIRE

[illegible]

Figure 2-6. Desiccant contamination test facility layout in desiccant cooling laboratory

Figure 2-7. Photograph of the desiccant contamination test facility

2.3 Description of Test Cells

Each test cell was designed to hold 100 sample test tubes containing desiccant material. Each cell contains a test cell holder with 100 cylindrical sleeves attached to it, a test cell box enclosing the holder, and two reducers for connecting the test cell to the other components of the facility (Figure 2-8).

The sample test tubes are made of brass and have the following dimensions:

Outer diameter:	11/32 in.
Wall thickness:	0.014 in.
Length:	3.0 in.

Each test tube can hold either desiccant particles (with screens on both ends for holding them in place) or a desiccant matrix (with walls coated or impregnated with desiccant materials). Figure 2-9 shows a sample test tube with desiccant silica gel particles and two screens.

The sample test tubes can be inserted into the sleeves of the test cell holder (see detail A in Figure 2-8). About 1/4 in. of each sample tube will be wrapped with Teflon tape so the tube does not go into the sleeve completely and can easily be removed. The brass sleeves have an outer diameter of 3/8 in., wall thickness of 0.014 in., and are 3 in. long. The test cell holder is mounted at the end of the test cell box with 12 bolts. The test cell box, which is made of 1/8-in. stainless steel sheets, has a cross section of 8 by 8 in. and is 11-5/8 in. long. The box has a removable door for easy access to the sample test tubes in the sleeves of the test cell holder. The walls of the box also serve as mounting bases for measuring sensors. A section at the other end of the test cell holder which is 3-7/8 in. long and 8 by 8 in. in cross section is used for mounting measuring sensors.

The air from the 1.5-in. pipe enters a reducer that smoothly goes from a round cross section to a square cross section of the test cell box. The reducer is designed for smooth and uniform transition of the air flow. The air passes through the test tubes containing desiccants and enters another reducer for smooth and uniform transition of air from the square cross section of the test cell to the round cross section of the piping. Both reducers are about 25 in. long, having a 1.5-in. round cross section on one end and an 8-by-8 in. square cross section at the other end. The reducing angle is 7.5 degrees. A photograph of the test cell is shown in Figure 2-10. The opened test cell with the 100 sleeves showing is depicted in Figure 2-11.

2.4 Description of Smoking Machine

To contaminate desiccant materials with fresh cigarette smoke for the worst-case experiments, a smoking machine was needed. We contemplated various ideas, from in-house design and fabrication to purchasing commercial smoking machines. We contacted Phillip Morris of Richmond, Virginia, a major tobacco company, to assist us. They provided useful information and the names of two major manufacturers of smoking machines: Filtrona of England and Borgwaldt of West Germany.

We contacted the U.S. representatives of these two companies and obtained further information about their products. Neither had machines to meet our unique applications. We also found that in-house fabrication of a smoking machine required a basic knowledge about cigarette handling unavailable at SERI. We then specified our unique needs to the U.S. representatives of two machine manufacturers. Fidus Instrument Corporation, the U.S. representative of Filtrona, accepted the task of assembling a smoking machine to our specifications.

L. HOLE .0005" DIA.
LARGER THAN O.D. OF
VE. HEAT SHRINK
LEEVES TO PLATE.
"R SLEEVES TO
E.

MESH STAINLESS
SCREEN PLUG (TYP)

BORE ID. BEAM
TO .381 DIA.

1/2" O.D. STD. TUBING
304 STAINLESS STEEL
ASTM A276 OR EQUIV
W/.083" WALL THK.

.334" I.D.

3.25"
4.15"

UNION REDUCER - 1/2" TO 1/4"
SWAGelok NO.
810-6-6 (TYP)
SEE NOTE 3

AIR PURGE TEST CELL HOLDER

SCALE: NONE

DETAIL A

100 - 3/16" O.D.
HOLES AS
NOTED

ASTM B-16 BRASS
PLATE OR EQUIV.

SEE TEST CELL BOX
FLANGE DETAIL FOR
BOLT HOLE SIZE AND
PLACEMENT.

TEST CELL HOLDER

SCALE: NONE

NOTES

- 1) USE TYPE 304 STAINLESS STEEL EXCEPT WHERE NOTED
- 2) ALL SEAMS TO BE SEAL WELDED AND AIRTIGHT.
- 3) ONE EA 1/2 - 1/4 AND 1/4 - 1/8 UNION REDUCER, ARE REQUIRED TO CONNECT TO EXISTING 1/2" TUBING ON EACH END. SWAGelok NO. 810-6-6 & 400-6-2 RESPECTIVELY.
- 4) USE GORETEX PTFE "TEFLON" FLANGE JOINT SEALANT - 1/4" - AT ALL FLANGE CONNECTIONS

(TYP)

	DESIGNED BY SERI DRAWN BY W BOWERS CHECKED BY APPROVED BY SCALE AS NOTED		JOB NO. 777.00 CENTENNIAL ENGINEERING INC. ARVADA, COLORADO	SOLAR ENERGY RESEARCH INSTITUTE 15003 DENVER WEST PARKWAY GOLDEN, CO. 80401-3393	DESICCANT CONTAMINATION TEST FACILITY DESICCANT TEST CELL M-3
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Figure 2-3. Details of desiccant test cell

Figure 2-9. Sample test tube with silica gel and screens

Figure 2-10. Photograph of an uninsulated test cell

Figure 2-11. Photograph of desiccant test cell (open) showing sample holder sleeves

We identified the following specifications for the smoking machine:

- The machine must burn an equivalent of six cigarettes per hour continuously.
- The machine must smoke for at least 24 hours a day, requiring a minimum capacity of 144 cigarettes.
- The machine should generate smoke for three days without reloading, requiring a capacity of 432 cigarettes.
- The machine must be in an enclosure that is air tight except for about 0.3 cfm air drawn from ambient through a 1-in. hole in the enclosure.
- The generated smoke must be supplied to the contaminated test cell via a 1.5-in. pipe.
- The cigarette or tobacco ashes must be prevented from going into the main air stream in the facility. Ashes should be easily collected and removed from the machine for proper disposal.
- The overall dimensions of the machine should not exceed 4 ft × 4 ft × 5 ft.

Fidus Instrument Corporation was contracted to build the smoking machine and started fabrication in December 1988. The machine was installed at SERI in March 1989.

According to Fidus, the smoking machine can burn 530 cigarettes consecutively (1 every 10 minutes) without reloading and with no operating or maintenance requirements after start-up. The machine consists primarily of the following parts:

- Plexiglass-fronted, air-tight cabinet with fixtures for venting to the test cell of the desiccant contamination test facility
- Frame for smoking machine
- Hopper to hold 530 cigarettes, with an approximate run time of 3.5 days
- Smoking drum to hold cigarettes in front of lighter
- Hopper drum to transfer cigarettes from hopper to the smoking drum
- Electric cigarette lighter
- transformer
- timing circuits with photoelectric sensors.

The machine operates with 120-V single-phase power. During operation, the hopper drum transfers one cigarette from the hopper to the smoking drum. The smoking drum holds the cigarette toward the lighter to be lit. The cigarette is burned horizontally. Then the smoking drum rotates, drops the butt, and grabs another cigarette from the hopper drum. The process repeats every 20 minutes. Figure 2-12 shows the smoking machine.

Figure 2-12. Photograph of smoking machine

2.5 Instrumentation and Control

The experimental parameters of the desiccant contamination test facility are monitored, controlled, and recorded by various software and hardware. The air temperatures, air humidity, and air flow rates are controlled by stand-alone control hardware like thermostats and humidistats. Figure 2-13, the process and instrumentation diagram (P & ID) flow sheet of the facility, shows the control strategies and the instrumentation.

The humidifier is controlled with a humidistat. The air humidity is measured with a dewpoint hygrometer (Model 1100DP, manufactured by General Eastern) and is fed back to the humidistat and compared with the set-point dewpoint. The humidistat, in turn, will energize or de-energize the electric humidifier to obtain the desired set-point temperature.

The heaters are controlled with thermostats. Type T thermocouple probes are used to sense the air temperature in the two main lines of the facility and send signals to the thermostat. The air temperature is compared with the set-point temperature, and necessary action is relayed to the heaters to obtain the desired set-point.

The flow rate in each line is controlled with a flowmeter, a flow controller, a position controller, and a butterfly valve. The flowmeter measures the flow rate and a signal to the flow controller, which compares this flow rate with the set-point flow rate. Depending on the offset, a signal is sent to the position controller, which opens or closes the butterfly valve to obtain the desired set-point flow rate.

The cycling time between regeneration and adsorption in each test cell is controlled by simultaneously opening (or closing) one set of valves (1, 4, 5, 8, and 9) and closing (or opening) another set of valves (2, 3, 6, 7, and 10) by a repeat cycle timer (Series DA 100 Miniflex, manufactured by Eagle Signal Industrial Controls).

The electrical design and wiring diagrams were prepared by Behrent Engineering Company, a subcontractor of Centennial. The electrical diagrams and wiring for start-up, control, and instrumentation of the facility are given in Appendix B. An annunciator/control panel with on/off lights to show the status of various components of the facility has been designed and fabricated. For example, the panel can show if heaters, the humidifier, the smoking machine, and the blower are operating or have failed. During continuous and unattended operation of the test facility, this panel is very useful for indicating which components are working properly. Figure B-4 in Appendix B shows the layout of the panel.

In the event of shutdown of the air blower (accidentally or purposefully), other components of the facility are automatically turned off to prevent any damage to the test facility.

The data-acquisition system for the test facility combines software and hardware to handle the collection and analysis of data. The air flow rates are measured with three 1.5-in. turbine flowmeters (Model 6822, manufactured by Hydril) in each branch and in the main flow into the facility. These units provide a 4-20 ma signal proportional to the air flow rate. Humidity measurements are taken with a General Eastern Model 1100DP dewpoint hygrometer with 1111D chilled-mirror sensors. Temperatures along the flowstreams are measured with six type T thermocouple probes (manufactured by Thermetrics). A cross section of the air temperatures in and out of each test section is measured with four type T thermocouples, using an array similar to that used at the SERI heat- and mass-transfer test facility. Also used are two MKS Baratron 221A differential pressure sensors to monitor the pressure drop across each test cell. The total pressure in each test cell is measured with a MKS 220A pressure transducer. The location of sensors is shown in Figure 2-14.

REV.	DATE	ISSUE AND REVISION
1	8/28/88	TEMPERATURE TRANSMITTER

Figure 2-13. Desiccant contamination test facility P&ID flow sheet showing control strategies and instrumentation

Figure 2-14. Sensor locations for data-acquisition system

The hardware to collect, display, and analyze the data is similar to that used in other test equipment at the Desiccant Cooling Laboratory. The Hewlett Packard 3497A scanner, with a digital voltmeter (DVM) option, is one of the most reliable and accurate scanner/DVMs. The HP3497A takes the analog signals from the sensors and transducers and measures the voltage or resistance signals. The measured signals are then passed through an IEEE-488 bus to an IBM PC equipped with a National Instruments GPIB PC-2 interface board. The IBM PC is equipped with high-resolution VGA graphics and a graphics printer. An overview of the data-acquisition system is presented in Figure 2-15. A photograph of the data-acquisition hardware is shown in Figure 2-16.

The software chosen for data acquisition is LabTech Notebook from Laboratory Technologies. It is capable of graphically displaying the data in real time and is easily changed as the requirements of the test change. LabTech Notebook is a generic data-acquisition program that can be adapted to most test situations. Also used is Laboratory Technologies' Real Time Access, which allows for data acquisition in the background and access to the data in the foreground for analysis. This allows us to run an independent analysis program (1-2-3 or a Pascal program) to analyze the data while they are being collected. The Real Time Access Option allows us to display customized presentations such as multiple windows while data are being collected.

In addition to the above measurements, the concentration of certain pollutants will be measured with a portable gas chromatograph (Scentograph Model, manufactured by Sentex Sensing Technology, Inc.). The chromatograph, which has an Argon Ionization/Electron Capture (AI/EC) Detector, belongs to the SERI Building Research Branch. It will be used once or twice a week to monitor the major constituents of cigarette smoke such as acetaldehyde, methylchloride, acetone, ammonia, formaldehyde, and hydrogen sulfide. By replacing the AI/EC detector with a thermal conductivity detector and adding an appropriate packed column, the chromatograph can measure the concentration of carbon monoxide and carbon dioxide. Infrared or chemiluminescent analyzers are needed to measure the concentrations of nitrogen oxide and nitrogen dioxide.

Figure 2-15. Data-acquisition system flow chart

2.4 Description of Smoking Machine

To contaminate desiccant materials with fresh cigarette smoke for the machine was needed. We contemplated various ideas, from in-house commercial smoking machines. We contacted Phillip Morris (company), to assist us. They provided useful information and the smoking machines: Filtrona of England and Borgwaldt of West

We contacted the U.S. representatives of these two companies and products. Neither had machines to meet our unique applications of a smoking machine required a basic knowledge about cigarette specified our unique needs to the U.S. representatives of two companies. Corporation, the U.S. representative of Filtrona, accepted the machine our specifications.

3.0 EXPERIMENTAL PROCEDURE

The function of the desiccant contamination test facility is to contaminate desiccant samples under conditions found in the operation of solar desiccant cooling dehumidifiers. Experiments or analysis to measure the degree and cause of degradation will be done elsewhere. This section covers the desiccant material selected for investigation, the operation of the facility, and the measurements needed to characterize degradation.

3.1 Desiccant Materials for Testing

3.1.1 Number of Desiccants to be Tested

Before we select the desiccants to be tested in the facility, we need to identify the maximum number of materials we can test. The desiccant samples being tested are removed from the facility to obtain a time history of their degradation. Once removed, a sample cannot be returned to the facility, because the measurements done to obtain its sorption properties may change it. The number of samples for each desiccant depends on how many data points should be obtained for 10 months of continuous testing. We believe that five data points at intervals of 0.5, 1, 2, 4, and 10 months is reasonable.

At Least 2 samples of each desiccant should be tested each time in order to account for variation in properties. This amounts to 10 samples per desiccant. If possible, 2 batches of each desiccant should be tested to account for batch-to-batch variation caused by changes in manufacturing conditions. The minimum number of samples for a desiccant is 10; therefore, with 100 sample holders, the maximum number of different desiccants that can be tested simultaneously is 10. Of course, as the samples are removed from the facility for sorption measurements, new ones can be added and tested, thus increasing the number of data points that can be obtained for a given desiccant.

3.1.2 Materials Considered

The desiccant materials suitable for solar cooling applications usually are coated on or impregnated into the walls of a dehumidifier matrix. In this investigation, we will consider desiccant materials in both bulk (i.e., particulate) form and matrix form, if possible. For example, silica gel will be tested both in bulk form, in a packed bed configuration, and in matrix form, in which silica gel particles are coated on the walls of a parallel passage test sample.

In this study we have focused on solid desiccants. Based on the industry and the 1987 DOE Solar Cooling Peer Review input, we have selected the following desiccants for investigation:

1. Microporous silica gel particles (batch A)
2. Microporous silica gel particles (batch B)
3. Microbead silica gel in parallel passage configuration
4. Fine silica gel particles in parallel passage configuration
5. 13X molecular sieve particles (batch A)
6. 13X molecular sieve particles (batch B)

7. Activated alumina particles
8. Activated carbon particles
9. Cargocaire lithium chloride/corrugated matrix (batch A)
10. Cargocaire lithium-chloride/corrugated matrix (batch B).

The particulate samples will be tested in a packed bed form with an average particle size of 1.5 mm. In a packed bed configuration the first few particles facing the air flow may filter most of the particulate matter and thus guard the rest of the particles. This differs from most dehumidifier geometries considered for cooling applications. Therefore, testing of the materials in a parallel passage configuration where desiccant is coated on the walls of the passage may become critical. We will evaluate this after removing the first series of test samples.

3.1.3 Sample Preparation

Two batches of particulate desiccants will be tested. From each fresh batch, we will select three sample sets. The first set will be stored in a cool, dry container (as virgin samples). The second set will be screened to an average particle size of 1.5 mm and then loaded in cylindrical sample test tubes for placing in the clean test cell of the desiccant contamination test facility (as clean samples). The third set, also screened to 1.5-mm particle size, will be loaded in test tubes for placing in the contaminated test cell of the facility (as contaminated samples). Test tubes will be cleaned with a solvent before they are loaded with desiccant.

We expect to load about 0.5-1 g of desiccant into each test tube (see Figure 2-12 for a photograph of the test tube). Stainless steel screens on the ends of the tube will hold the desiccant in place. For the silica gel parallel passage configuration, the material is first coated on both sides of a double-sided mylar tape and then rolled in a sinusoidal shape and inserted into each test tube. Plastic caps put on both ends of each tube will block off ambient air when the tube is not in the test facility. It should be noted that each test tube has a specific label for identification. A section of the lithium-chloride/corrugated matrix of Cargocaire will be cut and inserted into the test tubes for testing. Sample test tubes will be placed in the clean and contaminated test cells.

3.2 Test Facility Operation

The following steps will be taken to operate the facility (see figures in Section 2.0 for reference).

1. Prepare the desiccant sample test tubes as discussed in Section 3.1.3, and place them in the appropriate test cells. Note that each test tube holder is identified with a number and a letter (e.g., A1 and J10) as shown in Figure 3-1 to identify where each desiccant sample is placed. The columns in clean test tubes are identified as 1 to 10 and the columns in the contaminated test tubes are identified as 11 to 20.
2. Turn on the data-acquisition system.
3. Start the repeat cycle timer to open set A valves (globe valve numbers: 1, 4, 5, 8, and 9) and close set B valves (globe valve numbers: 2, 3, 6, 7, and 10).

Figure 3-1. Cross section of test cells showing sample tube locations

4. Turn on the blower and adjust the total flow to 40 cfm.
5. Adjust the flowmeters to supply approximately 20 cfm air to each branch of the facility.
6. Turn on the heaters and steam humidifier.
7. Adjust the flow rate, air temperature, and air humidity to desired set-points.
8. Turn on the smoking machine (or start injecting other pollutants).
9. Set the repeat cycle timer to the appropriate cycle time for switching the hot and warm air streams between the two test cells.
10. Start the cycle counter.
11. Keep monitoring the status of the facility to assure that all components are working properly and all the experimental parameters are within the specified range.
12. Load the smoking machine with a statistically representative batch of commercially available cigarettes every three days.
13. At the proper time (0.5, 1, 2, 4, or 10 months after the start of the experiment), turn off the cycle counter, heaters, steam humidifier, and blower.
14. Open the two test cells, remove the appropriate desiccant sample tubes for analysis.
15. Place new sample test tubes in place of those removed and close the test cell doors.
16. Repeat steps 4 through 15 until the first 100 samples have been processed in the facility, i.e., for 10 months.

The sorption properties of desiccant samples removed from the facility will be measured according to the outline discussed in the next section. The air flow rates, air temperatures, and air humidities will be measured and recorded on a continuous basis every minute. Selected data of several cycles in a day will be measured and stored every five seconds to ascertain the behavior of the desiccant. In this case, inlet and outlet air temperature and humidity to and from the test tubes will be measured and recorded. The pressure drop across the test cell will also be measured.

The concentration of the pollutants will be measured intermittently with the various gas analyzers. Once or twice a week, air samples from both ends of the two test cells will be drawn through the gas chromatograph for analysis. Data will be stored on floppy disks. When available, a nitrogen cold finger will also be installed to condense all the gaseous pollutants for residual gas analysis. Infrared and chemiluminescent analyzers will be used for analysis of the gases not detectable with a gas chromatograph.

3.3 Desiccant Material Characterization

3.3.1 Capacity Measurements

After the samples are removed from the clean and contaminated test cells, they will be placed in an air purge test tube holder and installed in the SERI sorption test facility to measure the adsorption and desorption water-vapor capacity of the desiccants at 30°C. The experimental facility and the procedure for this facility are discussed elsewhere (e.g., Bingham and Pesaran 1989). The sorption capacity of virgin

samples will also be measured in the facility. The difference in capacity between virgin and clean samples is caused by thermal cycling. The difference in capacity between clean and contaminated samples is caused by contamination.

3.3.2 Micrometric Measurements

The internal structure of a porous desiccant may change as a result of contamination and thermal cycling. The pore volume, pore surface area, and pore size distribution (micrometric properties) are measures of the internal structure of a porous desiccant. We will send virgin, clean, and contaminated samples of porous desiccants to a commercial laboratory (e.g., Micrometrics in Georgia or Coors Analytical Laboratories in Colorado) for measurement of their micrometric properties. Differences in the results are caused by contamination and thermal cycling.

3.3.3 Surface Analysis

The elemental composition of the surface monolayer(s) of contaminated solids can be determined using x-ray photoelectron spectroscopy (Pesaran et al. 1986). This technique will be used to determine the elemental composition on the surfaces of clean and contaminated samples. Thus, we can identify the elemental composition of surface contaminants on the contaminated samples. Scanning electron microscopy also will be used on some of the samples to determine visual differences.

4.0 FUTURE WORK

4.1 Anticipated Results

We anticipate that we will obtain a time history of desiccant degradation from thermal cycling and cigarette smoke. We will obtain contamination data 24 hours a day for 10 months. This is equivalent to about 5 years of field testing of typical dehumidifiers (assuming that a dehumidifier operates 8 hours a day and 6 months in one year and the concentration in the field is the same as in the experiment). The desiccant degradation will be expressed as loss of moisture capacity at various humidities and by change in internal structure. The pollutants that caused the degradation will be also identified.

The loss in capacity as a function of time will be used in dehumidifier and cooling system models to predict reduction in the performance of typical dehumidifiers and cooling systems as a function of time. Figure 4-1 depicts the anticipated hypothetical results graphically.

4.2 Schedule

The work has been continued in FY 1989 and FY 1990. The activities shown in Table 4-1 will be performed to achieve the objectives of the desiccant contamination research. The activities include SERI internal control and tracking milestones. The contamination experiment was actually started in mid-August 1989. A draft report describing the preliminary results obtained in FY 1989 was prepared.

Figure 4-1. Anticipated results from the desiccant contamination research

Table 4-1. Schedule of Activities to Perform for Desiccant Contamination Research in 1989

Activity	Date
Complete fabrication of the test facility	1/89
Complete assembly of data-acquisition system	3/89
Complete fabrication of smoking machine	2/89
Installation and shakedown of the smoking machine	3/89
Shakedown of the test facility complete	5/89
Secure and prepare desiccant test samples	5/89
Begin contamination experiments (M)	6/89*
Continue contaminating desiccant samples	6/89-12/89
Remove samples for sorption properties measurements	6/89-12/89
Prepare a letter report on preliminary results on desiccant contamination tests (D)	7/30/89*
Analyze removed samples	8/89-12/89
Prepare draft report on FY 1989 desiccant contamination experiments (D)	01/30/90*

* Control milestone/deliverables

M Milestone

D Deliverable

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APPENDIX A

VIEWGRAPHS OF FY 1988 PRESENTATION TO DOE SOLAR DESICCANT COOLING PEER REVIEW

Desiccant Materials Contamination Research

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Solar Energy Research Institute

Solar Cooling Program Peer Review

Golden, Colorado

February 17, 1988

Outline

- Objectives/Significance
- Background/Issues
- FY 1987 Activities
 - Literature review
 - Analytical study
 - Workshop
 - Experiment requirements
- FY 1988 Planned Activities

Solar Desiccant Cooling/Dehumidification

Long-Term Objectives

- To assure solar cooling equipment and buildings industry can provide efficient, **reliable**, and cost-effective solar cooling options (can supply up to 60 percent of a buildings peak cooling requirements)
- To assure that solid desiccant cooling systems will perform at least within 90 percent of design performance during their service life

Desiccant Materials Contamination Research

Objective

To investigate any effect of pollutants found in residential areas on solid desiccant materials used in dehumidifiers that may reduce their performance for solar cooling applications

Significance

The data will be used to evaluate reliability and service life of dehumidifiers that are needed for the design of desiccant cooling systems and their cost analysis. The data will be used to evaluate mitigation approaches

Background

- Performance and reliability:
 - of a desiccant cooling system depends on its components
 - of a dehumidifier component depends on ...
 - geometry/structure
 - desiccant material (sorption characteristics)
 - Isotherm properties
 - Heat of sorption
 - Moisture sorption rate

Definition of Desiccant Degradation/Contamination

Desiccant degradation can happen when the water **sorption characteristics** of the desiccant is changed unfavorably; i.e.:

- the isotherm shape is changed **unfavorably**

- the maximum water up-take is reduced

- a hysteresis between adsorption and desorption is generated

- the heat of adsorption is **increased**

- the moisture sorption rates have **decreased**

Background

- ASHRAE concern about degradation of desiccant dehumidifiers was raised in a DOE Desiccant Cooling Review Meeting at SERI in 1984
- In FY 1985, SERI performed an exploratory investigation of field tested desiccant samples
- Desiccant degradation remains an issue
 - 1986 Desiccant Cooling/Dehumidification Workshop (at TVA)
 - DOE Multi-Year Cooling Plan

FY 1985 Results

XPS Survey Scans of Silica Gel Samples With Elements Present Identified (XPS = X-Ray Photoelectron Spectroscopy)

Capacity Loss for a Silica Gel Packed Bed Used in Dehydration of Natural Gas

(W. R. Grace)

FY 1987 Activities:

Roadmap to the Problem of Desiccant Contamination

Literature Review

- Literature search on nature and concentration of pollutants
 - 9 literature data bases (1970-1987) including EPA and NTIS were searched, about 50 out of 500 titles were ordered. (EPA, TVA, GRI, LBL, ORNL, EPRI)
 - Usually the indoor-to-outdoor concentration ratio of a pollutant is higher than 1 (except for SO₂, sulfates). Indoor air can be more degrading to desiccants than outdoor air.
 - The nature and concentration of air varies drastically from residence to residence and from season to season.
 - Source and nature of indoor air pollutants are relatively well defined for combustion products and less for volatile organics.
 - Statistically meaningless to define the average and worst conditions for an average residence. The most probable range is closer to reality.

Residential and Commercial Building Pollutants

Carbon Dioxide	Sulfate	Respirable Particles
Carbon Monoxide	Radon and Progeny	Asbestos
Sulfur Dioxide	Ozone	Mineral and Synthetic Fibers
Nitrogen Dioxide	Formaldehyde	Viable Organisms
Tobacco Smoke		Organic Vapors

Common Desiccants

Silica Gel	Molecular Sieve
Lithium Chloride	Alumina Gel

Sources of Indoor Pollutants

- Consumer Products
 - Paints and Solvents
 - Household Products
 - Pesticides
- Soil and Water
- Building Materials
- Insulation Materials
- Decorating Materials
- Smoking
- Unvented or Improperly Vented Combustion
 - Kerosene or Gas Space Heater
 - Wood Stoves
 - Gas Range
 - Cooking
 - Hobbies

Sources, Possible Concentrations, and Indoor-to-Outdoor
Concentration Ratios of Some Indoor Pollutants

Pollutant	Sources of Indoor Pollution	Possible Indoor Concentration ^a	I/O Concentration Ratio	Location
Carbon monoxide	Combustion equipment, engines, faulty heating system	100 ppm	>>1	Skating rinks, offices, homes, cars, shops
Respirable particles	Stoves, fireplaces, cigarettes, condensation of volatiles, aerosol sprays, resuspension, cooking	100-500 $\mu\text{g}/\text{m}^3$	>>1	Homes, offices, cars, public facilities, bars, restaurants
Organic vapors	Combustion, solvents, resin products, pesticides, aerosol sprays	NA	>1	Homes, restaurants, public facilities, offices, hospitals
Nitrogen dioxide	Combustion, gas stoves, water heaters, dryers, cigarettes, engines	200-1,000 $\mu\text{g}/\text{m}^3$	>>1	Homes, skating rinks
Sulfur dioxide	Heating system	20 $\mu\text{g}/\text{m}^3$	<1	Removal inside
Total suspended particles without smoking	Combustion, resuspension, heating system	100 $\mu\text{g}/\text{m}^3$	1	Homes, offices, transportation, restaurants
Sulfate	Matches, gas stoves	5 $\mu\text{g}/\text{m}^3$	<1	Removal inside
Formaldehyde	Insulation, product binders, particleboard	0.05-1.0 ppm	>1	Homes, offices
Radon and progeny	Building materials, groundwater, soil	0.1-30 nCi/ m^3	>>1	Homes, buildings

<u>Pollutant</u>	<u>Sources of Indoor Pollution</u>	<u>Possible Indoor Concentration^a</u>	<u>I/O Con- centration Ratio</u>	<u>Location</u>
Asbestos	Fireproofing	<1 fiber/cc	1	Homes, schools, offices
Mineral and synthetic fibers	Products, cloth, rugs, wallboard	NA	—	Homes, schools, offices
Carbon dioxide	Combustion, humans, pets	3,000 ppm	>>1	Homes, schools, offices
Viable organisms	Humans, pets, rodents, insects, plants, fungi, humidifiers, air conditioners	NA	>1	Homes, hospitals, schools, offices, public facilities
Ozone	Electric arcing, UV light sources	20 ppb 200 ppb	<1 >1	Airplanes Offices

^aConcentrations listed are only illustrative of those reported indoors. Both higher and lower concentrations have been measured. No averaging times are given. NA, not appropriate to list a concentration.

Literature Review (continued)

- Co-adsorption of water and pollutants on desiccants
 - Pollutants can degrade the moisture capacity of the desiccant when at high concentrations, not sufficient data on the low level concentrations.
 - Adsorbents (activated carbon and molecular sieves) for removal of CO and CO₂ and silica gel for removal of H₂O to prevent adsorbent poisoning in the space cabins (NASA).
 - The affinity of water vapor toward desiccant is much higher than that of most gases. However, upon regeneration, depending on the temperature, a gas may not be desorbed and accumulate in a desiccant until it degrades the water sorption characteristics of the desiccant.
 - The pollutants may permanently react with the adsorption sites and reduce the sorption characteristics of a desiccant.
 - Dust particles (10-20 μm) do not reduce the adsorption capacity of solid desiccants. However, they reduce the moisture pick up rate.

Literature Review (continued)

- Recently, Oklahoma State University has studied the pollutant adsorption capacity of silica gel.
- Recently, IIT Research Institute investigated the removal of CO, NO₂, and SO₂ by two dehumidifiers (silica gel and molecular sieves) for improving indoor air quality. The dehumidifiers, in fact, removed the pollutants; molecular sieves better than silica gel.
- Experimental techniques along with associated instruments were identified for monitoring some gaseous and particulate pollutants.
- Several options for contamination experiments were identified.

Pollutants Build-Up on a Desiccant

- Assumptions

- Typical air flow rate through dehumidifier: $0.12 \frac{\text{kg air}}{\text{S kg desiccant}}$

- Time of operation ($8 \times 365/3$): **980** hours/year

- Average pollutant concentration in air: 100 ppm

- Average water capacity of desiccant: 0.2 kg H₂O/kg desiccant

- Fraction of pollutants that stick to the desiccant: S_f

- One pollutant molecule attached to the desiccant avoids adsorption of one molecule of water

Pollutants Build-Up on a Desiccant

(w = 0.2 kg water/kg desiccant; wp = 100 ppm)

Questions

“So what if the desiccant contaminates or degrades by X%? How much does this degradation reduce the system performance?”

Systems Modeling Degradation Trends

Objective

Quantify relative effects of possible desiccant degradation scenarios on ventillation cycle performance.

Degradation:

- Pollutants contaminating adsorption sites
- Thermal cycling and aging changing material characteristics

Systems studies:

- Lack of actual data → what if: games
- Wheel design: recommended 80 °C regeneration (constant wheel speed)

Two Possible Degradation Scenarios Examined

- Reduced water adsorption capacity

Year	Adsorption factor
0 (fresh)	1.0
2	0.8
5	0.6
10	0.4

- Changed isotherm shape

Degraded Silica Gel Isotherms

Microbead Silica Gel

50°C, 60% r.h.

Two Levels of Cycle Component Performance

Level	Direct		Regenerative heat	
	evaporative cooler effectiveness		exchanger effectiveness	
Low	0.86		0.79	
High	0.90		0.95	

Desiccant Degradation, Reduce Isotherm

Treg = 80°C, low DEC & HX effectiveness

Desiccant Degeneration, Reduce Isotherm

High DEC and HX effectiveness

Desiccant Degradation, Change Isotherm

T_{reg} = 80 °C

- [1] Fresh isotherm, hi effectiveness
- [2] Fresh isotherm, low effectiveness
- [3] Mod isotherm, hi effectiveness
- [4] Mod isotherm, low effectiveness

Systems Conclusions

Degradation may have significant (up to 40 - 50% reduction) impact on desiccant cooling performance

- Changing isotherm shape had a greater effect on performance than reducing the silica gel water capacity
- Reduction of silica gel water capacity 40% reduces overall COP 20%
- Magnitude of degradation effect on system performance is dependent on other component effectiveness
- Experimental data is needed to evaluate true degradation effect

DOE Desiccant Contamination Workshop

(DOE/HQ, Washington D.C., June 15-16, 1987)

- Participants: Universities, manufacturers, research laboratories, SERI and DOE
- Desiccant degradation can happen
 - Aging and thermal cycling
 - Contamination
- The gaseous pollutants that may be a problem are: SO₂, NO₂, NH₃, acetone, chlorinated hydrocarbons.
- Particulate matter may be a problem.
- Tobacco smoke is the worst frequent pollutant in a residence.

Contamination Workshop Recommendations

- Scoping experiments are needed: desiccant degradation as a function of time
 - Base case: thermal cycling desiccant with clean humid air
 - Worst case: thermal cycling desiccant with humid air charged with tobacco smoke or gaseous pollutants
- Degradation appreciable { $\xrightarrow{\text{No}}$ basic investigation $\xrightarrow{\text{stop}}$ stop
- Analytically quantify impact of degradation on system performance

Table 3.

Composition of Tobacco Smoke: Aromatic Fraction^a

Compound	Concentration (ppm)
Carbon monoxide	42,000
Carbon dioxide	92,000
Methane, ethane, propane, butane, etc.	87,000
Acetylene, ethylene, propylene, etc.	31,000
Formaldehyde	30
Acetaldehyde	3200
Acrolein	150
Methanol	700
Acetone	1100
Methyl ethyl ketone	500
Ammonia	300
Nitrogen dioxide	250
Methyl nitrite	200
Hydrogen sulfide	40
Hydrogen cyanide	1600
Methyl chloride	1200
Major Classes	Number of Compounds
Alkanes	27
Alkenes and alkynes	51
Aromatic hydrocarbons	96
Sterols and oxygenated isoprenoid compounds	15
Alcohols	24
Esters	272
Aldehydes, ketones, and quinones	45
Nitriles, cyclic ethers, and sulfur compounds	30
Acids	57
Phenols and phenolic ethers	55
Alkaloids and other bases	107
Brown pigments (volatile bases and alkaloids)	11
Amino acids, proteins, related compounds	14
Miscellaneous components	
Inorganics	17
Agricultural chemicals (– decomposition products)	12
Others	8
Total	841

^aThis fraction is usually identified by means of benzo-*a*-pyrene (BaP); from Siedman (1968).

Experiment Requirements

Purpose

To degrade desiccant samples under typical solar desiccant cooling conditions in a controlled manner so that the history of degradation (thermal cycling and exposure to smoke) is known

Accelerated Testing

- Options
 1. Pollutant concentrations and temperatures much higher than typical; shorter operation time
 2. Typical concentrations and temperatures; longer operation time
- Based on advantages and disadvantages, option 2 preferred.
24 hr/day for 9 months ($\approx$ 4-6 years of field operation)

Experiment Requirements (continued)

- Multiple desiccant samples [individual sample holders]
- Thermal cycling (2 to 5 min) between adsorption (100° F) and regeneration (240° F) temperatures [heaters/coolers, temperature sensors]
- Air flow through system (100-300 FPM) [air supply, flowmeters, pressure transducers]
- Humidity (0.011-0.016 lb water/lb air) [water vapor generator, humidity sensors]
- Base case: clean air [bottled, purified or filtered air]
- Worst case: tobacco smoke (6 mg TPM/m³) [smoke generator, smoke analyzer]

Table 4.

Measurements of Constituents of Tobacco Smoke^a

Constituent	Location	Ventilation, Air Changes Per Hour	Amount of Tobacco Burned	Concentration	Source ^b
<i>Experimental Conditions</i>					
CO	80-170 m ³ rooms	6.4-2.3	46-101 cigarettes	4.5-75 ppm	1, 2
	Small car, 25 m ³ chamber	none	4-9	12-110 ppm	3, 4
Nicotine	57-80 m ³ rooms	6.4-8.2	42 cigarettes, 9 cigars	<0.1-0.42 mg/m ³	2, 1, 5
	38-170 m ³ rooms	none	10 cigarettes, 9 cigars	0.13-1.04 mg/m ³	2, 5
Total particulate matter	15-425 m ³ homes	1-3	7-35 cigarettes	1.1-3.0 mg/m ³	6, 7
	25 m ³ chamber	none	4-24 cigarettes	2.28-16.65 mg/m ³	3
Dimethylnitrosamine	4-m ³ box, 20 m ³ room	none	10-100 cigarettes	0.23-2.9 µg/m ³	8
Acrolein	30-170 m ³ rooms	none-2.4	5-150 cigarettes	0.02-0.20 ppm	5, 9
Acetaldehyde	38-170 m ³ rooms	none-2.4	5-150 cigarettes	0.06-0.56 ppm	5
Formaldehyde	30 m ³ box	none	5-10 cigarettes	0.23-0.46 ppm	9
NO	30 m ³ box	none	5-10 cigarettes	0.19-0.36 ppm	9
NO ₂	30 m ³ box	none	5-10 cigarettes	0.02-0.04 ppm	9
<i>Natural Conditions</i>					
CO	Office, restaurant club, tavern, arena	-	-	2.5-28 ppm	10, 11, 12, 13, 14
	submarine, boat, autos, bus, airplane	none-20	4-150 cigarettes	3-33 ppm	15, 16, 17, 18
Nicotine	submarine, terminal, restaurant	-	Up to 150 cigarettes	1-35 µg/m ³	15, 19
Total particulate matter	tavern, arena	none-6	-	0.15-0.98 mg/m ³	11, 12
Particles	house	-	1 cigar	48 × 10 ⁶ particles/ft ³	20
Benzopyrene	arena	-	-	0.0071-0.021 µg/m ³	12, 21
Dimethylnitrosamine	bar	-	-	0.11-0.24 µg/m ³	8
Respirable particulate matter (RP)	restaurants, sports arena, bowling alley	-	-	100-700 µg/m ³	22

^aFrom Chapter 11, *Smoking and Health—A Report of the Surgeon General*, HEW (1979).

^bSources: (1) Anderson and Dalhamn (1973); (2) Harke (1970); (3) Hoegg (1972); (4) Harke et al. (1974); (5) Harke et al. (1972); (6) Lawther and Commins, (1970); (7) McNall (1975); (8) Brunnemann and Hoffman (1978); (9) Weber et al. (1976); (10) Chappell and Parker (1977); (11) Cuddeback et al. (1976); (12) Elliott and Rowe (1975); (13) Harke (1974); (14) Sebben et al. (1977); (15) Cano et al. (1970); (16) Godin et al. (1972); (17) Harke and Peters (1974); (18) Seiff (1973); (19) Hinds and First (1975); (20) Lefcoe and Inculet, 1975; (21) Galuskinova (1964); (22) Repace and Lowrey (1980).

Experiment Requirements (continued)

Degradation Measurements

- Adsorption capacity (isotherms)
 - Pore surface area
 - Pore volume and pore size distribution
 - Composition of pollutants on pore surfaces
- (All the above measurements can be done elsewhere — not in the contamination apparatus.)

Experiment Requirements (continued)

- Sample size: 1-2 grams
 - Large enough for sorption properties measurements
 - Small enough to make the size of the experiment small
 - Packed bed configuration
- Number of samples for statistically meaningful results:
 - Minimum of 4 samples per desiccant for base case tests
 - Minimum of 28 samples per desiccant for worst case tests (7 measurements in 0, 2, 4, 8, 16, 32, and 39 weeks)
- Size of the experimental apparatus depends on
 - Size and number of samples
 - Total air flow rate (100-300 FPM/sample)
 - Flow rate of tobacco smoke

Emission Factors for Mainstream and Sidestream Smoke

Properties	Source ^a	Mainstream	Sidestream	Sidestream/ Mainstream Ratio
<i>General Characteristics</i>				
Duration of smoke production	2	20 sec	550 sec	27
Amount of tobacco burnt	2	347 mg	411 mg	1.2
Number of particles per cigarette	2	1.05×10^{12}	3.5×10^{12}	3.3
Particle number median diameter	2	0.2 μ m	0.15 μ m	0.75
<i>Particulate Phase</i>				
		μ g/cigarette	μ g/cigarette	
Total suspended particulate matter	2	36,200	25,800	0.7
Tar (chloroform extract)	9, 2	<500-29,000	44,100	2.1
Nicotine	4, 9	100-2500	2700-6750	2.7
Total phenols	2	228	603	2.6
Pyrene	4	50-200	180-420	3.6
Benzo(a)pyrene	4	20-40	68-136	3.4
Naphthalene	4	2.6	40	16
Methylnaphthalene	4	2.2	60	28
Aniline	4	0.36	10.8	30
NNN ^b	4	0.1-0.55	0.5-2.5	5
NNK ^c	4	0.06-0.22	0.8-2.2	10
Cadmium	2	0.13	0.45	3.6
Nickel	3	0.08	-	-
Arsenic	3	0.012	-	-
2-Naphthylamine	4	0.002-0.028	0.08	39
Hydrogen cyanide	5	74	-	-
Polonium-210	7	0.029-0.044	-	-
		pCi/cigarette		
<i>Gases and Vapors</i>				
		μ g/cigarette	μ g/cigarette	
Carbon monoxide	4, 9	1000-20,000	25,000-50,000	2.5
Carbon dioxide	4	20,000-60,000	160,000-480,000	8.1
Acetaldehyde	1, 3	18-1400	40-3100	2.2 ^d
Hydrogen cyanide	4	430	110	0.25
Methylchloride	4	650	1,300	2.1
Acetone	4	100-600	250-1500	2.5
Ammonia	1, 3, 4	10-150	980-150,000	98
Pyridine	1, 3, 4	9-93	90-930	10
Acrolein	1, 3	25-140	55-300	2.2 ^d
Nitric oxide	3, 6, 8	10-570	2300 ^e	4
Nitrogen dioxide	3, 6, 8	0.5-30	625 ^e	20
Formaldehyde	3, 6	20-90	1300	15
DMN ^f	4	10-65	520-3380	52
NPy ^g	4	10-35	270-945	27

^aSources: (1) Wakenam (1972); (2) Hoegg (1972); (3) HEW (1979, Chap. 14); (4) HEW (1979), Chap. 11; (5) Schmeltz et al. (1975); (6) Weber et al. (1979); (7) Kelley (1965); (8) Jenkins and Gill (1980); (9) FTC (1981).

^bNitrosornicotine (NNN).

^c4-(N-methyl-N-nitrosamino)-1-(3-pyridyl)-1-butanone (NNK).

^dRatioed from total aldehydes.

^eBased on the data of Weber et al. (1979), Table 1, assuming a mixing factor of 1.0. Values will be lower if mixing was less than ideal.

^fDimethylnitrosamine (DMN).

^gNitrosopyrrolidine (NPy).

From "Indoor Air Pollution" by Wadden and Scheff, 1983, p. 59

Experiment Requirements (continued)

- Sample size: 1-2 grams
 - Large enough for sorption properties measurements
 - Small enough to make the size of the experiment small
 - Packed bed configuration
- Number of samples for statistically meaningful results:
 - Minimum of 4 samples per desiccant for base case tests
 - Minimum of 28 samples per desiccant for worst case tests (7 measurements in 0, 2, 4, 8, 16, 32, and 39 weeks)
- Size of the experimental apparatus depends on
 - Size and number of samples
 - Total air flow rate (100-300 FPM/sample)
 - Flow rate of tobacco smoke

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Properties	Source ^a	Mainstream	Sidestream	Sidestream/ Mainstream Ratio
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		$\mu\text{g/cigarette}$	$\mu\text{g/cigarette}$	
Total suspended particulate matter	2	36,200	25,800	0.7
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Nicotine	4, 9	100-2500	2700-6750	2.7
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		pCi/cigarette		
<i>Gases and Vapors</i>				
		$\mu\text{g/cigarette}$	$\mu\text{g/cigarette}$	
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^fDimethylnitrosamine (DMN).

^gNitrosopyrrolidine (NPy).

From "Indoor Air Pollution" by Wadden and Scheff, 1983, p. 59

Smoke Generation Requirements

- Tobacco smoke concentration, $c = 6 \text{ mg tpm/m}^3$
- Cigarette emission rate, $E = 36.66 \text{ mg/cigarette}$
- Burning rate = 10 minutes/cigarette
- Number of cigarettes/hour =
$$\frac{c * \text{Air Flow Rate}}{E}$$

<u>Air Flow Rate (cfm)</u>	<u>Number of Cigarettes Burned/Hour</u>
2	0.6
10	3
20	6
100	30*
500	150

*Cost of smoke generation = $30 \times 24 \times 270(\$1/20) = 9720\$/9 \text{ months}$

Base Case Configuration Options

Worst Case Configuration Options

(W1)

(W2)

(W3)

Experiment Apparatus Selection

- SERI existing test facilities vs options
 - QCM: not a flow-through system, samples too small
 - Sorption: needs modification for base case study; expensive to operate (bottled water)
 - Single blow: needs modification for either base case or worst case; expensive for worst case (100 cfm)
 - Cyclic: addition of smoke generator, very expensive for worst case (500 cfm)
- Other organizations' test facilities
 - Sent experiment specifications to several organizations
 - IIT Research Institute cyclic facility
 - Thermoelectron dual bed facility
- Building a new facility (cost, space, time considerations)

Experimental Apparatus Selection

- SERI existing facilities not appropriate
 - Do not meet the contamination experiment requirements
 - Costly to modify
 - Costly to operate
- Others existing facilities not appropriate
 - Do not meet all the contamination experiment requirements
 - Needs modification
 - Can operate only for a short period of time
- New facility appropriate
 - Can be built to meet the contamination experiment requirements
 - Costly initial investment
 - Low operating expenses

Final Selection for New Test Facility

Combine B4 and W2 to make only one facility (less expensive)
Two fixed desiccants, two air stream, smoked ambient air in
one desiccant, filtered ambient air in the other

Schematic of the Proposed Contamination Test Facility

The Contamination Test Facility

- A small subcontract to a local firm
 - Mechanical design
 - Electrical design
 - Cost estimate
- Smoke generator
 - Cigarette companies/research firms
 - Several conceptual designs

Desiccant Materials Contamination Research

Planned Activities

- Finalize the design of the contamination test facility including design of smoke generator
- Build the contamination test facility
- Shakedown the contamination test facility
- Degrade silica gel samples and measure their sorption properties as a function of time
- Use the results in a system model for quantification of performance degradation
- Prepare a status report

Anticipated Accomplishments

- Fabrication of a contamination facility to test any desiccants
- Experimental data on degradation of silica gel samples under controlled conditions
- Some indications if contamination causes a problem

Desiccant Contamination Research

Anticipated Results

SERI

APPENDIX B

**ELECTRICAL DIAGRAMS OF THE
DESICCANT CONTAMINATION TEST FACILITY**

Figure B-1. Desiccant contamination test facility electrical schematic—P&ID flow sheet

B/30/BB		TEMPERATURE TRANSM	
REV.		DATE		ISSUE AND REVISION

Figure B-3. Desiccant contamination test facility electrical schematic—Instrument loop diagrams

DOOR LAYOUT - FRONT VIEW
SCALE: 1/4" = 0'-1"

MOUNTING PANEL LAYOUT
(DOOR REMOVED)
SCALE: 1/4" = 0'-1"

CONTROL PANEL LAYOUT

NOTES

- PANEL SHALL BE FABRICATED AND INSTALLED BY CONTRACTOR. PANEL SHALL BE MOUNTED IN A LOCATION AS DIRECTED BY SERI.
- ALL CONTROL PANEL EQUIPMENT SHALL BE PROVIDED BY THE CONTRACTOR UNLESS OTHERWISE DIRECTED BY SERI.

REV.	DATE	ISSUE AND REVISION RECORD	BY	APPR.	AS
2	28/05	CONTROL RELAY (CR9) ADDED	GDP		
1	30/05	TEMPERATURE TRANSMITTERS R1 (OVED	GDP

Figure B-4. Desiccant contamination test facility electrical schematic—control panel layout

A

B

C

D

E

F

G

NOTES

1. ALL PANEL DEVICES AND WIRING SHALL BE TAGGED WITH IDENTIFICATIONS AND WIRE NUMBERS AS SHOWN ON DRAWING.
2. ALL PANEL WIRING SHALL BE #14AWG, MULTISTRANDED COPPER, COLORED AS REQUIRED, UNLESS OTHERWISE NOTED.
3. INSTRUMENTATION WIRING AND CONTROL WIRING SHALL BE ISOLATED WITHIN CONTROL PANEL WHERE POSSIBLE. USE OF PLASTIC WIRING DUCT WITHIN CONTROL PANEL IS RECOMMENDED, BUT NOT REQUIRED.

DOOR CONNECTIONS (REAR VIEW)

REV.	DATE	ISSUE AND REVISION RECORD	BY
1	28/08/00	CONTROL RELAY (CR9) ADDED	GDP
2	30/00	TEMPERATURE TRANSMITTERS REMOVED	GDP

Figure B-5. Desiccant contamination test facility electrical schematic—control panel internal connection diagram

C

ITEM	QTY.	DESCRIPTION	MFG. & CAT. NO.
(1)	2	ELECTRIC DAMPER ACTUATOR, STANDARD REVERSIBLE, WITH 1000 OHM FEEDBACK POSITION POTENTIOMETER (SUPPLIED WITH VALVE - SEE DRAWING M-2)	CRANE CONTROLS MAR-1010 (SUPPLIED W/VALVE)
(2)	3	INLINE TURBINE TYPE FLOWMETER, FOR AIR MEASUREMENT, 1.5" LINE, 8-80 ACFM FLOW RANGE, STANDARD PICK-UP WITH LEADS AND CANNON CONNECTOR WITH 15' CABLE	HYDRIL SERIES 8822 #822 02-44-3-01
(3)	6	THERMOCOUPLE, TYPE "T", EXPOSED TIP, 300Y MAX TEMP CONTRIN (EXACT CATALOG NUMBER IN FIELD WITH LOCAL SALES OFFICE - PROCESS EQUIPMENT SALES CORP.) SEE NOTE J.	THERMOTRICS (TO BE DETERMINED BY FIELD)
(4)	1	OPTICAL CONDENSATION DEWPOINT MONITOR, CHILLED MIRROR DEWPOINT SENSOR AND SAMPLING SYSTEM	BY SERI
(5)	1	LOW PRESSURE SWITCH, 0-1.0 INCHES OF WATER	DWYER SERIES 3000 #3001
(6)	1	SIZE 0, FLUX VALUING, NON-REVERSING MOTOR STARTER, NEMA TYPE 1, SURFACE MOUNTED ENCLOSURE COMPLETE WITH 1 N.O. & 1 N.C. AUX. CONTACT AND 1 SEAL-IN N.O. CONTACT, 120V, 60HZ	SIMILAR TO ALLEN-BRADLEY A509-AXXD WITH AUX CONTACTS
(7)	2	TEMPERATURE SWITCH, DIRECT VERTICAL IMMERSION TYPE, 140 TO 290 DEGREES F, ADJUSTABLE OPERATING RANGE	ALLEN-BRADLEY #B37-V3A

1. ALL WIRING RUNS SHALL BE IN CONDUIT, AS DIRECTED BY S.E.R.I. ALL CONDUIT & WIRING SHALL CONFORM TO THE LATEST NATIONAL ELECTRIC CODE (NEC).
2. ALL EQUIPMENT, CONDUIT, WIRING & ETC. SHALL BE PROVIDED BY CONTRACTOR UNLESS OTHERWISE SPECIFIED BY S.E.R.I.
3. THERMOCOUPLES SHALL BE MOUNTED IN TEE WITH END OF EXPOSED IN CENTER OF AIR FLOW LINE. THERMOCOUPLE LENGTHS AND HANGERS SHALL BE FIELD DETERMINED. SEE ITEM 3 IN SCHEDULE ABOVE.
4. ALL WIRES AND DEVICES SHALL BE TAGGED WITH NUMBERS AS SHOWN ON DRAWING.

[illegible]

APPENDIX C
SELECTED DISTRIBUTION LIST

SELECTED DISTRIBUTION LIST

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