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NATIONAL DESICCANT COOLING PROGRAM

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ABSTRACT

This paper briefly describes the concepts under development by Department of Energy desiccant cooling contractors, the status of these efforts and the work remaining, and the efforts underway in SERI's desiccant cooling research program. The desiccant cooling programs at Zeopower Co. and the University of Wisconsin—Madison are not described here because they are discussed in separate papers for this review meeting.

BACKGROUND

Contractors for the U.S. Department of Energy (DOE) are performing R&D on residential-size solar cooling systems using desiccation processes. Four contractors are developing solar cooling systems which use open-cycle adsorption processes: AiResearch Manufacturing Co., Illinois Institute of Technology (IIT), Institute of Gas Technology (IGT), and University of Wisconsin—Madison. These projects are in various stages of completion, ranging from basic research and analysis to cooling system development and prototype testing. One contractor, Zeopower Co., is currently working on a closed-cycle adsorption system using natural zeolites as the desiccant material; prototypes are being constructed and will be laboratory tested late in FY80. Colorado State University (CSU) recently began to evaluate analytically and experimentally an open-cycle absorption system using a packed tower concentrator. The Solar Energy Research Institute (SERI) has DOE program management responsibilities for national solar desiccant cooling programs and is continuing its own research program.

The open-cycle adsorption process is receiving most of the effort in the current DOE desiccant cooling program. The major, unique component in these systems is the dehumidifier bed, which removes moisture from the process airstream. These systems usually can operate in one of two modes: ventilation or recirculation. The ventilation system configuration is shown in Fig. 1. In the supply stream, ambient air is adiabatically dehumidified, sensibly cooled, evaporatively cooled, and then introduced into the conditioned space. In the regenerating stream, air removed from the conditioned space is evaporatively cooled, then heated as it cools the supply stream, heated again by solar energy, cooled and humidified in the dehumidifier, and finally exhausted to the ambient air (see Fig. 2; the numbers correspond to the bulk airstream conditions at the numbered system locations shown in Fig. 1). The AiResearch and IGT systems follow this basic process.

In the recirculation system configuration the supply and regenerating airflow streams are separate. The supply stream air is removed from the conditioned space, adiabatically dehumidified, sensibly cooled, evaporatively cooled, and then reintroduced into the conditioned space. In the regenerating stream, ambient air is evaporatively cooled, then heated as it cools the supply stream, heated again by solar energy, humidified and cooled as it regenerates the dehumidifier, and exhausted to the ambient air.

IIT is developing a dehumidifier in which a portion of the heat of adsorption is removed by a cross-cooling air stream. This improves desiccant performance but requires additional parasitic power to provide the cross-cooling.

The liquid desiccant cooling process of open-cycle absorption, under investigation at CSU, is shown schematically in Fig. 3. This cycle is similar to its closed-cycle counterpart except that the weak absorbent solution is regenerated by evaporating refrigerant (water) to the atmosphere instead of recovering it in the condenser. The dilute solution is heated

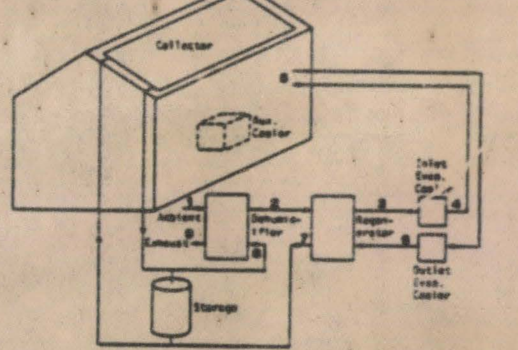

Figure 1. VENTILATION SYSTEM CONFIGURATION

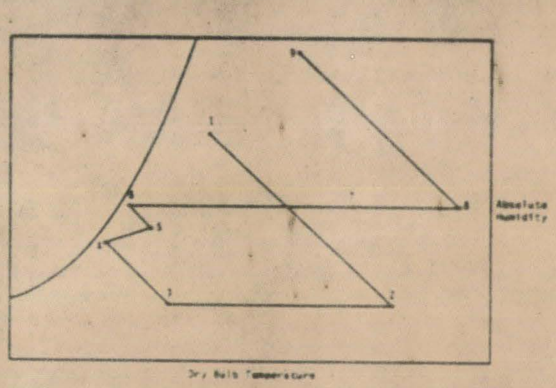

Figure 2. VENTILATION MODE PSYCHROMETRIC DIAGRAM

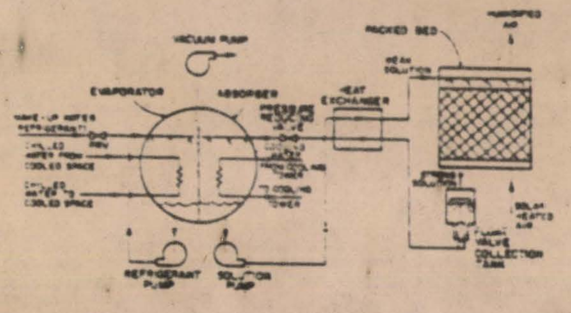

Figure 3. OPEN-CYCLE ABSORPTION SYSTEM SCHEMATIC

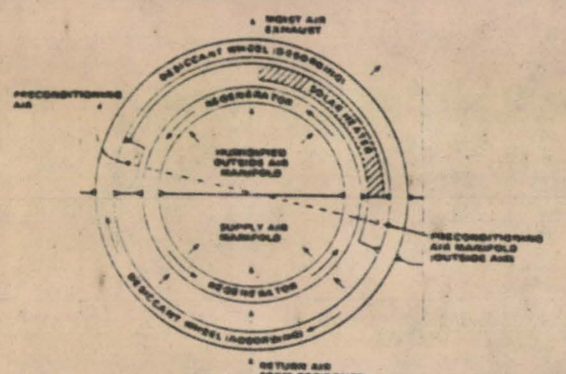

Figure 4. AIRESEARCH ROTARY RADICAL OUTFLOW DEHUMIDIFIER

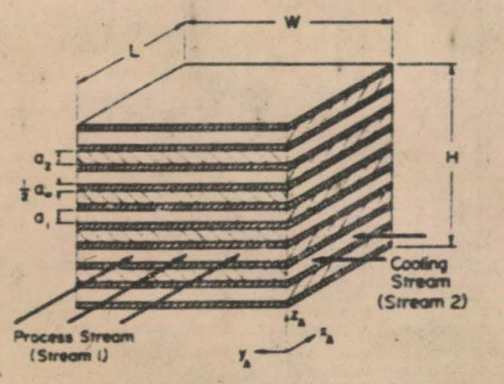

Figure 5. IIT CROSS-COOLED DEHUMIDIFIER

and regenerated using an air collector system and a packed-tower concentrator. The strong, regenerated solution leaves the concentrator and passes through a valve in which pressure is reduced from atmospheric levels. The solution passes through a regenerative heat exchanger and then to the absorber, where the solution absorbs water from the evaporator, maintaining the reduced pressure required by the evaporator. The heat of absorption for the water-absorbent solution is removed by a cooling tower loop. In the evaporator, water from an external source is evaporated at reduced pressure with the heat supplied from the cooled space. The resulting weak solution is pumped from the absorber back to atmospheric pressure through the regenerative heat exchanger and to the concentrator, completing the cycle. A vacuum pump deaerates the solution after it has been exposed to the atmosphere. The useful output of the CSU system is the evaporation of water. For every pound of water evaporated in the concentrator, one pound of water can be evaporated in the evaporator and absorbed in the absorber. Thus, the water evaporation rate from the concentrator determines cooling system performance.

AIRESEARCH MANUFACTURING COMPANY

AiResearch is developing a solar desiccant cooler which features a rotary radial outflow configuration [1,2,3]. The design is intended to reduce parasitic power requirements by increasing the face areas of the dryer and regenerative heat exchanger and reducing their airflow length. The desiccant bed and the regenerator are two counter-rotating concentric drums. The desiccant material is silica gel, and the regenerator matrix is a fine screen of galvanized steel. A top view of the dehumidifier along the axis of rotation is shown in Fig. 4. The prototype dehumidifier drum is 86 cm (34 in.) high, and 86 cm in diameter, has a 3-cm (1.15-in.) thick airflow length through the desiccant, and rotates at 5 rph. The system was designed for 5.3-kW (1.5-ton) cooling capacity, a COP of 0.52, and parasitic power input at full flow of 0.6 kW.

Fabrication of the prototype was completed in June 1979, and the unit was installed in a controlled atmosphere chamber for testing in September 1979. Preliminary tests indicated that the prototype unit cooling capacity was 4.2 kW (1.2 tons) with a COP of 0.45, a performance lower than expected. Further investigations revealed defects in the desiccant drum. Variations in the desiccant drum thickness caused flow maldistributions through the desiccant material, decreasing the system performance. The prototype test program was halted while the desiccant drum was rebuilt. The new drum has been installed in the prototype, and the system is ready for further tests. This effort is scheduled to be completed by May 1980.

ILLINOIS INSTITUTE OF TECHNOLOGY (IIT)

IIT is developing a solar desiccant cooling system that uses silica gel in a cross-cooled dehumidifier [4]. The dehumidifier is constructed of paper-like sheets of silica gel in a Teflon matrix. (See Fig. 5 for schematic representation.) The cooling system consists of two cross-cooled dehumidifiers of equal size with evaporative coolers. One dehumidifier removes moisture from the process air while the other is regenerated by solar energy.

Much of the work to date on this concept has been basic R&D, including the development of mathematical analysis methods, production and testing of silica gel sheets, and testing of a small model of the cross-cooled bed. However, a prototype dehumidifier equivalent to approximately 2.6-kW (0.75-ton) cooling capacity has been built and is being laboratory tested.

The small dehumidifier (15 x 15 x 15 cm, or 6 x 6 x 6 in.) was built and tested under periodic steady-state conditions [5]. The major parameters affecting system performance were studied (process stream flow rate, temperature, and humidity; cross-cooling stream flow rate and temperature; regeneration stream flow rate, temperature, and humidity). These tests indicated that cross-cooling could improve dehumidifier performance about 40%.

The system currently undergoing laboratory testing includes a 0.6 x 0.6 x 0.6 m (2 x 2 x 2 ft) dehumidifier. Inlet conditions to the system are controlled and held constant

Table 1. EFFECT OF REGENERATION TEMPERATURE ON CAPACITY AND COP

ENERGY INPUT TYPE	CONDITIONS DB/DP, °F OUTDOOR	CONDITIONS DB/DP, °F INDOOR	THIRD STREAM FRACTION	REGEN'R EFFECT. %	REACT. TEMP., °F	ENERGY INPUT BTU/HR	FRACTION SOLAR INPUT, %	COOLING CAPACITY TONS	COP	EER
S-G	93.8/67.5	79.6/60.0	0.28	96.1	194	70310	44.8	2.52	0.45	22.4
S-G	94.2/66.7	79.6/60.6	0.27	95.7	195	64580	46.5	2.60	0.48	23.1
S-G	96.0/67.3	80.7/59.3	0.27	97.7	204	65570	50.9	2.58	0.47	22.9
S-G	94.8/67.1	79.9/59.5	0.18	92.4	211	67820	49.9	2.38	0.42	21.2
S-G	95.8/67.5	80.4/60.5	0.22	94.5	209	67890	50.0	2.42	0.42	21.5
G	95.4/67.9	80.9/60.2	0.23	95.0	251	76005	0	3.09	0.49	27.5

during each run. For an air flow rate of 0.22 kg/s, the system has shown a cooling capacity of 2.1 kW (0.6 ton) and a COP of 0.50.

Future work will aim to completely characterize the performance of the prototype dehumidifier through laboratory testing, refine and improve dehumidifier performance modeling, and model the total cooling system. In addition, a total cooling system will be built, complete with solar collectors and two dehumidifier beds, to test the system performance under outdoor operating conditions with solar energy input. Construction of this system will be completed by May 1980, and testing will be conducted during the summer.

INSTITUTE OF GAS TECHNOLOGY (IGT)

IGT is developing a solar desiccant cooling system which uses a molecular sieve rotary dehumidifier wheel and a natural gas-fired burner to supplement the solar energy input [6]. As shown in the SOLAR-MEC III schematic in Fig. 6, the rotary desiccant wheel is divided by a partition into two balanced-flow segments, one for moisture removal and the other for passage of the high-temperature reactivation air stream. These two streams flow in opposite directions. Considerable design and testing efforts were conducted at IGT on the SOLAR-MEC cooler previous to the current DOE-funded program. Two units were field tested, and the results of these tests provide the basis for the present program.

The SOLAR-MEC III, showing results from the current DOE program, includes several improvements over previous versions in the following areas: air seals, wheel support and drive mechanisms, air distribution and fans, and rotary heat exchange wheel. Two significant design changes include staged regeneration of the desiccant wheel and unbalanced flow operation of the heat exchange wheel. Table 1, resulting from laboratory tests of SOLAR-MEC III, illustrates the effect of regeneration temperature on system cooling capacity and COP. The parasitic power consumption of SOLAR-MEC III is 1.35 kW, whereas the early version used 2.31 kW.

IGT also developed a mathematical model and computer program for the SOLAR-MEC and, in conjunction with AB Carl Munters of Sweden, developed a nonasbestos-substrate desiccant wheel to replace the asbestos-substrate wheel. The computer model was used to help determine optimum system design, part load operation, and seasonal performance of the SOLAR-MEC. The nonasbestos desiccant wheel (using a LiCl desiccant) was recently incorporated into the SOLAR-MEC III and initial laboratory tests show satisfactory performance.

Future work in this program will include laboratory testing of the SOLAR-MEC III with the nonasbestos desiccant wheel and refinement of the seasonal simulation model. Numerous laboratory tests will be performed to completely characterize the SOLAR-MEC III performance over expected operating ranges. These tests will be conducted with regeneration energy input from solar energy alone and from the solar/natural gas combination. The seasonal simulation model will be revised to include an allowance for air leakage and a detailed parasitic power calculation.

COLORADO STATE UNIVERSITY (CSU)

CSU began an experimental investigation of an open-cycle lithium chloride absorption cooler (Fig. 3) in February 1980. The major purpose of the work is to measure the heat and mass transfer characteristics of a packed tower containing Raschig rings and Berl saddles over the potential operating range of the cooling system. Results will be compared with previous CSU theoretical analyses of the reconcentration of lithium chloride in a packed column [7,8].

The apparatus being assembled for the experiments is shown in Fig. 7. Heated air will be supplied from a fuel-fired heater to the packed column. The lithium chloride solution will be circulated through the column, diluted, and cooled in a heat exchanger to the desired supply temperature. The humidity and temperature of the air supply will be controlled. Based on the results of these experiments, CSU will design a complete 3-ton cooling system.

SOLAR ENERGY RESEARCH INSTITUTE (SERI)

A large part of the in-house work of the SERI Desiccant Cooling Program has been aimed at comparing the performance of desiccant machines with that of absorption, Rankine, and vapor-compression machines [9]. SERI is developing a universal, desiccant-bed heat- and mass-transfer

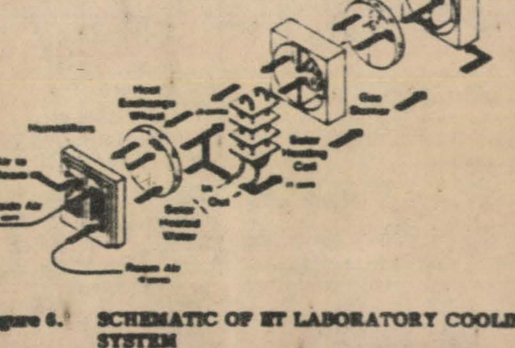

Figure 6. SCHEMATIC OF IGT LABORATORY COOLING SYSTEM

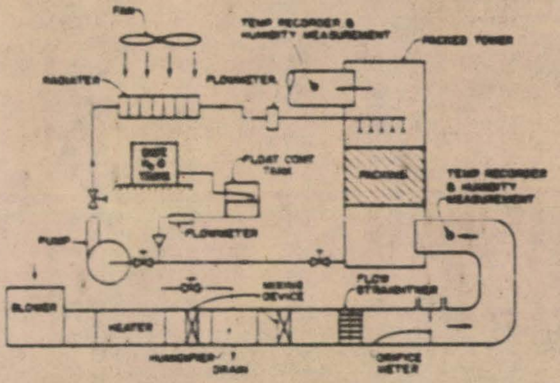

Figure 7. CSU EXPERIMENTAL APPARATUS

model that will allow simulation of solar desiccant machines and generation of tools for their proper design.

Consultants from the Colorado School of Mines are providing SERI with experimental data (equilibrium capacities of desiccants as a function of concentration and temperature) as well as expertise in adsorption modeling. Once the mass transfer and diffusion coefficients are determined, breakthrough curves (solute concentration in the effluent stream vs. time) can be obtained from the equilibrium capacities by solving the energy and mass balances in the bed. From these curves and the mass- and heat-transfer model, rates of adsorption, bed exhaustion times, and degree of regeneration can be predicted. The SERI model will be used to generate this information for the numerous desiccant materials described by the Radke-Prausnitz isotherm.

The analytical model will be validated in the SERI desiccant laboratory and with a specially designed gas chromatograph [10]. The desiccant laboratory can supply 17 m^3/min (600 cfm) of air at 121°C (250°F) and a wide range of humidities to full-scale drier beds. Effluent humidity is measured with an optical dew-point hygrometer and plotted as a function of time to give breakthrough curves. Ambient conditions and solar regeneration can also be simulated to verify the predictions of the model. The gas chromatograph records breakthrough curves and equilibrium data (adsorption isotherms) by means of perturbation chromatography. Diffusion coefficients for the bed can be measured directly, and diffusion coefficients within a single particle of desiccant material can be predicted from the breakthrough curves [10].

SERI is also exploring the role desiccants can play in meeting the latent cooling load in passive buildings. A desiccant machine, such as the IGT or AiResearch device, used for dehumidification only will be modeled. The heat- and mass-transfer model will be extended to include these systems, and the materials characterization work will include desiccants such as natural zeolites, which are particularly interesting for passive applications. Design tools will be generated using the heat- and mass-transfer model and the desiccant laboratory. In particular, parametric studies will evaluate the trade-offs among bed efficiency, parasitic energy, bed geometry and packing, thermodynamic strategy for cooling, and economics.

The investigation of solid-to-solid phase-change energy storage materials is a third SERI research task. A class of simple organic compounds with tetrahedral structure exhibits reversible solid-to-solid structural transformations with large enthalpy changes. One such compound is pentaerythritol ($C_5H_{12}O_4$), a chemical mass-produced for use in paint resins. Pentaerythritol can reversibly store 77 cal/g at 188°C in a solid-to-solid transformation. This and related low-cost compounds are being studied as candidate materials for direct-contact storage/heat exchangers to help level the temperature of regeneration air entering desiccant coolers.

SERI is also exploring the possibility of combining an open-cycle absorption chiller with a solar-assisted heat pump for summer cooling and winter heating. For this task, the thermal effectiveness of open-flow collectors (the salt-solution working fluid flows over the collector in direct contact with the atmosphere) is being analyzed. If the salt solutions (LiCl and $CaCl_2$) do not freeze or lose water in the winter, the same collectors which evaporate refrigerant to the atmosphere in the summer can be used to supply energy to a vapor-compression heat pump for winter heating. The vapor-compression heat pump is normally needed for backup cooling in any case. Computer models of the refrigeration system for the cooling season are being adapted to winter conditions for candidate cities.

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