Experimental Testing of Cooling by Low Pressure Adsorption in a Zeolite

**C.M. Redman
New Mexico Solar Energy Institute**

January 1985

**Prepared by
New Mexico Solar Energy Institute
for Pacific Northwest Laboratory
under Contract DE-AC06-76RLO 1830
with the U.S. Department of Energy**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy	
Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

EXPERIMENTAL TESTING OF
COOLING BY LOW PRESSURE
ADSORPTION IN A ZEOLITE

C. M. Redman (a)

January 1985

Prepared by
New Mexico Solar Energy Institute
for Pacific Northwest Laboratory
under Contract DE-AC06-76RLO 1830
with the U.S. Department of Energy
Subcontract B-B5238-A-0

Pacific Northwest Laboratory
Richland, Washington 99352

(a) New Mexico Solar Energy Institute
New Mexico State University

FOREWORD

Seasonal thermal energy storage (STES) involves storing thermal energy, such as winter chill, summer heat, and industrial waste heat, for future use in heating and cooling buildings or for industrial processes. Widespread development and implementation of STES would significantly reduce the need to generate primary energy in the U.S. In fact, 1980 data indicate that STES is technically suitable for providing 5 to 10% of the nation's energy with major contributions in the commercial, industrial, and residential sectors.

Part of the Pacific Northwest Laboratory's (PNL) objective with the STES Program is to identify new and promising methods for STES. Under sponsorship of the U.S. Department of Energy, PNL (operated by Battelle Memorial Institute) issued a request for proposals for development of innovative methods for performing or augmenting seasonal chill storage for space or process cooling. In response to this request for proposal, a contract was awarded to New Mexico Solar Energy Institute to design, construct, and operate a small-scale facility to test the use of zeolite adsorption of water vapor to augment chill storage in ice for conventional space cooling. The facility uses solar-derived energy for the heat source and evaporatively chilled water for the heat sink. Cooling is provided by sublimation of the ice instead of melting. This report describes the design and construction phases, as well as system performance.

The system, as configured for the experiments described in this report, has substantial parasitic energy requirements. These requirements might be avoided by using other adsorbents or by developing new adsorbents having improved adsorption/desorption properties. (This latter alternative is now being explored and could result in dramatic reduction of parasitic energy requirements while improving the effectiveness per cycle by as much as a factor of 5.) Because water vapor flows at low pressure in the system, high vapor flow rates are necessary. However, these high flow rates were not a limiting factor in the testing. Additional study is being considered in selected technical areas supportive to both seasonal and diurnal energy storage with adsorbents.

Landis D. Kannberg, Manager
Underground Energy Storage Program

SUMMARY

The New Mexico Solar Energy Institute, under contract to Pacific Northwest Laboratory (operated for the U.S. Department of Energy by Battelle Memorial Institute) designed, constructed, and utilized a small scale facility to test the use of zeolite adsorption of water vapor to augment chill storage in ice for conventional space cooling. The facility uses solar-derived energy,* for the heat source and evaporatively chilled water for the heat sump. The product cooling uses sublimation of ice instead of melting. The specific tasks of this project were to 1) develop and design a detailed specification for a solar zeolite chill-augmented storage system, which includes a zeolite tank, ice tank, and heat exchanger; 2) construct the system as approved by PNL; 3) instrument and test the system; 4) perform a study of adsorbers; and 5) analyze and report the findings.

The ZCAT facility utilizes a heat pumping technique in which a water vapor adsorbent functions as the compressor and condenser. The design was based on use of 13X zeolite as the adsorber because of its high adsorbence at low pressures. However, as a result of the work done on this project it has been determined that other materials such as silica gel should give superior performance. Table S-1 below shows that while zeolite 13X holds more water in the pressure and temperature ranges of interest, silica gel cycles more water and has less residue water. Both points are very important in the design of an efficient and cost effective system.

*To speed up the overall test schedule an electric water heater was added to the test apparatus.

TABLE S-1. Adsorber Comparison

Temperature (°F)	Pressure (psia/torr)	Silica Gel (lbs water/100 lbs adsorber)	Zeolite
167	0.256/13.2	3.1	20.2
77	0.087/4.5	10.2	23.6
Water cycled		7.1	3.4
Residual water		3.1	20.2

DESIGN AND CONSTRUCTION

The ZCAT facility consists of three primary subsystems. 1) The central part of the facility is the evacuated system consisting of 64 zeolite tubes, 64 condenser tubes, manifold, ice tank, and a daily cooling storage tank. 2) The thermal drive is a solar water heating system. 3) The heat sump is an evaporative water chiller. Design and construction details are provided in Appendix D of this report. The solar panel and evaporative water chiller were available from previous projects and were not optimized for this project.

OPERATIONAL CONCEPT

The ZCAT facility utilizes zeolites in a heat-pumping mode, which reduces the pressure below 0.0887 psia. Heat from stored ice is transferred via water vapor to the zeolite. The vapor sublimated releases its heat to the zeolite upon adsorption. The heat of adsorption varies inversely with zeolite temperature, but in the temperature range of most interest it is typically between 1200 and 1400 Btu per pound. Circulating water carries the heat from the zeolite to the heat sump. The 1218.7 Btu removed from the ice for each pound of ice sublimated can be used to freeze an additional 8.5 pounds of water, cool ice, or cool a heat load.

Zeolite is a good compressor-condenser only when it is sufficiently dry. The major complexity of this heat-pumping technique is the process

for drying the zeolite. The "dryness" increases with increasing temperature and decreasing pressure in the zeolite. The ZCAT facility utilizes hot water from a solar heating system and condensing water from an evaporative water chiller to dry the zeolite.

SYSTEM TESTING

Systems testing of the zeolite heat pumping system was initiated on January 30, 1984. In the next 7 weeks, 17 test runs were made, critical temperatures were plotted, adsorption and desorption end points were plotted on zeolite isobars, and desorption versus time plots were drawn. Performance analysis was done and estimates of system effectiveness were made.

Table S-2 summarizes the performance of 14 test runs. These test runs averaged 141 percent in performance when comparing actual water processed (cooling furnished) to the theoretical water processed. The average time to 90 percent of desorption was 70 minutes. Since the ZCAT facility did not have a vapor flow meter, adsorption time was not determined. The table also shows that performance increased significantly after long vacuum pumping (typically 6 to 10 hours) and then decreased with time if significant vacuum pumping was not done.

Detailed data for these runs are provided in the report and appendices.

CONCLUSIONS

The zeolite chill-augmented test facility was designed, constructed, and tested and found to conform to the theory based on the zeolite manufacturer's data. Other noteworthy factors are listed below.

1. Testing results indicate that the ZCAT facility performance is dependent on the duration of vacuum pumping done prior to initiation of testing. No method of measuring the "cleanness" of the zeolite was available but indications of "gas poisoning" are implied by some test data.

TABLE S-2. Summary of Performance

Date of Test	Desorbed ¹ Water, Lbs	Percent ² of Theoretical	Desorption ³ Time	Time to ⁶ 90% of Desorption
1/30	10.40	179 ⁴	140	82
1/31	6.85	134	168	132
2/2	5.64	115	183	140
2/7	4.30	88	47	28
2/10	6.40	121 ⁴	81	47
2/14	6.80	155 ⁴	119	36
2/18	5.15	123	79	52
2/24	6.00	140	120	55
3/1	6.15	154 ⁵	87	56
3/6	5.50	131	100	80
3/11	1.64	51	120	59
3/12	4.74	296 ⁵	123	80
3/13	4.75	151	120	76
3/14	5.06	144	130	63
	Average	141	116	70

¹Desorbed water as measured with a graded cylinder.

²Percent of measured water to that determined by pressure and temperature measurements and zeolite manufacturer's data.

³Time in minutes to reach the desorption.

⁴Long vacuum pumping the day before the test.

⁵Long vacuum pumping the night before the test.

⁶Time in minutes to reach 90 percent of final desorption.

2. Indications are that both adsorption and desorption flow rates were higher than projected.

3. The speeds of adsorption and desorption seem to be limited by the rate of heat flow out of and into the zeolite and out of the vapor during condensation.
4. The zeolite used for this test was not optimum. Other materials have been found to process more water (furnish product cooling) and leave less residual water.

The general design of the system was suitable for this project. However, the tanks housing the zeolite, condenser, and manifold sections did not allow differential pressurization, and operational problems resulted. Thermal insulation of the system was marginal, allowing some ambient air and solar derived heating. Also, a bidirectional low pressure vapor flowmeter should be used to more thoroughly analyze system performance.

RECOMMENDATIONS

A parallel program of laboratory investigations to include old adsorbers and new adsorbers with better structural design for low pressure operation should be carried out. This would include a theoretical investigation of adsorbers to identify new designs with the low pressure high water adsorption of zeolite 13X and the low pressure low temperature drying characteristics of silica gel. These new materials should then be tested in the ZCAT facility.

While the general design of the ZCAT facility was suitable for analysis of pumping heat from ice, some design changes are recommended. A technique for allowing some differential pressurization of the water in the zeolite and condenser tanks would greatly ease test operation. Additional hot and cool water storage would lower the temperature transients and improve the accuracy of the temperature measurements. A better pressure transducer for the 0.01 to 1.00 psia range and differential temperature measurements for the zeolite tank and condenser tank water inputs and outputs would substantially improve analysis capabilities. Also a bidirectional water vapor flow meter for use down to 0.01 psia is necessary for complete analysis of the ZCAT facility performance.

ACKNOWLEDGMENTS

The initial design for the zeolite tubes was done by Mr. Robert Sabin of the New Mexico State University Physical Science Laboratory. Mr. Sabin also furnished extensive support in the areas of system design and testing. Dr. Kenneth McCorkle of the Chemical Engineering Department, New Mexico State University, furnished considerable advice concerning performance of zeolite and was responsible for the zeolite materials study portion of this contract. Dr. R. J. Liefeld of the Physics Department, New Mexico State University, furnished a mass spectrometer helium leak detector and technical support in its use as well as other very helpful guidance on vacuum techniques.

We wish to thank the U.S. Department of Energy for financial support and Dr. Landis Kannberg of the Battelle Pacific Northwest Laboratories for his technical support which greatly aided in the success of this project.

We also wish to thank New Mexico State University students John Bauer and Jerry Tyree for the construction and testing of the zeolite chill-augmented test facility.

CONTENTS

SUMMARY	v
ACKNOWLEDGMENTS	xi
INTRODUCTION	1
BACKGROUND	1
OBJECTIVES	1
ZEOLITE CHILL-AUGMENTED TEST FACILITY	3
DESIGN	4
PERFORMANCE	15
CALCULATED PERFORMANCE	17
SYSTEMS CHECKOUT	18
Zeolite Tube	18
Manifold-Condenser	22
Condensate Receiver	23
Ice Tank	23
SYSTEMS TESTING	23
TEST AND ANALYSIS	25
Electrical Analysis	44
PROPERTIES OF ZEOLITES FOR ADSORPTION REFRIGERATION SYSTEMS	46
REFERENCES	56
APPENDIX A - SUMMARY OF TEST RUNS	A.1
APPENDIX B - EXHIBIT OF DATA FROM TEST RUNS	B.1
APPENDIX C - CALIBRATIONS OF TEMPERATURES AND CONDENSATE RECEIVER	C.1
APPENDIX D - DETAILS OF CONSTRUCTION	D.1
Evaporative Water Chiller	D.3
Zeolite Tank	D.12
Condenser Manifold	D.15
Condensate Receiver	D.25
Solar System	D.25
Vacuum Gauges	D.25
Ice Tank	D.25
Labor and Material Breakdown	D.34

CONTENTS (continued)

Data Collection	.	.	.	.	.	.	.	.	.	.	D.42
Test Control	.	.	.	.	.	.	.	.	.	.	D.46

FIGURES

1	Solar Zeolite Adsorptive Cooling	5
2	Zeolite Tube	8
3	Solar Zeolite System, Looking East	9
4	Solar Zeolite System, Looking North	11
5	System Looking East	13
6	System Looking West	14
7	Solar Day Heat Flow, 82.7°F to 180°F	19
8	Constant Moisture, 56°F to 82.7°F, 0.0887 psia to 0.222 psia	19
9	Nocturnal Heat Flow, 147.7°F to 56°F	20
10	Constant Moisture, 180°F to 147.7°F, 0.222 psia to 0.0887 psia	20
11	Molecular Sieve 13X Isobars	21
12	Zeolite Isobars	29
13	Temperatures for March 14 Test Run	31
14	Desorption Response	37

APPENDIX B

B-1-a	Zeolite Isobars	B.5
B-1-b	Data Run, January 30, 1984	B.6
B-1-c	Desorption Response	B.7
B-1-d	Data Printout	B.8
B-2-a	Zeolite Isobars	B.9
B-2-b	Data Run, January 31, 1984	B.10
B-2-c	Desorption Response	B.11
B-2-d	Data Printout	B.12
B-3-a	Zeolite Isobars	B.13
B-3-b	Data Run, February 2, 1984	B.14
B-3-c	Desorption Response	B.15
B-3-d	Data Printout	B.16
B-4-a	Zeolite Isobars	B.17

B-4-b	Data Run, February 7, 1984		B.18
B-4-c	Desorption Response		B.19
B-4-d	Data Printout		B.20
B-5-a	Zeolite Isobars		B.21
B-5-b	Data Run, February 10, 1984		B.22
B-5-c	Desorption Response		B.23
B-5-d	Data Printout		B.24
B-6-a	Zeolite Isobars		B.25
B-6-b	Data Run, February 14, 1984		B.26
B-6-c	Desorption Response		B.27
B-6-d	Data Printout		B.28
B-7-a	Zeolite Isobars		B.29
B-7-b	Data Run, February 18, 1984		B.30
B-7-c	Desorption Response		B.31
B-7-d	Data Printout		B.32
B-8-a	Zeolite Isobars		B.33
B-8-b	Data Run, February 24, 1984		B.34
B-8-c	Desorption Response		B.35
B-8-d	Data Printout		B.36
B-9-a	Zeolite Isobars		B.37
B-9-b	Data Runs, February 28, 1984		B.39
B-9-c	Desorption Response		B.41
B-9-d	Data Printout		B.42
B-10-a	Zeolite Isobars		B.44
B-10-b	Data Run, March 1, 1984		B.45
B-10-c	Desorption Response		B.46
B-10-d	Data Printout		B.47
B-11-a	Zeolite Isobars		B.48
B-11-b	Data Run, March 6, 1984		B.49
B-11-c	Desorption Response		B.50
B-11-d	Data Printout		B.51
B-12-a	Zeolite Isobars		B.52
B-12-b	Data Run, March 11, 1984		B.53
B-12-c	Desorption Response		B.54

B-12-d	Data Printout	B.55
B-13-a	Zeolite Isobars	B.56
B-13-b	Data Run, March 12, 1984	B.57
B-13-c	Desorption Response	B.58
B-13-d	Data Printout	B.59
B-14-a	Zeolite Isobars	B.60
B-14-b	Data Run, March 13, 1984	B.61
B-14-c	Desorption Response	B.62
B-14-d	Data Printout	B.63
B-15	Data Printout	B.64

APPENDIX C

C-1	Temperature Calibrations	C.3
C-2	Condensate Receiver Calibration	C.8
C-3	Mechanical Pressure Gauge Calibrations	C.9

APPENDIX D

D-1	Solar Zeolite System, Looking East	D.5
D-2	Solar Zeolite System, Looking North	D.7
D-3	Plan View of System	D.9
D-4	Hypothetical Performance, Psychrometric Plot	D.11
D-5	Geometry of Zeolite Tubes in Zeolite Tank	D.13
D-6	Plan View, Manifold	D.17
D-7	Cut-Away of Condenser-Manifold, Section DD	D.21
D-8	Cut-Away of Condenser-Manifold, Section EE	D.23
D-9	Construction Details, Ice Tank	D.27
D-10	Ice Tank System, Plan View	D.31
D-11	Variation of ΔT Versus Time for Miscellaneous Material Samples	D.33
D-12	System, Looking East	D.35
D-13	System, Looking West	D.36
D-14	System, Looking North	D.37
D-15	System, Looking Northwest	D.38
D-16	Zeolite Tubes and Condenser	D.39

TABLES

S-1	Adsorber Comparison	vi
S-2	Summary of Performance	viii
1	Summary of Performance	16
2	Summary of Energy Flow	18
3	Zeolite Tank Temperature and Heat Input Data, March 14, 1984	36
4	Condenser Tank Temperature and Heat Removal Data, March 14, 1984	36
5	Test Summary	41

APPENDIX D

D-1	Materials Breakdown, ZCAT Facility	D.40
D-2	System Performance Measurements	D.43

EXPERIMENTAL TESTING OF COOLING BY LOW PRESSURE ADSORPTION IN A ZEOLITE

INTRODUCTION

BACKGROUND

This project was subcontracted to the New Mexico Solar Energy Institute by the Pacific Northwest Laboratory (PNL) operated for the U.S. Department of Energy by Battelle Memorial Institute. PNL has the responsibility of managing the Seasonal Thermal Energy Storage (STES) program for the Division of Energy Storage Technology, U.S. Department of Energy. The goal of the STES program is to develop the technology for economic storage and retrieval of energy on a seasonal basis to the point of adoption by entrepreneurial groups. Concepts that utilize heat or cold available on a seasonal basis from waste sources or other surplus sources to reduce peak period energy demand, reduce the peaking requirements of electric utilities, or contribute to favorable economics for district heating and cooling systems are within the scope of program study.

OBJECTIVES

Part of PNL's mission in managing the STES program is to identify new and promising methods for STES. Pursuant to this, PNL released a request for proposals for development of innovative methods for performing or augmenting seasonal chill storage for space or processing cooling. In response, the New Mexico Solar Energy Institute proposed and received a contract for the construction and use of a test facility for examining a concept for augmenting ice storage with sublimation heat pumping utilizing solar-dried zeolites. This facility uses solar-derived energy for the heat source and evaporatively chilled water for the heat sump. For cooling, sublimation of ice is used instead of melting. The specific objectives of this project were to 1) develop a detailed specification for a solar zeolite chill-augmented storage system, which includes a zeolite tank, ice tank, and heat exchanger for testing purposes; 2) construct the system as

approved by PNL; 3) instrument and test the system; 4) perform a study of zeolites; and 5) analyze and report the findings.

ZEOLITE CHILL-AUGMENTED TEST FACILITY

Ice storage can furnish 143.3 Btu of cooling for each pound melted or 1218.7 Btu of cooling for each pound sublimated. However, sublimation requires a pressure of 0.0887 psia or less, which makes it a more difficult process. The ZCAT facility utilizes zeolites in a heat-pumping mode to reduce the pressure below 0.0887 psia. Heat from stored ice is transferred via water vapor to the zeolite, where it is sorbed by the zeolite. The vapor sublimated releases its heat to the zeolite upon adsorption. The heat of adsorption varies inversely with zeolite temperature, but in the temperature range of most interest it is typically between 1200 and 1400 Btu per pound. Circulating water then carries the heat away from the zeolite. The 1218.7 Btu removed from the ice for each pound of ice sublimated can be used to freeze an additional 8.5 pounds of water, cool ice, or cool a heat load.

Zeolite is a good heat pump when it is sufficiently dry. The major complexity of this heat-pumping technique is the drying process. The ZCAT facility utilizes hot water from a solar heating system along with condensing water from an evaporative water chiller to "pump" the system. The dryness of the zeolite increases with increasing temperature and decreasing pressure. The pressure is held low by the cooling water, which circulates around the condenser tubes causing vapors desorbed from the zeolite to be condensed. The condensate is periodically measured and removed from the system.

The ZCAT facility has high vapor flow rates. Saturated vapor at 0.0887 psia has a volume of 3500 cubic feet per pound. Moving ten pounds of the vapor per hour through the 5-inch section of the manifold gives a velocity of 71.0 feet per second. The 0.5-inch diameter condenser tubes are scaled so all have similar flow rates. Condensing, however, is done under higher pressures and has substantially lower volume flow rates.

DESIGN

The design, shown in Figure 1, consists of three primary subsystems: 1) The central part of the facility is the evacuated system consisting of 64 zeolite tubes, 64 condenser tubes, manifold, ice tank, and a daily cooling storage tank. 2) The thermal drive is from a solar water heating system. 3) The heat sump is an evaporative water chiller. Note that the solar panel and evaporative water chiller were available from previous projects; neither item was optimized for this project. Optimizing these subsystems should lead to a substantial reduction in the electrical energy used for blowing air and circulating water.

Subsystem (1) is an evacuated system that consists of the condenser manifold, the condensate receiver, the ice tank, and the 64 zeolite tubes in a tube-in-shell heat exchange configuration. A zeolite tube is shown in detail in Figure 2. The zeolite is contained between 1/2-inch copper pipes and 1-1/2-inch copper pipes. Holes in the 1/2-inch pipes allow vapor to enter and exit the zeolite with a maximum path length of 1/2 inch. The zeolite tank section is 54 inches long. The 64 zeolite tubes hold approximately 100 pounds of zeolite and are completely sealed except for the end that connects to the condenser.

Subsystems (2), the solar thermal drive, and (3), the heat sump, consist of on-hand equipment and are discussed in Appendix D, Details of Construction.

The layout of the system is shown in Figures 3 and 4 and photographs are given in Figures 5 and 6. The 64 zeolite tube assemblies are installed in the top section of the 18-inch diameter solar zeolite fiberglass tank shown in Figures 3 and 4. This tank is the tall object of Figures 5 and 6 (photographs). The 64 tube assemblies are connected via silicon thermal break tubing to 64 heat exchange tubes which in turn are manifolded into one 5-inch copper tube. The heat exchange tubes and manifold are in the bottom of the 18-inch diameter solar zeolite fiberglass tank. Thermal insulation isolates the zeolite tube assemblies from the heat exchange and manifold assemblies. This allows hot water to circulate around the zeolite tubes while cool water circulates around the lower heat exchanger. The water is thereby driven from (desorbed) the zeolite and condensed in the

FIGURE 1. Solar Zeolite Adsorptive Cooling

Figure 1 legend

- V₁ Valve to block hot water
V₂ Valve to switch hot and cold water to zeolite tank
V₃ Valve to switch hot and cold water from zeolite tank
V₄ Valve to block condenser water flow
V₅ Valve to block cooled water flow
V₆ Three-inch vacuum valve
V₇ 3/8-inch vacuum valve
F₁ Cooling water flow meter, zeolite tank/condenser
F₂ Cooling water flow meter, condensate receiver
F₃ Water flow meter, zeolite tank
AWS Ice tank heat exchanger water source
HWS Hot water source
CWS Chilled water source
T₀ Condenser input water thermocouple
T₁ Condenser output water thermocouple
T₂ Zeolite tank input water thermocouple
T₃ Zeolite tank output water thermocouple
T₄ Condensate receiver cooling input thermocouple
T₅ Condensate receiver cooling output thermocouple
T₆ Condensate receiver thermocouple
T₇, T₈, T₉, T₁₀, T₁₁, T₁₂, T₁₃, T₁₄, T₁₅, T₁₆
These thermocouples measured the dry bulb and wet bulb air temperature at 5 points on the evaporative water chiller
T₁₇ Condenser mix thermocouple
T₁₈ Zeolite tank mix thermocouple
T₁₉, T₂₃ Ice tank bottom thermocouples
T₂₀, T₂₁, T₂₂ Ice tank top
P₁ Chilled water circulating pump, zeolite tank/condenser
P₂ Chilled water circulating pump, condensate receiver
P₃ Hot water circulating pump
P₄ Ice tank heat exchange cold water circulating pump
Note: T₂₂ and T₂₃ were switched half way through the test program to check T₀ and T₁

FIGURE 2. Zeolite Tube

FIGURE 3. Solar Zeolite System, Looking East

FIGURE 4. Solar Zeolite System, Looking North

FIGURE 5. System, Looking East

FIGURE 6. System, Looking West

heat exchanger-manifold section to dry the zeolite. Cool water in the entire tank then causes adsorption to take place in the zeolite which in turn causes heat to be pumped by means of water vapor from the ice tank to the zeolite tank and then removed by water circulated around the zeolite tubes.

The ice tank is shown in Figure 4. It is a 15-foot long, 12-inch diameter stainless steel tank layed horizontally on the roof of the building. The picture shows the tank uninsulated as it was during early testing. It was insulated during later tests. The ice tank is connected to the manifold via a condensate receiver section which is shown below the solar zeolite fiberglass tank in Figure 3.

The cooling system to remove heat from the zeolite and condenser is shown in Figures 3 and 4 as the water chiller, chilled water storage, and interconnecting plumbing and pumps. It is an evaporative cooler with blower, heat exchanger, water spray, evaporative pad, and ducting.

The hot water system shown in Figures 3 and 4 consists of a solar panel, backup electric water heater, a hot water storage tank, and connecting plumbing and pumps. Figure 5 shows the solar panel on the right, the hot water storage to its left, and the electric water heater back of the panel.

PERFORMANCE

Table 1 lists results from 14 test runs. Three additional speed-of-response tests were performed on February 28 but since they are not directly comparable, they are not included in the table.

Table 1 gives the measured values, in pounds of water desorbed, for each test run. The percent of measured water to that projected is also tabulated. The table also lists the time that desorption was 90 percent of the final desorption.

The data shows the significant improvement in performance after a long vacuum pumping cycle. The data also shows that in 12 out of 14 tests the performance was above theoretical.

TABLE 1. Summary of Performance

<u>Date of Test</u>	<u>Desorbed ¹ Water, Lbs</u>	<u>Percent ² of Theoretical</u>	<u>Desorption ³ Time</u>	<u>Time to ⁶ 90% of Desorption</u>
1/30	10.40	179 ⁴	140	82
1/31	6.85	134	168	132
2/2	5.64	115	183	140
2/7	4.30	88	47	28
2/10	6.40	121 ⁴	81	47
2/14	6.80	155 ⁴	119	36
2/18	5.15	123	79	52
2/24	6.00	140	120	55
3/1	6.15	154 ⁵	87	56
3/6	5.50	131	100	80
3/11	1.64	51	120	59
3/12	4.74	296 ⁵	123	80
3/13	4.75	151	120	76
3/14	5.06	144	130	63
	Average	141	116	70

¹Desorbed water as measured with a graded cylinder.

²Percent of measured water to that determined by pressure and temperature measurements and zeolite manufacturer's data.

³Time in minutes to reach the desorption.

⁴Long vacuum pumping the day before the test.

⁵Long vacuum pumping the night before the test.

⁶Time in minutes to reach 90 percent of final desorption.

CALCULATED PERFORMANCE

Table 2 shows the projected performance and actual data from tests performed on January 30, 1984, and March 14, 1984. The January 30 data run was preceded by a lengthy purging operation. This data may indicate that when the zeolite is thoroughly purged of any undesirable gases, the actual performance can significantly exceed the projected performance. Although the March 14 run had a very short purging operation, the results are still in line with the differential temperatures and exceed the projected performance values. The ZCAT facility has some brass fittings which are likely to outgas under the test conditions of pressure and temperature. Eliminating such materials should lessen the need for long periods of vacuum pumping prior to the test runs.

The calculated heat flows for an idealized cycle based on six pounds of cycling water are shown in Figures 7 through 10. This cycle is shown on the isobar plots in Figure 11. Figure 7 shows 7775 Btu for desorption of water and 6891 Btu for heating the residual water, zeolite, copper, and fiberglass tank (point A to point B on Figure 11). Figure 8 shows 1902 Btu for heating the system mass while the internal temperature increases from 56°F to 82.7°F and the internal pressure increases from 0.0886 psia to 0.222 psia (point D to point A on Figure 11). Figure 9 shows 7884 Btu of cooling to adsorb six pounds of vapor and 6195 Btu of cooling to cool the system mass (point C to D on Figure 11). Figure 10 shows 2161 Btu of cooling to cool the system and drop the pressure (point B to point C on Figure 11). Heating and cooling the mass of the materials in the zeolite tank seriously affects the efficiency of operation. For this test facility, about one-half the energy is used for sensible heating and cooling and does not contribute to performance.

The zeolite is the compressor-condenser of the zeolite chill-augmentated system with a standard heat pump. It was calculated that 328.9 Btu of solar heat (Btu in) and 445.4 Btu of evaporative cooling (Btu out) would cycle the solar zeolite chill-augmentated system so that it could furnish 144 Btu of 32°F cooling (see Table 2). This cooling was calculated to use 81.1 Btu of electrical energy, but this could be

TABLE 2. Summary of Energy Flow

	<u>Projected</u>	<u>Jan. 30, 1984 Test</u>	<u>March 14, 1984 Test</u>
Sublimation/evaporation	6 lbs/day	10.4 ¹ /5.8 ²	5.06 ¹ /3.5 ²
Freezing capacity	50.4 lbs/day	87.4 lbs/day	42.5 lbs/day
Solar energy required	16,577 Btu/day	12,621 Btu/day	18,215 Btu/day
Cooling required	22,447 Btu/day		
Solar energy/lb of ice	328.9 Btu/lb	144.4 Btu/lb	428.6 Btu/lb
Water chilling/lb of ice	445.4 Btu/lb		
Hot water temperature minus cooling water temperature	124°F	108°F	105°F
Cooling water temperature minus ice tank water temperature	24°F	-4°F	18°F
Solar Coefficient of Performance	0.44	0.99	0.33

¹Based on measurement of water desorbed.

²Based on temperature and pressure parameters and zeolite manufacturers technical data.

substantially reduced by optimizing the solar thermal evaporative water chiller systems and the electrically driven pumps and blower.

SYSTEMS CHECKOUT

Zeolite Tube

Initially, single tube tests were run to verify design and operation. A single zeolite tube was connected to a glass beaker by copper tubing. A

FIGURE 7. Solar Day Heat Flow 82.7°F to 180°F

FIGURE 8. Constant Moisture, 56°F to 82.7°F, 0.887 psia to 0.222 psia

6# of 32° vapor extracts 176 Btu
 6# of added water gives up 275 Btu

FIGURE 9. Nocturnal Heat Flow 147.7°F to 56°F

FIGURE 10. Constant Moisture, 180°F to 147.7°F, 0.22 psia to 0.0887 psia

Figure 11. Molecular Sieve 13X Isobars

vacuum pump was connected to the beaker via a vacuum valve and tubing. The zeolite tube and beaker assembly was pumped to less than 0.4 torr pressure and the valve closed. The zeolite tube was heated by means of heat lamps while the beaker remained cool. Vapor was desorbed from the zeolite, raising the internal pressure, and condensed in the beaker.

Then the lamps were turned off, and the zeolite tube was allowed to cool. As the zeolite tube cooled, it adsorbed the vapor in the system, causing the pressure to drop. As the pressure dropped to that of boiling at the temperature of the condensate, the condensate began to vaporize and release heat. The temperature of the zeolite and the internal system pressure dropped until the remaining condensate froze.

While not a precision test, the single tube processed 50 cubic centimeters of water when cycled between 75°F and 300°F. Ice was formed and sublimated in the beaker during the zeolite cooling. Since at ambient temperature the zeolite was well below saturation temperature, the water processed was less than it would have been at full saturation.

Each zeolite tube assembly was flushed with distilled water before and after filling with zeolite and vacuum tested, but only the first assembly was run through a series of sorption-desorption cycles.

Manifold-Condenser

The manifold-condenser section, the most complex subassembly to construct, was prepared for vacuum testing by soldering caps on all 64 of the 1/2-inch open ends and the open 5-inch end blocked with a brass plate and gasket. The brass plate had a pipe brazed in that was connected to the vacuum pump. The section was then pumped down to 0.3 torr and monitored for leaks. Leaks were found along the top of the 5-inch cap. Apparently, in cutting the 0.625-inch diameter holes, small cracks were formed which were too small to see. The manifold was too massive to allow good brazing, but repairs using a combination of sand blasting and soldering were successful and subsequent vacuum testing showed no leaks.

Condensate Receiver

The condensate receiver, the 5-inch by 5-inch by 3-inch tee, and the 3-inch vacuum valve were tested for air leaks as a unit with a brass plate and gasket blocking the open end. This section showed no leaks during these tests. In later tests, leaks were found in the bellows part of the vacuum valve and in the gasket around the condensate view window. It is not known when these failures occurred.

The condensate receiver is mounted under the manifold and below the bench. Water circulating through the condenser-manifold tank does not cool the condensate receiver. The condensate receiver should be kept cold to keep condensate from reevaporating. For cooling, four turns of 3/8-inch OD copper tubing with a manifold at each end were installed to use chilled water being pumped to the evaporative water chiller sprays.

Ice Tank

The ice tank was constructed by T and R Mechanical Contractors, Inc., of El Paso, using a 12-inch diameter stainless steel pipe furnished by the New Mexico Solar Energy Institute. It was pumped down to 0.5 torr and the valves closed. It appeared to hold this vacuum indefinitely.

SYSTEMS TESTING

A vacuum pump was attached to the 1-inch vacuum valve on the lower part of the manifold. A zeolite water trap, fabricated from 5-inch copper pipe, was inserted between the vacuum valve and the vacuum pump. Pumping was performed in relatively short runs as water desorbed out of the zeolite in the ZCAT facility saturated the drying zeolite in the water trap and infiltrated the pump oil. The sequence was to pump a while, change or dry the zeolite in the water trap, and then pump some more. Several weeks were used to pump the vacuum to a low pressure, turn off the pump, and watch for pressure drift. The daily temperature cycling also caused vacuum pressure cycling so an extended period was required to determine whether leaks were present.

Systems testing for air leaks was performed with a Bell and Howell helium mass spectrometer leak detector borrowed from the Physics Department

at New Mexico State University. Major leaks were found in the stainless steel bellows, part of the 3-inch vacuum valve. A copper 3-inch bellows was purchased and installed.

Small leaks were difficult to determine or find. The leak detector had to be carefully adjusted to ensure enough sensitivity to show the leaks. Also during this period, the mechanical pump motor and the diffusion pump in the leak detector failed and were repaired.

Because the unsupported silicone tubes tended to collapse under negative pressure, the zeolite tubes were lowered so that the thermal breaks were each less than 0.5 inches. There was concern that leaks could occur where the silicone tubes were clamped around the 1/2-inch copper tubes.

Small leaks were found along the condensate receiver window and the gasket was replaced with an O-ring. Further vacuum testing did not reveal any more leaks.

Late afternoon on September 21 the pressure reading was 0.85 torr. The system had been dried and pumped for one month. A 5-gallon jug of distilled water was connected through a 1/2-inch vacuum valve to the bottom of the ice tank. This was done in a manner to minimize any air entering the ice tank. When the 3-inch vacuum valve was opened, a continuous path was created from inside the ice tank to the zeolite. The vacuum valve was then just cracked open. The water passing through the valve immediately vaporized or froze into snow. The vapors passed through the system and were adsorbed by the zeolite. Loud noise from the vapor indicated a very high flow rate. The water was then allowed to enter at a higher rate and spread out over the bottom of the ice tank. The water boiled at such a high rate that it splashed over the entire inside of the 26.5-cubic foot ice tank. Part of the water froze, part remained, and part was adsorbed into the zeolite. Twelve hours later there was still ice in the ice tank although the tank was not insulated.

A scaffold was constructed over the zeolite-condenser-manifold system, and a block and tackle was installed at the top of the scaffold. The system was lifted and the bench and other items were moved from the area. The wheeled scaffold was then rolled to the stairwell leading down from the

roof. Next, the fiberglass tank was pushed up onto the system from inside the stairwell. The system was then returned to the test position; the bench and other test items were placed back into position. The system was lowered onto the bench and reconnected to the rest of the ZCAT facility.

The system was then pumped down to 1.8 torr, all vacuum valves closed, and the pump turned off. During the next three weeks the daily pressure cycling was monitored while the plumbing between the hot water and cold water systems was connected to the zeolite-condenser tank. While the vacuum system showed no leaks, the plumbing connections to the fiberglass tanks were troublesome. Apparently, poor epoxy had been procured and the joints were not holding. A different type of fiberglass resin was obtained and the connections were redone.

TEST AND ANALYSIS

The evaporative water chilling testing was performed as part of the New Mexico Energy Research and Development Institute (NMERDI) Project 2-71-4224 (Redman 1984). Performance details are given in the final project report to that institute. Copies of that report will be made available upon request.

Other than the magnitude of heat inserted into the zeolite tank, the hot water system was not evaluated. The performance of the solar panel used is typical of the products of many companies. It was manufactured in Las Cruces by Squires Laboratories-American Products Division.

The 4500-watt, 80-gallon electric water heater, manufactured by the Bradford-White Corporation, was used as a solar water heating system backup heater. Its performance was not evaluated.

Systems testing of the zeolite heat pumping system was initiated on January 30 after extensive testing to assure that there were no air leaks, that the hot and cold water systems were suitable for the tests, and that the zeolite was clean (no gas or other materials blocking the pores). Seventeen test runs were made, critical temperatures were plotted, adsorption and desorption end points were plotted on zeolite isobars, and desorption versus time plots were drawn. Summaries of the 17 tests runs are enclosed in Appendix A. Data were reduced and, along with the above

plots, are enclosed in Appendix B. Calibration curves and computer programs are enclosed in Appendix C. All data test runs used 20-minute temperature logging intervals, except for the March 14 run, which was logged at 5-minute intervals. In each isobar plot, points are furnished for the water content in the zeolite at the end of adsorption (points a and b) and desorption (points c and d). The isobars were extracted from data published by Linde, a Division of Union Carbide. A chart is included to give saturated pressure for eight different temperatures. A chart is also included giving the zeolite water content based on:

- a. Ice tank temperature and zeolite temperature at the end of adsorption
- b. System pressure and zeolite temperature at the end of adsorption
- c. System pressure and zeolite temperature at the end of desorption
- d. Condensate receiver temperature and zeolite temperature at the end of desorption

During the adsorption phase, the vapor pressure in the ice tank, and therefore, the entire sealed system, was influenced by the temperature of the water surface in the ice tank. The temperature of the vapor evaporating from the water surface was a measure of the surface temperature after the initial transient condition. Opening the 3-inch vacuum valve when the zeolite is dry and cool causes a very sudden adsorption of water vapor. This causes an equally fast pressure drop and violent boiling. The pressure drops well below saturation pressure for the temperature of the water. As the boiling continues and the zeolite adsorbs the vapor, the pressure rises, the boiling slows and a stable condition is approached. It is as the system approaches stabilization that the vapor stays at the temperature of the water from which it evaporates. This water temperature was used to obtain saturation pressure from steam charts. These saturation pressures and the temperature measurements of the water cooling the zeolite were used to locate end adsorption points on the isobars. Another point was obtained by means of direct pressure measurements and the above same temperatures of the zeolite cooling water. The assumption here is that as the temperature of the water exiting the zeolite tank is changed very

little from the temperature of the water entering the tank the zeolite is very close to the temperature of the water.

At the end of desorption phases, the water temperature in the condensate receiver was considered to be close to the temperature of the vapor saturation pressure. The temperature of the condensate was the primary control over the water temperature in the condensate receiver. There was insulation around the receiver and a cooling water coil to minimize any ambient air heating. These were precautions to assure that the receiver was a passive device (that is, that no water would evaporate or vapor condense in the receiver). In this quiet state the vapor pressure was the saturation pressure for the specific temperature. This temperature was then referenced to the saturation line in steam charts and the saturation pressure obtained. The temperature measurements of the hot water flowing through the zeolite tank were used to obtain measures of the zeolite temperature. These pressures and temperatures plotted on zeolite isobars furnished measures of water content in the zeolite. Other points were plotted on the isobars by direct measurements of pressure and temperatures.

The two means of obtaining points for the isobar plots should coincide and did, very closely, for the ends of the adsorption phases. At the end of the desorption phases, the two point plots were typically different by about one pound of water content in the zeolite.

The March 14 data run is used as a specific example of system performance. The March 14 data run can be called an average data run. That is, the measured water processed by the system divided by that theoretically processed was 1.4. The average for 14 data runs was 1.4. The March 14 results were, therefore, not as good as some and better than others. The March 14 data was logged at 5-minute intervals instead of 20-minute intervals like the other data runs, therefore, analysis was easier to perform. All test runs are summarized in Appendix A and the data listings and plots are in Appendix B.

The initial conditions of the March 14 test were

Zeolite tank

Temperature:	83.4°F
Water in tank:	empty

Condenser tank

Temperature:	66.8°F
Water in tank:	full
Circulation rate:	0 gpm

Ice tank

3-inch vacuum valve:	closed
Water in tank:	220 lbs
Temperature	52.2°F

The zeolite isobar plots (see Figure 12) show the zeolite water content at the end of the adsorption phase to be 24.2 pounds using pressure gauge data. At the end of the desorption phase the water content was 20.7 pounds using pressure gauge data. Theoretical water desorption was 3.5 pounds. The measured water desorbed was 5.06 pounds.

At the beginning of the test run, the system was vacuum pumped for 10 minutes. At that point, the pump was turned off, and the oil was changed. The system was then pumped for 8 more minutes. The purpose of this pumping was to purge any "poison" in the zeolites (remove any gas from the zeolites). The data show the system warming caused by the sun shining on the evaporative water chiller system, the zeolite-condenser tank, and the ice tank. At the end of a 30-minute period the conditions of the system were

Zeolite tank

Temperature:	83.5°F
Water in tank:	empty

Condenser tank

Temperature:	76.0°F
Water in tank:	full
Circulation rate:	0 gpm

Date: March 14, 1984

a 25.2 lbs/100 lbs

b 24.2 lbs/100 lbs

c 20.7 lbs/100 lbs

d 21.2 lbs/100 lbs

b-c = 3.5 lbs

a-d = 4.0 lbs

measured 5.06 lbs

Figure 12. Zeolite Isobars

Ice tank

3-inch vacuum valve:	closed
Water in tank	220 lbs
Temperature	53.4°F

During the first 30 minutes of the March 14 test run, there was no test facility activity other than vacuum pumping. The zeolite tank was empty of water and the water in the condenser tank was not circulating. The vacuum pump was run 18 minutes to purge the system. The 3-inch vacuum valve was closed during this period. During this period, the sun was in a good position for heating the tanks even though there were single layers of aluminum-covered, 3-inch insulation batts on the zeolite and condenser tanks and two layers on the ice tank. The 3-inch vacuum valve and related piping were not insulated. A 9.2°F condenser temperature rise was, therefore, attributed to solar. The early morning sun was radiating the side of the tank. The condenser tank has a capacity of 4.9 cubic feet; 0.49 cubic feet is occupied by copper pipes, 0.07 cubic feet by iron, and 0.17 cubic feet by rubber. This leaves 4.2 cubic feet for the water. Most of the sensible heat was in the 4.2 cubic feet (262 pounds) of water. Sensible energy change during the 30-minute preparation phase of the March 14 test run was $262 \times 9.2 = 2410$ Btu assuming that the entire tank was heated at the same rate. This heat gain cannot be attributed to solar radiation, since the tank was insulated with aluminum covered batting. There is a strong likelihood that water was warmed on the solar side and under the effect of gravity flowed to the top where the thermocouple was located. The zeolite tank thermocouple was in air about 6 inches above the condenser tank thermocouple and showed no temperature change.

The following temperature data are plotted in Figure 13 and the manually recorded data are tabulated in Figure 13 for the adsorption period:

Zeolite input and output water

Condenser mix (0 water flow in condenser tank)

Vacuum pumping start 0820
 Vacuum pumping stop 0830
 Vacuum pumping start 0845
 Open 3 inch valve, point a 0850
 Close 3 inch valve, point b 0853
 Vacuum pumping stop 0853
 Start Z-tank filling, point c 0855
 Full of cold water, point d 0904
 Mechanical vacuum gauge
 stayed below 0 reading from
 0820 to 0904 and generally
 increased to the 0 reading
 by 1319. Zero reading was
 calibrated to be 3.9 torr.
 Calibration scaling was:
 reading $\times 3.4 \div 4 + 3.9$.
 Open 3 inch valve 0904
 Start Z-tank drain, point h 1319
 Start Z-tank filling 1329
 Full of hot water, point i 1338
 Condenser flowing 1338
 Drain: 0.568 lbs 1338
 Drain: 0.700 lbs 1341
 Drain: 0.700 lbs 1344
 Drain: 0.700 lbs 1347
 Drain: 0.700 lbs 1352
 Drain: 0.700 lbs 1358
 Drain: 0.458 lbs 1403
 Drain: 0.286 lbs 1430
 Drain: 0.178 lbs 1515
 Drain: 0.178 lbs 1546
 Measure of total: 5.06 1546
 Adsorption:
 cold water flow: 3.5 gpm
 Desorption:
 cold water flow: 3.6 gpm
 hot water flow: 2.8 gpm

FIGURE 13. Temperatures for March 14 Test Run

Ice tank water

Ice tank vapor

Because there was no water flow and the temperature transducers are outside the tank, the zeolite tank input and output water temperatures are not significant during the first 30 minutes of system operation. The condenser mix temperature given above is from the condenser mix transducer, which was centered inside the tank about 3 inches from the condenser tank top. The temperature transducers, zeolite mix and condenser mix, are placed to measure water temperatures prior to any infiltration of water across the divider between the zeolite tank and the condenser tank.

At test initiation plus 30 minutes ($T + 30$, see point a Figure 13), the 3-inch vacuum valve was opened. The resultant vapor flow could not be directly measured. Failure of the pirani gauge and dependence on the mechanical pressure gauge made it difficult to determine the pressures below 4 torr and the amount of water evaporated could not be measured. The temperature of the bottom of the ice tank near the vapor exit pipe dropped 9°F during the 3 minutes the 3-inch valve was opened and the vacuum pump was on. The valve was closed and the pump was turned off and the 1-inch valve in the pump line closed. The 3-inch vacuum valve was again opened and the temperature at the bottom of the ice tank dropped another 8.5°F within 10 minutes. The temperature leveled off at the end of the second drop at 37.8°F . The ice tank was about 30 percent full of water at the start of the March 14 test. During the few minutes after opening the 3-inch valve vapor appeared to form at all levels of the water and water splashed over the entire inside of the tank. There is a strong likelihood that this violent boiling kept all the water at the same but rapidly dropping temperature.

At the end of the March 13 test run, there was about 21.2 pounds of water in the zeolite. The vacuum pumping on May 14 could not have lowered the water content much as the March 13 zeolite desorption temperature ended at 156°F and the March 14 zeolite temperature during test run initiation was about 40°F (ambient air temperature early on March 14 was 36°F). It seems reasonable that most of the vapor released from the water during the 3 minutes the 3-inch valve was open and the vacuum pump was on, went to the

zeolite since the zeolite adsorption pumping is far greater than that of the mechanical pump. All of the vapor released from the ice tank went to the zeolite during the 10 minutes following the second opening of the 3-inch valve.

During the 25 minutes after the first 3-inch valve opening, the ice tank water dropped a total of 16.5°F (there appeared to be a 1°F rise just before the second opening). Due to the violent boiling along the length of the ice tank, all the water quickly reached a common temperature (the hottest water boiled the most lowering its temperature to the average). The amount of water in the ice tank was not directly measured but from the level it was calculated to be 220 pounds and with the mass of the steel tank the sensible heat capacity was 280 Btu/°F. The loss of heat from the tank must have gone with the vapor. Therefore, $280 \times 16.5 = 4620$ Btu went into vapor. At an average water temperature during this period of 45°F, the 4620 Btu would evaporate 4.3 pounds of water. As noted above, practically all of this water went to the zeolite even though the pump was on for 3 minutes. The adsorption was, therefore, practically finished within 25 minutes including the 11 minutes between the two openings of the 3-inch valve. The water in the zeolite just prior to the March 14 test run (21.2 pounds) plus the 4.3 pounds is 25.5 pounds which is within 0.5 pounds of zeolite saturation at the low pressure observed. The zeolite then almost went into saturation during the first 13 minutes that the 3-inch vacuum valve was open. The adsorption of 4.3 pounds of water would raise the temperature of the zeolite tank filled with water by 79°F assuming a sensible heat factor of 70.8 Btu/°F and adsorption of 1300 Btu/pound. Since the cooling water was flowing through the filled zeolite tank when the 3-inch valve was opened the second time the high heat dissipation shows up as heat added to the water. The cooling water, flowing at 29.2 pounds/minute, had an initial temperature increase through the tank of 15°F which removed the heat at 438 Btu/minute. The heat removal rate dropped as the zeolite temperature dropped and it required over 30 minutes to bring the temperature of the zeolite down to near that of the cooling water. The cooling by the water was complicated by further adsorption and further heating of the zeolite.

For a period of 220 minutes, there appeared to be some evaporation. Average measured temperature gain of the cooling water over this period was 2.3°F, and water flow rate was 3.5 gallons per minute. After adsorption was well stabilized, the ice tank water was at 42°F, indicating an internal system pressure of 0.132 psia and 25.6 pounds of water in the zeolite. There were three operational glitches at points e, f, and g, shown on Figure 13, and some solar heat was added, making it difficult to develop a good sensible heat and adsorption heat relationship. The glitches were due to adding tap water to the cooling water drainback tank.

The temperature of the ice tank vapor was sampled at the ice tank top next to the 3-inch exit pipe. Because the 3-inch pipe and valve were not insulated, heat from the sun and the ambient air heated the pipe and, therefore, the vapor and the water below. As the water warmed, there was a small amount of evaporation which cooled the water keeping the water at about 37.5°F for 60 minutes. After that, there was so little activity in the system that the temperatures around the ice tank appeared to drift with solar gain. As the ice tank water and vapor temperatures approached 40°F, the sun began to shine on the 3-inch piping, causing a large rise in vapor temperature and some rise in water temperature. As the sun passed on, the vapor temperature dropped again. This anomaly was not noted until too late to correct for it by adding more insulation. The rise in vapor pressure should not have affected the test results, but the related rise of about 2°F in water temperature may have had a small impact.

At $T + 300$ minutes, the cooling water was drained from the zeolite tank and replaced with hot water. This procedure took about 20 minutes and was complete by $T + 320$ minutes; point i, Figure 13. The dashed lines in the Z-tank (zeolite tank) input and output curves show a scale change to the high temperature scale.

The ice tank temperature plots were terminated at the end of the adsorption period as the 3-inch valve was closed and the ice tank was sealed from the rest of the system. The condensate receiver temperature plot was initiated at start of desorption along with the condenser tank input and output temperature plots. Cooling water was pumped through the

condenser tank during desorption, making the input and output temperature measurements valid.

The Z-tank input temperature changed from 59.3°F at T + 300 minutes to 175°F at T + 320 minutes. The output temperature changed from 61.1°F to 124°F over the same period. The zeolite tank temperature readings are given in Table 3 for the critical period from T + 320 to T + 345 minutes, points i to point j on Figure 13.

The temperature of the hot water was about 180°F at the initiation of the desorption phase, dropped to 163.5°F within 30 minutes, and recovered to 165.5°F by 25 minutes. This shows the need for a large reservoir of hot water.

During the period from T + 320 to T + 345, Table 3, the Z-tank heating water flow rate was 2.8 gallons per minute. Based on this flow rate and the temperature changes, the heat input was calculated and listed in Table 3. After the initial 25-minute period, 5236 Btu were added for a total of 17,403 Btu.

The condenser tank temperature readings are given in Table 4 for the critical period from T + 320 to T + 345 minutes, point i to point j on Figure 13. During the critical period, 5349 Btu were removed in the condenser. Figure 14, "Desorption Response," shows that during this period 4.5 pounds of water was desorbed, condensed, and removed from the condensate receiver. Condensation required about 4725 Btu. There was also an average of about 1°F of cooling of the condenser during this period. The desorption was 82.6 percent complete in 25 minutes.

The solid line in Figure 14 is a plot of the condensate drained from the condensate receiver with respect to time. Immediately before the condensate was drained, the test operators recorded time and the condensate level as viewed through the condensate receiver window. Often early in desorption, the level rose above the top of the window. When this occurred, the precise position of the level was not known. The operator-recorded data is tabulated on Figure 13 for the March 14 test run. Figure C-2 is the calibration for these points. For example, water volume at level 10 of C-2 is 258 cubic centimeters. The circled points are the condensate as measured by graduated cylinder. There was a 5/16-inch copper

TABLE 3. Zeolite Tank Temperature and Heat Input Data,
March 14, 1984

Time Minutes	Input °F	Output °F	Differential °F	Heat Input Btu
T + 320	175	124	51.0	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <div style="border-left: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; right: -5px;">}</div> </div> </div> <div style="border-top: 1px solid black; width: 100px;"></div> </div>
T + 325	177.1	143.4	33.7	
T + 330	177.9	158.3	19.6	
T + 335	177.1	159.6	17.5	
T + 340	174.6	167.1	7.5	
T + 345	167.1	166.7	0.4	
Total heat added				12,167

TABLE 4. Condenser Tank Temperature and Heat Removal
Data, March 14, 1984

Time Minutes	Input °F	Output °F	Differential °F	Heat Removed Btu
T + 320	60.6	71.7	11.1	1,591
T + 325	60.6	71.3	10.7	1,292
T + 330	63.4	70.4	7.0	941
T + 335	64.3	70.2	5.9	817
T + 340	64.4	69.7	5.3	708
T + 345	65.0	69.4	4.4	
Total heat removed				5,349

FIGURE 14. Desorption Response

line to drain the condensate receiver. Near the drain point there was a vacuum valve. After the vacuum valve, the drain line continued for about 2 feet to a gallon glass jug via a sealing stopper. There was a second vacuum valve between the jug and the pump. Prior to draining any condensate, the vacuum pump was used to evacuate air from the gallon jug. Both of the 5/16-inch valves were then closed. Periodically the test operator recorded the condensate level and the time, and opened the 5/16-inch valve next to the condensate receiver. The condensate ran into

the jug without allowing any air to enter the system. During the March 14 test run, the water collected in the jug was twice poured into a graduated liter cylinder for measurement. It was initially planned to use a peristaltic pump for this purpose. It did not work. Dr. Liefeld of the Physics Department suggested the jug approach and it worked very well. The condenser mix temperature was close to 64°F during the desorption period. It is given in Table B-15 but was not plotted on Figure 13. During desorption, it started at 63.9°F, went up to 68.5°F and at the end had dropped to 59.5°F.

Figure 12 presented earlier in this section, gives the zeolite isobars and end points for adsorption and desorption. Points a and b are based on the final adsorption phase zeolite temperature of 60°F. Point a is also based on the ice tank water temperature (41.5°F). Point b is also based on the pressure gauge measurement (less than 3.9 torr, 0.075 psia) (this pressure is discussed farther below). The ice tank water temperature was cycling about the 42°F level and saturation pressure was, therefore, indicated to be 0.132 psia. Point a is a plot of 60°F and 0.132 psia, which gives a water reading of 25.2 pounds. An estimated 0.082 psia was plotted on the 60°F line, giving 24.2 pounds of water, point b on Figure 12. Points c and d are based on the final desorption phase zeolite temperature of 164.5°F, a mechanical gauge reading of 14.5 torr (point c), and a condensate receiver temperature of 71°F (point d). The calibrated pressure reading was 16.22 torr (0.314 psia). Point c of Figure 12 shows that the zeolite should contain 20.7 pounds of water at 164.5°F and 0.314 psia at thermal balance. The saturation vapor pressure at 71°F condensate receiver temperature is 0.3763 psia. At 164.5°F, this plots at point d, which is 21.2 pounds of water. Points d and c differ by 0.5 pounds. Point b to point c gives a change in water in the zeolite of 3.5 pounds; point a to point d gives 4.4 pounds. During desorption, 5.06 pounds of water were drained from the system.

The pirani gauge used a hot wire for measuring pressure and did not prove satisfactory. Five of the sensors were procured as they failed so often and in December 1983 the electronics failed. The mechanical pressure gauge was then substituted for the pirani. Figure C-3 gives the

calibration points and best straight line plot. The line follows the equation: corrected value equals $3.9 + 3.4/4 \times \text{reading}$. The 15 points were obtained by bringing water in the condensate receiver just to the vaporization temperature, measuring the temperature of the receiver close to the water line, and obtaining the saturation pressure from the steam charts. Fifteen different temperatures were obtained and, thereby, 15 pressure points. Tests run on January 31, February 2, February 28, and March 6 all had ice in the ice tank so when vaporization reached a very low level during adsorption, the pressure had to be very close to 0.0887 psia. These points confirm the calibration down to 0.0887 psia (4.6 torr). At the end of the March 14 test run adsorption phase, the pressure gauge indicated below 0.075 psia. However, since the gauge readings did not have much significance below 0.0887 psia and there was no ice in the tank at the end of adsorption it is reasonable to believe that the pressure was very little below 0.0887 psia. A pressure of 0.082 psia is not an exact figure, but is as close as could be estimated for the end of the adsorption phase.

The large ΔT early in a desorption between the vapor and the bottom of the ice tank illustrates a limitation to the speed of system response. For about 70 minutes, the vapor was below 32°F. Boiling sometimes appeared to be from the bottom of the ice tank as at times water erupted and splashed over the inside of the tank.

A key instrument that was not available for this project was a vapor flowmeter. At the time of the proposal, none could be found to measure bidirectional flow of vapor down to 0.05-psia pressures. Therefore it is not directly known when adsorption and desorption reached zero. At $T + 204$ minutes the ice tank vapor temperature and the temperature at the bottom of the ice tank were equal, indicating that there was no ΔT vertically through the water. The vapor flow must have been close to zero at that point. This is 159 minutes after the vacuum valve was opened.

Table 5 summarizes all the test runs. Detailed data for these runs are in Appendix A. Apparently zeolite "poisoning" was a severe problem in runs made on February 2, 7, and 28, and March 11, 1984, as water processed was very low. Poisoning is analogous to decreasing the amount of zeolite in the system. That is, the water vapor does not have access to many of

the pores in the zeolite. The three runs made consecutively on February 28 were unsatisfactory in that very little water was processed when the adsorption and desorption were run in 1-hour phases. Referring to Figure 14, which uses March 14 data, the desorption should be 83 percent complete by the end of 25 minutes; thus a 60-minute run should be close to 90 percent complete. This indicates that desorption times for the February 2, 28, and March 11 tests should not have had a significant impact on the amount of water processed. More testing of the nature of the February 28 test runs needs to be performed since multiple cycles per day can greatly increase the value of the system.

Table 5 furnishes differential temperatures between the hot water and the cooling water and between the hot water and the condensate. These differences were taken toward the end of the desorption periods when desorption was nearly complete and temperatures and pressures were assumed to be comparatively steady. The desorption of water from the zeolite is a direct function of the zeolite temperature and an inverse function of pressure. Maximum desorption requires a high temperature and a low pressure. The hot water sets the temperature of the zeolite. The cooling water causes the desorbed vapor to condense and, thereby, the pressure is kept low. The cooler the water, the lower was the pressure. A large differential is, therefore, desired to maximize the zeolite drying. The condensate receiver temperature and its relationship to the other temperatures is important in that if it becomes too high, there would be a tendency for the condensate to reevaporate.

Desorption typically occurred very fast during the first 30 minutes and then slowed. During the testing, the operators watched the condensate receiver water level. When it appeared that condensation had finished, the operators terminated the tests. As shown in Table 2, the desorption time averaged 116 minutes but was as fast as 47 minutes and as slow as 183 minutes. One factor of desorption which has not yet been analyzed is that in many cases, after desorption appeared to be finished and the hot water was draining, additional condensate would run into the receiver.

Once the ZCAT facility was found to be free of air leaks and PVC plumbing was properly attached to the fiberglass tanks, the primary

TABLE 5. Test Summary

Date	Hot Water ¹	Cold Water ²		Water ³		Condensate ⁴	Hot/ ⁵	Hot ⁶	Desorption ⁷	Vacuum	Ice tank ⁸	Ice tank ⁹
	Temperature	Temperature		Processed		Receiver	Cold	Water/		Pump	Vapor	Water
	°F	Adsorption/Desorption		Pounds		°F	Δ	ΔT		Time	Low/high	Low/high
		°F	°F	Measured/Theoretical			°F	°F	Minutes	Minutes	°F	°F
1/30/84	163	43	51	10.4	5.8	52	112	111	141	30 ¹⁰	49/53	48/48
1/31/84	162	47	53	6.85	5.1	61	109	110	173	29	38/58	36/42
2/2/84	164	50	55	5.64	4.9	61	103	103	193	56	33/63	37/44
2/7/84	165	54	63	4.3	4.9	62	102	103	52	0	36/54	39/57
2/10/84	167	55	67	6.4	5.3	69	100	98	81	0	45/56	49/59
2/14/84	164	53	66	6.8	4.4	68	98	96	119	30 ¹⁰	38/56	41/57
2/18/84	152	49	57	5.2	4.2	60	95	92	79	30	39/56	43/53
2/24/84	158	50	62	6.0	4.3	66	96	92	120	27 ¹⁰	46/55	51/57
2/28/84	160	47	49	0.8		52	111	108	66	60	49/54	40/47
	153	57	55	1.2		57	98	96	61	0	53/58	43/55
	149	55	51	1.4		54	98	95	52	0	51/63	43/58
3/1/84	151	57	59	6.2	4.0	64	92	87	89	45 ¹⁰	59/62	63/64
3/6/84	146	43	49	5.5		50	97	96	106	38	25/54	33/40
3/11/84	139	54	54	1.6	3.2	67	85	72	120	10	42/52	47/51
3/12/84	132	55	56	4.7	1.6	66	76	66	120	32 ¹⁰	29/41	41/45
3/13/84	157	55	60	4.7	3.1	70	97	87	130	46	29/42	38/41
3/14/84	159	68	63	5.1	3.6	72	96	87	137	18	24/58	37/44

Table 5 Notes

1. Temperature just before the end of desorption; thermocouple 02.
2. Temperatures just before the end of adsorption and desorption. Adsorption is from thermocouple 02. Desorption is from thermocouple 17 except for March 11, 12, 13, and 14 which are from thermocouple 00.
3. Water processed was measured using a graduated cylinder and estimated using the zeolite isobar plots.
4. Temperature just before the end of desorption; thermocouple 06.
5. Column 1 minus column 3.
6. Column 1 minus column 6.
7. Time the system was in the desorption phase. It was terminated when the test operators saw no additional water entering the condensate receiver.
8. Thermocouple 20 data during adsorption.
9. Thermocouple 19 data during adsorption.
10. Eight hour vacuum pumping before the test. The minutes of pumping given in this column for each date were done the morning of the test and typically included opening the 3-inch vacuum valve for a short period.

operational problems involved water flow adjustments and water pumps. The hot and cold water flows had to be adjusted carefully and were sometimes readjusted both to keep hot and cold water from mixing at the condenser tank-zeolite tank interface and to keep the zeolite tank full but not overflowing. The general design of the zeolite, condenser, and manifold sections was adequate. However, the sections should be installed in a manner that allows some differential pressurization of the two tank sections without mixing hot and cold water and without overflowing the zeolite tank.

The system to freeze water in the ice tank by means of nocturnal radiation was completed but not tested.

Electrical Analysis

Electrical input (January 30, 1984)

Cooling water flow rate	3.3 gpm
Spray water flow rate	0.5 gpm
Hot water flow rate	3.0 gpm
Air flow rate	485 cfm
Adsorption phase	250 minutes
Desorption phase	119 minutes

From pump manufacturer's literature

Cooling water pressure rise	8 feet
Spray water pressure rise	27 feet
Hot water pressure rise	12 feet

Adsorption phase energy (water pumps):

$$3.3 \text{ gpm} \times 8.34 \text{ lb/gal} \times 8 \text{ ft} \times 0.0012854 \text{ Btu/ft lb per min} \times 250 \text{ min} + 0.5 \times 8.34 \times 27 \times 0.0012854 \times 250 = 70.75 + 36.18 = 106.93 \text{ Btu.}$$

Desorption phase energy (water pumps):

$$119 \div 250 \times 106.93 + 3 \times 8.34 \times 12 \times 0.0012854 \times 119 = 50.90 + 45.93 = 96.83 \text{ Btu.}$$

Total fan energy:

$485 \text{ ft}^3/\text{min} \times 0.0648 \text{ lb}/\text{ft}^3 \times 0.167 \text{ ft (water)} \times 62.4 \text{ lb}/\text{ft}^3 \text{ (water)} \div$
 $0.0648 \text{ lb}/\text{ft}^3 \text{ (air)} \times 0.0012854 \text{ Btu}/\text{ft lb per min} \times (250 + 119) = 2,397$
Btu.

Total electrical energy = $106.93 + 96.83 + 2,397 = 2,602$ Btu (rounded off)

Energy pumped from the 48°F ice tank water was:

$10.4 \text{ lb (vaporized)} \times 1,066.4 \text{ Btu}/\text{lb} = 11,091 \text{ Btu.}$

$\text{COP} = 11,091/2,602 = 4.3 \text{ (electrical)}$

The fan efficiency was 40 percent and the pump efficiencies were about 6 percent. The pump efficiencies can be boosted to 60 percent by use of better pumps, but pump energy is only 7.8 percent of the total electrical energy used. A big improvement would come by decreasing the static air impedance through the evaporative water chiller. If this is done by using two heat exchangers, instead of one, the energy requirement drops to 50 percent of present use. This would increase the electrical COP to 8.6.

PROPERTIES OF ZEOLITES FOR ADSORPTION REFRIGERATION SYSTEMS

The principal uses for natural or synthetic zeolites and molecular sieves are for ion exchange and as substrates for heterogeneous catalysis (typically gas phase cracking of petroleum hydrocarbons). A secondary use has been as desiccants, but in the latter applications silica gel and activated alumina have been preferred because of their lower cost. Typical costs are 5 to 8 cents per pound for silica gel and 15 to 18 cents per pound for activated alumina in carload lots versus about \$2.09 per pound in carload lots for the Linde 13X molecular sieve used in the experimental test equipment at the New Mexico Solar Energy Institute. The Linde 13X has a tailored, controlled structure. It is a sodalite-type structure in which the SiO_4 and AlO_4 tetrahedral groups link to form truncated octahedra having six square faces and eight hexagonal faces. This structure has very low density and is capable of containing about 28 to 30 weight percent of water (0.17 to 0.2 ft^3 of H_2O (ℓ) per bulk ft^3 adsorbent) at a water vapor pressure of about 17.5 torr (about 0.34 psia, the saturation pressure of water at 68°F). It will hold up to 35-40 weight percent of water when saturated by immersion.

The constraints on the temperature cycling of the adsorbent using evaporatively cooled water and a flat-plate solar energy collector under ambient summer conditions in Las Cruces are about $65\text{--}70^\circ\text{F}$ ($18\text{--}21^\circ\text{C}$) minimum to $200\text{--}205^\circ\text{F}$ ($93\text{--}96^\circ\text{C}$) maximum, which give about a 6-pound change in water content per 100 pounds of zeolite on top of 19 pounds of preadsorbed ("dead") water on the oxide substrate when making ice. A slightly greater change, 6- to 7-pounds in water content per 100 pounds of zeolite occurs when making 50°F cool water. The expected amounts and ranges of water adsorption are based on isotherms supplied by Union Carbide Corporation, manufacturer of Linde 13X.

The X-type molecular sieves have, as a class, the greatest gross water adsorption capacity. The natural faujasites and Y-type molecular sieves have structures very similar to X-type, and may, on the basis of cost comparisons, be candidates for direct substitution for the Linde 13X (X-type) selected for the demonstration system.

Faujasite-type zeolites, which are topologically similar to the X and Y type synthetic zeolites, have a high and fairly uniform energy of adsorption after the first two layers of water have been adsorbed. About 50 percent of the crystal volume in the dehydrated state is voids. The theoretical pore diameter is 8 to 10 angstroms, compared to a dynamically effective average H₂O molecular diameter of 3.9 angstroms. The molecular sieve chosen for the demonstration unit, Linde 13X, operates in the water vapor pressure range of 4 to 10 mmHg.

The open, definite, structures of the crystalline molecular sieves such as Linde 13X are advantageous and worth the cost compared to silica gel or activated alumina in gas phase catalysis of reactions involving large molecules. However, it is worth evaluating whether or not the simpler service for water adsorption requires the added control and cost of such a "tailored," crystalline structure. For simple water adsorption, detailed structural specifics hardly matter as long as the pores will admit the relatively small water molecule. Adsorption of water by aluminosilicates will be structure sensitive, varying as the average diameter of a water-containing pore is changed. However, adsorption will not show as great a structural sensitivity as chemically active catalytic centers typically show toward structural changes.

The vapor pressure of adsorbed water on the surface of a porous solid depends on two main properties: the intrinsic energy of surface adsorption and the diameter of the pores in which the water is adsorbed. The effect of the intrinsic energy (enthalpy) of adsorption on vapor pressure is described by the Clausius-Clapyron equation where ΔH^{vap} of bulk liquid is replaced by ΔH^{des} , the heat of desorption from the surface:

$$d (\ln P^{\text{des}})/dT \cong \Delta H^{\text{des}}/RT$$

for low pressures, in the range of practical interest for refrigerative adsorption applications. The integrated form of this equation, assuming ΔH^{des} is not a function of temperature, is

$$\ln [P^{\text{des}}(T_2)/P^{\text{des}}(T_1)] = [-\Delta H^{\text{des}}/R] [1/T_2 - 1/T_1].$$

Since ΔH^{des} is a function of T , the foregoing equation is only approximately valid, but is satisfactory for engineering calculations when:

- (1) T_1 and T_2 are not "too far" apart,
- (2) $T_c > \sim 1.3 \times (T_1 \text{ or } T_2)$, whichever of T_1 and T_2 is higher, where T_c is the critical temperature of the fluid being adsorbed,
- (3) V_{vapor} per unit mass (mole) $\gg V_{\text{liquid}}$ per unit mass (mole), and
- (4) the vapor behaves nearly like an ideal gas.

When all these criteria are met, the foregoing equation can be solved for (ΔH^{des}) :

$$(\Delta H^{\text{des}}) \simeq -R \{ \ln [P^{\text{des}}(T_2)/P^{\text{des}}(T_1)] \} / (1/T_2 - 1/T_1)$$

where R = the gas constant.

The temperature to which (ΔH^{des}) is referred specifically is

$$T_{\text{Avg}} = [(1/T_2 + 1/T_1)/2]^{-1} \text{ if } \Delta H^{\text{des}} \text{ varies linearly versus } (1/T).$$

The following data are given in manufacturer's literature (Union Carbide Corporation) for adsorption of water vapor on Linde 13X molecular sieve adsorbent.

At $T_1 = 273.2^\circ\text{K}$ (32°F) , $P_1^{\text{ads}} = 281 \times 10^{-5} \text{ g/cm}^2$ ($4.00 \times 10^{-5} \text{ psia}$)

At $T_2 = 294.1^\circ\text{K}$ (69.8°F) , $P_2^{\text{ads}} = 169 \times 10^{-4} \text{ g/cm}^2$ ($2.40 \times 10^{-4} \text{ psia}$)

At $T_3 = 338.8^\circ\text{K}$ (150.1°F) , $P_3^{\text{ads}} = 365.6 \times 10^{-3} \text{ g/cm}^2$ ($5.20 \times 10^{-3} \text{ psia}$)

At $T_4 = 360.9^\circ\text{K}$ (190°F) , $P_4^{\text{ads}} = 1.16 \times \text{g/cm}^2$ ($1.65 \times 10^{-2} \text{ psia}$)

These temperatures cover the adsorbent operating range in the chill generation equipment.

The form of the Clapyron equation is general and applies to any phase-change type process, including vapor-solid (sublimation), liquid-solid (freezing), and vapor-adsorbate (adsorption) so long as the substance whose phase is changing is a single pure substance.

Therefore $(\Delta H_{H_2O}^{des})$ at $T_{Avg} \approx R T_{Avg}^2 [\ln p^{ads}(T_2) - \ln p^{ads}(T_1)] / (T_2 - T_1)$

$$(T_{1,2})_{Avg} = [(1/294.1 + 1/273.2)/2]^{-1} = 283.27^\circ K (50.2^\circ F) ; (T_2 - T_1) = 20.9^\circ K$$

$$(T_{2,3})_{Avg} = [(1/338.8 + 1/294.1)/2]^{-1} = 314.87^\circ K (107.1^\circ F) ; (T_3 - T_2) = 44.7^\circ K$$

$$(T_{3,4})_{Avg} = [(1/360.9 + 1/338.8)/2]^{-1} = 349.50^\circ K (169.4^\circ F) ; (T_4 - T_3) = 22.1^\circ K$$

$$(\Delta H_{H_2O}^{des})_{283.27^\circ K} \approx 1.987 [\ln 169 \times 10^{-4} - \ln 281 \times 10^{-5}] (283.27)^2 / 20.9 = 13686.9 \text{ cal/g-mole } H_2O$$

$$(\Delta H_{H_2O}^{des})_{314.87^\circ K} \approx 1.987 [\ln 365.6 \times 10^{-3} - \ln 169 \times 10^{-4}] (314.87)^2 / 44.7 = 13548.4 \text{ cal/g-mole } H_2O$$

$$(\Delta H_{H_2O}^{des})_{349.50^\circ K} \approx 1.987 [\ln 1.16 - \ln 365.6 \times 10^{-3}] (349.50)^2 / 22.1 = 12680.7 \text{ cal/g-mole } H_2O$$

At the foregoing temperatures, the enthalpy of vaporization of bulk water is

<u>T°F</u>	
50.2	$\Delta H^{vap} = 1065.346 - [0.2/10] (5.7076) = 1065.232 \approx 1065.2 \text{ Btu/lb}$
	$= 10,664 \text{ cal/g-mole}$

$$107.1 \quad \Delta H^{\text{vap}} = 1037.161 - [7.1/10] (5781) = 1033.056 \approx 1033.1 \text{ Btu/lb} \\ = 10,342 \text{ cal/g-mole}$$

$$169.4 \quad \Delta H^{\text{vap}} = 1002.24 - [9.4/10] (6.01) = 996.591 \approx 996.6 \text{ Btu/lb} \\ = 9,977 \text{ cal/g-mole.}$$

Compare ΔH^{des} versus (ΔH^{vap}) for H_2O at the same temperature:

<u>T°K</u>	$\Delta H_{\text{H}_2\text{O}}^{\text{des}}$ cal/g-mole	$\Delta H_{\text{H}_2\text{O}}^{\text{vap}}$ cal/g-mole	Difference cal/g-mole	% Difference based on ΔH^{vap}
283.2	13,687	10,664	3,023	28.3
314.9	13,548	10,342	3,206	31.0
349.5	12,681	9,977	2,704	27.1

Since the original data are probably not better than 3 significant figures, and the temperature intervals are fairly large, it is appropriate to round the results:

<u>T°K</u>	$\Delta H_{\text{H}_2\text{O}}^{\text{des}}$ cal/g-mole	% Difference compared to $\Delta H_{\text{H}_2\text{O}}^{\text{vap}}$
283	13,700	30%
315	13,500	30%
350	12,700	30%

The error in these values of $\Delta H_{\text{H}_2\text{O}}^{\text{des}}$ should be considered to be in the vicinity of ± 3 percent, if the manufacturer's data are good to the readability of the adsorption isotherm graphs which were supplied. The effect of pore diameter on vapor pressure is

$$(P^{VP}/P_f^{VP}) = \exp [2\gamma V_{\text{water}}/rRT]$$

where P_f^{VP} is the ordinary bulk liquid vapor pressure

V_{water} is the volume of water

r is pore radius

γ is surface tension

Since the pore size in Linde 13X molecular sieve is about 1×10^{-7} cm diameter at about 40°C, the vapor pressure of water inside the pores will be about 86 percent of the ordinary vapor pressure of bulk liquid. Some of the 19 pounds of "dead" water per 100 pounds of Linde 13X is due to lowering of vapor pressure by pore-capillarity. If the pore size could be increased enough to make the capillarity effect negligible, about 2 to 3 pounds of the 19 pounds of "dead" water could be eliminated.

"Dead" water harms the thermal efficiency and capital costs of the system by having to be heated up and cooled down during each desorption-adsorption cycle without contributing to process performance other than adjusting the water vapor pressure over the adsorbent to the operating value set by the temperature limits on equipment operability. Since the specific heat of bulk water is 1.8 Btu/lb °F (1 cal/g °C) versus about 0.2 Btu/pound °F for the solid dry adsorbent, the 19 pounds of adsorbed "dead" water contributes almost as much useless thermal inertia to the system as the solid adsorbent itself. The adsorbed water should have somewhat less specific heat than free bulk water since some degrees of freedom of motion have been lost. The first layer of water will be chemically reacted to immobile surface hydroxyl, losing all degrees of freedom except vibration. The next layer of water molecules, which is the first layer of hydrogen-bonded water, will lose one translational degree of freedom. Layers beyond the first will possess all degrees of freedom although to a variably restricted extent. The linearity of the adsorption isobars versus temperature down to 8 pounds water per 100 pounds zeolite suggests that the first hydrogen-bonded water layer on the surface

hydroxyls is completed at somewhat less than 8 pounds water per 100 pounds adsorbent.

As long as the adsorbent has surface hydroxyls on an aluminosilicate surface, it is unlikely that the $(\Delta H_{\text{des}} - \Delta H_{\text{H}_2\text{O}}^{\text{vap}})$ will drop below about 20 kcal/g mole for the first 3 to 4 pounds of water absorbed per 100 pounds of zeolite. The difference is unlikely to drop below about 7 kcal/g mole for the first 6 to 7 pounds per 100 pounds. Thus, if the "dead" water content of molecular sieve-type adsorbents is to be dropped by more than 10 to 15 percent, it will be necessary to chemically modify the adsorbent surface, to make it act more like a compound containing weakly incorporated water of hydration, like an immobilized clathrate water compound instead of a high-energy chemisorption surface compound. Many alum-type compounds contain 12 waters of hydration with 6 waters chemically coordinated to the Al^{3+} ion with strong forces and 6 ions trapped in lattice cavities by weak forces. The incorporation of alumina in an insolubilizing silica lattice and then reacting the alumina with SO_3 or H_2SO_4 vapor, to make a surface alum compound, offers a possible approach to increasing the proportion of water utilized in the absorption-desorption cycle beyond the current 20 to 25 percent of total adsorbed water.

The randomly structured permutites, while easier and cheaper to prepare than crystalline zeolites, are not as well characterized in the literature and their inherently indefinite structure make them less attractive for rigorous scientific study. For engineering use as water adsorbents (rather than for ion exchange, catalysis, or molecular sieving type separations) the structural indeterminacy could represent a minor drawback that might be worthwhile in view of the potential savings of cost and volume. The cost of the adsorbent is a secondary factor in small installations such as the current test system, but it will have more importance as the size of the equipment increases. The costs of tanks and bulk fluid handling equipment tend to grow as the $2/3$ to $3/4$ power of size or capacity, whereas the adsorbent inventory will grow linearly (first power) with respect to capacity.

The permutite-amorphous type desiccants should be evaluated for suitability of substitution for synthetic zeolite Linde 13X. A set of five

aluminosilicate samples of the permutite type (amorphous rather than crystalline aluminum silicates) were made for adsorption isotherm testing, first by titrating sodium silicate solution with aluminum sulfate solution with the desired Si/Al ratio and then with sufficient sulfuric acid or sodium hydroxide to achieve neutrality. Samples of 0 percent Al_2O_3 - 100 percent SiO_2 , 25 percent Al_2O_3 - 75 percent SiO_2 , 50 percent Al_2O_3 - 50 percent SiO_2 , 75 percent Al_2O_3 - 25 percent SiO_2 and 100 percent Al_2O_3 - 0 percent SiO_2 (mole percent) were prepared.

Aqueous coprecipitation of mixtures of soluble silicate and soluble aluminum salts at temperatures between 0°C and 100°C , followed by washing and drying to gel-flake produces permutite-type zeolites having amorphous to partially crystalline character. While their technical suitability for chill-adsorption application (compared to the highly controlled fully crystallized faujasite-type and X-type zeolites) is not certain, they are cheaper and can be made with less internal voidage.

Difficulty with adsorption apparatus leakage, breakage, and spare parts procurement prevented attaining satisfactory data in time for this report, but the experimental work is continuing and experimental results will be available later. When the adsorption isotherms of these samples are reproducibly well characterized, the Al_2O_3 bearing samples will be sulfated and the adsorption characteristics remeasured. Silica gel is included in the samples as a reference-control material and because it is the cheapest water adsorbent in wide use.

Linde 13X pellets have a settled bulk density of 38 pounds per cubic feet when dry and a dry pellet density of about 57 pounds per cubic feet. Pure alumina and silica have close-packed crystal densities of 250 pounds per cubic foot and about 138 pounds per cubic foot, respectively, with a mole ratio of about 1.2 ($\text{SiO}_2/\text{NaAlO}_2$). The density of the solid atomic framework, in a close-packed atom-ion sense, should be roughly 184 pounds per cubic foot, giving a solid volume for 57 pounds of about $1/3$ cubic foot. When the absorbent is being operated in its normal adsorbed water range of 19 to 26 pounds of water per cubic foot, about 0.3 to 0.4 cubic foot of adsorbed water is involved, which leaves about an additional $1/3$ of the volume inside the pellets as empty space, probably associated with

microscopic porosity between molecular sieve individual crystals in the pellets. For small, mobile molecules such as water, unlike bulky hydrocarbon molecules, this pore space increases equipment size costs without much advantage. The capillary action of fine pores toward adsorbed water and the strong forces of chemisorption of water make the high porosity pellet structure less necessary for rapid transport than in gas phase hydrocarbon catalysis. All-gel particles of the permutite type are likely to be a preferred form of adsorbent, both because of the low cost of fabrication compared to the crystalline zeolites and the decreased size (capital cost) of the adsorbent containment equipment. Since pellet packing fraction is not a function of pellet diameter in most ranges of typical adsorbent particle sizes, the change to all-gel pellets lacking the granular pore structure of Linde 13X pellets has potential for reducing the number or size of adsorption tubes required at a fixed capacity by 1/4 to 1/3. The low cost permutites and the pure and chemically modified silica gels both seem to be worthwhile candidates for exploration to bring down capital costs. Silica gel desiccants having adsorption capacities up to 30 pounds of water per 100 pounds of gel are commercially available.

About 35 to 40 different arrangements of the fundamental aluminosilicate zeolite-type structures are characterized in the current literature. The number of theoretically possible distinguishable zeolite structures is indefinitely large, depending on how small a variation over what repeating unit distance is considered significant. The most significant aspect of the structurally tailored crystalline-compound type zeolites and molecular sieves is the high cost of exerting the kind of process control needed to fabricate their precise structures for gas phase catalysis, compared to making amorphous gels of silica, alumina, and the permutite aluminosilicates.

Another current practical problem with the commercial molecular sieves is that their available forms are fine powders or porous, catalyst-type granular pellets rather than gel shards or beads, leading to about 2/3 of the adsorbent total volume being empty space. This empty space promotes rapid vapor transport and equilibration, but it should be possible to modify the catalyst pore structure so that, for small penalties on transfer

rates and equilibration times, significant savings of adsorbent volume, on the order of 1/3 of the volume now required, can be obtained by the inorganic gel technology developed initially for fabricating ceramic nuclear fuels ("sol-gel" technology).

Adsorbent packing has further potential for improvement by more than 1/3, when particles are of two distinct sizes, the smaller being about 1/3 to 1/4 the diameter of the larger. The tradeoff is, again, capital cost savings versus vapor flow rates and equilibration time penalties.

The directions of research in the adsorbent character which seem likely to be fruitful are to reduce the volume of "dead" water adsorbed by chemically modifying the surface to make the first and second water layers more loosely bound and more participative in the desorption-adsorption cycle. A second approach would be to adapt the physical pore structure of the catalyst for efficient space utilization in the adsorption tubes. In stationary applications, the weight of adsorbent required to provide a certain volumetric adsorbent-desorbent cycling capacity is less important than either the volume of adsorbent or the amount of "dead" water it contains. If one pound of "dead" water can be eliminated, up to 5 pounds of added dry aluminosilicate solids weight can be added before the thermal efficiency loss is equivalent to that of the water eliminated.

The following data was extracted from curves given in Dr. D. I. Tchernev's report "Solar Energy Applications of Natural Zeolites."

Silica Gel			
167°F	0.256 psig	13.2 torr	3.1 lbs/100 lbs
77°F	0.087 psig	4.5 torr	<u>10.2</u> lbs/100 lbs
			7.1 lbs/100 lbs
Zeolite 13X			
167°F	0.256 psig	13.2 torr	20.2 lbs/100 lbs
77°F	0.087 psig	4.5 torr	<u>23.6</u> lbs/100 lbs
			3.4 lbs/100 lbs

This example shows that even though zeolite 13X holds much more water, the silica gel cycles more water and keeps less dead water.

The Chemical Engineering Department of New Mexico State University is continuing a program of investigation of adsorbers. A gallon of montmorillonite was recently received from Multiform Desiccants, Inc., Multiform casts desiccants into many different forms including hollow cylinders. For example, cylinders 48 inches long by 1.5 inches in diameter with a 0.5-inch concentric hole lengthwise could alleviate the weight and complexity of the inner structure of the zeolite tubes in the ZCAT facility.

This program for continued investigation is to

1. Develop a bibliography of literature relevant to the adsorption isotherms and heats of adsorption of zeolites in relation to heating - cooling system design.
2. Experimentally prepare representative permutite-type zeolite samples and measure their adsorption isotherms in the 0°-100° C range.
3. Compare the properties of Linde 13X with those of the permutite-type zeolites and evaluate their potential for cost savings in the type of application being investigated.

REFERENCES

Redman, C. M. 1984. Test and Evaluation of Evaporative Water Chilling. Final Report. NMERDI Project 2-71-4224. New Mexico Energy Research and Development Institute Information Center, Santa Fe, NM.

Tchernev, D. I. "Solar Energy Applications of Natural Zeolites." (Report received from Dr. Tchernev in private communication. Report not dated and does not show name of publication.)

Union Carbide Corporation furnished test curves which were not dated.

APPENDIX A

SUMMARY OF TEST RUNS

Test Run Test Run 1: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.		Date January 30, 1984
Test Conditions		References
Adsorption: Cooling water Initial - 50°F Final - 43°F	Desorption: Hot water Initial - 181°F Final - 163°F Cooling water Initial - 46°F Final - 49°F	Figure B-1-a. Zeolite Isobars Figure B-1-b. Data Run Temperatures Figure B-1-c. Desorption Response Figure B-1-d. Data Printout
Key Results		
Actual water processed:		10.4 pounds
Cooling:		11,086 Btu/cycle
Theoretic water processed:		5.8 pounds
Cooling:		6183 Btu/cycle
Actual/theoretical:		1.79
Time for 90% desorption:		82 minutes
Comments		
<p>The first 267 minutes of the test run were used for zeolite adsorption of water. Some data logger problems caused loss of the temperature data during first 27 minutes and 160 minutes during the middle of the adsorption phase. Based on pressure gauge reading, the zeolite had 26.6 pounds of water and based on the temperature of the ice tank water, the zeolite had 26.7 pounds of water at the end of adsorption.</p> <p>Evaporatively chilled water cooled the zeolite during the adsorption phase. Hot water replaced the chilled water circulating through the zeolite tank at 267 minutes to start the desorption phase. The 3-inch vacuum valve was closed during this phase and condensate drained into the condensate receiver.</p> <p>Figure B-1-C shows the condensate collection versus time after initiation of desorption. The curve is based on reading the levels of condensate at the times it was drained from the receiver into the gallon jug. The last point is by measure using a graduated liter measure. Using the pressure gauge reading and zeolite temperature, desorption left 20.8 pounds of water in the zeolite and based on the temperature of the condensate receiver and zeolite temperature, there were 19.8 pounds. Using the temperature and pressure data and the zeolite isobars, the desorption was 5.8 pounds of water. The actual measured value was 10.4 pounds or 179 percent of that derived using the zeolite manufacturer's data.</p> <p>The condenser input/output temperature change followed the desorption response curve for the first 100 minutes of desorption and then the differential temperature reversed. This anomaly was caused by hot water in the zeolite tank flowing across the barrier into the condenser tank and only affected the top few inches of the condenser.</p> <p>The January 30 test run was preceded by an 8-hour vacuum pumping period.</p>		

<div style="display: flex; justify-content: space-between;"> <div style="width: 30%;"> Test Run </div> <div style="width: 40%;"> Test Run 2: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility. </div> <div style="width: 30%;"> Date </div> </div> <div style="text-align: right; margin-top: 5px;">January 31, 1984</div>	
Test Conditions	References
<div style="display: flex;"> <div style="flex: 1;"> Adsorption: Cooling water Initial - 54.9°F Final - 46.5°F </div> <div style="flex: 1;"> Desorption: Hot water Initial - 157.9°F Final - 162.5°F Cooling water Initial - 54.0°F Final - 44.3°F </div> </div>	Figure 8-2-a. Zeolite Isobars Figure 8-2-b. Data Run Temperatures Figure 8-2-c. Desorption Response Figure 8-2-d. Data Printout
Key Results	
<div style="display: flex; justify-content: space-between;"> <div style="width: 40%;">Actual water processed:</div> <div style="width: 60%;">6.85 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 60%;">7366.5 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Theoretic water processed:</div> <div style="width: 60%;">5.1 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 60%;">5484.5 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Actual/theoretical:</div> <div style="width: 60%;">1.34</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Time for 90% desorption:</div> <div style="width: 60%;">132 minutes</div> </div>	
Comments	
<p>There was an early vacuum pumping period of about 29 minutes with the 3-inch vacuum valve open. After filling the zeolite tank with circulating cooling water and opening the 3-inch vacuum valve again, there was violent boiling in the ice tank and the evaporative water chiller could not cool the zeolite as fast as the zeolite adsorption heating occurred. After about 60 minutes boiling practically stopped and the evaporative water cooling lowered the zeolite temperature causing continued low level evaporation in the ice tank. During the low level evaporation period, the insolation on the uninsulated ice tank exceeded the evaporative cooling in the ice tank. There was, therefore, a gradual heating of the ice tank water to about 42°F.</p> <p>At the end of adsorption, the water in the zeolite was 26.2 pounds by pressure gauge reading and zeolite temperature.</p> <p>The desorption phase started with 167°F water which dropped by over 10°F very quickly and then as desorption slowed it warmed again to the low 160s. The water exiting the zeolite tank showed evidence of cool water infiltration from the condenser tank during the entire desorption period and particularly after 120 minutes of adsorption. The zeolite mix temperature shows that cooling water reached the zeolite tank output but not 3 inches above the bottom of the tank.</p> <p>At the end of desorption, the water in the zeolite was 21.1 pounds by the pressure gauge reading and zeolite temperature measurement. The desorbed water was 5.1 pounds by pressure gauge readings, zeolite temperatures, and the zeolite isobars. The measured value was 6.85 pounds. The measured desorption was 134 percent of the theoretical.</p>	

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Run</div> <div>Test Run 3: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> </div>		<div style="border: 1px solid black; padding: 2px; font-weight: bold;">Date</div> <div>February 2, 1984</div>												
<div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Conditions</div> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 52°F</p> <p>Final - 50.4°F</p> </div> <div style="width: 45%;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 162.7°F</p> <p>Final - 163.6°F</p> <p>Cooling water</p> <p>Initial - 50.5°F</p> <p>Final - 55.0°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; font-weight: bold;">References</div> <div> <p>Figure B-3-a. Zeolite Isobars</p> <p>Figure B-3-b. Data Run Temperatures</p> <p>Figure B-3-c. Desorption Response</p> <p>Figure B-3-d. Data Printout</p> </div>													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 40%;">Actual water processed:</td> <td style="text-align: right;">5.64 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5963 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">4.9 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5181 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.15</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">140 minutes</td> </tr> </table>			Actual water processed:	5.64 pounds	Cooling:	5963 Btu/cycle	Theoretic water processed:	4.9 pounds	Cooling:	5181 Btu/cycle	Actual/theoretical:	1.15	Time for 90% desorption:	140 minutes
Actual water processed:	5.64 pounds													
Cooling:	5963 Btu/cycle													
Theoretic water processed:	4.9 pounds													
Cooling:	5181 Btu/cycle													
Actual/theoretical:	1.15													
Time for 90% desorption:	140 minutes													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Comments</div> <p>The first 265 minutes of the test run were used for zeolite adsorption of water. There was a preceding 62 minute vacuum pumping period with the 3-inch vacuum valve for 12 minutes open. The zeolite tank was filled with cooled water and adsorption started by opening the 3-inch vacuum valve. There was violent boiling of the water in the ice tank, frost formed on the outside, and ice on the inside. In places, the ice formed in piles. The ice tank water was at 32°F during adsorption, however, the thermocouples measured higher. This indicates that the thermocouples did not make good contact with the ice tank. The mechanical pressure gauge consistently read between 5.5 torr and 5.8 torr (0.091 psia to 0.107 psia). During the more violent boiling period, the gauge reading was below its zero mark (below 3.9 torr).</p> <p>The test was shifted to desorption at 270 minutes. The 162.7°F hot water quickly dropped to 156.3°F due to the heavy desorption heat requirement. As the load diminished, the hot water temperature rose to a 163.6°F. The condenser water (condenser mix thermocouple) started at 50.5°F and ended at 55.0°F.</p> <p>Figure B-3-a plots the water in the zeolite at the end of adsorption as follows: (a) 26.5 lbs/100 lbs based on the measured ice tank temperature, (b) 26.0 lbs/100 lbs based on the gauge pressure, (c) 25.2 lbs/100 lbs based on the presence of ice in the ice tank.</p> <p>Figure B-3-a plots the water in the zeolite at the end of desorption as follows: (c) 21.1 lbs/100 lbs based on gauge pressure (d) 20.3 lbs/100 lbs based on condensate receiver temperature. The desorbed water based on the zeolite manufacturers data and gauge pressures was 4.9 pounds. The desorbed water based on the zeolite manufacturers data, condensate receiver temperature, and the temperature of ice was also 4.9 pounds. The measured value was 5.64 pounds. The measured water was 115 percent of that based on the zeolite manufacturers data, the calibrated pressure gauge readings, and the temperatures.</p>														

<div style="display: flex; justify-content: space-between;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Test Run #</div> <div>Test Run 4: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> </div>		<div style="border: 1px solid black; padding: 2px; display: inline-block;">Date</div> February 7, 1984												
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">Test Conditions</div> <div style="display: flex;"> <div style="flex: 1;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 62.4°F</p> <p>Final - 53.5°F</p> </div> <div style="flex: 1;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 176.0°F</p> <p>Final - 165.3°F</p> <p>Cooling water</p> <p>Initial - 58.9°F</p> <p>Final - 63.7°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">References</div> <p>Figure B-4-a. Zeolite Isobars</p> <p>Figure B-4-b. Data Run Temperatures</p> <p>Figure B-4-c. Desorption Response</p> <p>Figure B-4-d. Data Printout</p>													
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px; text-align: center;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">Actual water processed:</td> <td style="text-align: right;">4.3 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">4546 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">4.9 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5181 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">0.88</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">28 minutes</td> </tr> </table>			Actual water processed:	4.3 pounds	Cooling:	4546 Btu/cycle	Theoretic water processed:	4.9 pounds	Cooling:	5181 Btu/cycle	Actual/theoretical:	0.88	Time for 90% desorption:	28 minutes
Actual water processed:	4.3 pounds													
Cooling:	4546 Btu/cycle													
Theoretic water processed:	4.9 pounds													
Cooling:	5181 Btu/cycle													
Actual/theoretical:	0.88													
Time for 90% desorption:	28 minutes													
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px; text-align: center;">Comments</div> <p>The first 240 minutes of this test run were used for zeolite adsorption of water. There was no preliminary vacuum pumping. Some boiling was noted during this entire period but not as violent as occurred during previous test runs. No ice was noted and the pressure gauge measurements stayed between 7.2 and 8.8 torr (0.14 and 0.17 psia). The ice tank was measured to be 53°F at the start and warming up to 57°F.</p> <p>The cooling water was 62.4°F at the start of the adsorption period and went to a peak of 63.5°F and as the adsorption load decreased, it dropped to 53.5°F.</p> <p>The hot water at initiation of the desorption cycle was 176°F and cooled to 165.3°F in 20 minutes. This was a very short desorption cycle and most likely it did not reach an energy balance position. There were only 46 minutes between the time the zeolite tank was full of hot water and the end of the test run.</p> <p>There also were preceding short adsorption and desorption cycles which did not appear to reach balance conditions and were not included in the reported data.</p> <p>Figure B-4-a plots the water in the zeolite at the end of adsorption as follows: (a) 26.6 lbs/100 lbs based on measured ice tank temperature, (b) 26.1 lbs/100 lbs based on the gauge pressure.</p> <p>Figure B-4-a plots the water in the zeolite at the end of the desorption period as follows, (c) 21.2 lbs/100 lbs based on the gauge pressure, (d) 20.4 lbs/100 lbs based on the condensate receiver temperature.</p> <p>The desorbed water based on the gauge pressures was 4.9 pounds. The measured water was 4.3 pounds. The measured water was 88 percent of that based on the zeolite manufacturers data and the calibrated pressure gauge readings. The short cycles may not have allowed the adsorption and desorption to reach balance conditions. Also the absence of any vacuum pumping for five days may have caused less water cycling due to "poisoning" of the zeolite.</p>														

<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;"> Test Run </div> Test Run 5: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px; float: right;"> Date </div> February 10, 1984												
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;"> Test Conditions </div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; vertical-align: top;"> Adsorption: Cooling water Initial - 64.5°F Final - 54.9°F </td> <td style="width: 50%; vertical-align: top;"> Desorption: Hot water Initial - 179.3°F Final - 166.6°F Cooling water Initial - 55.7°F Final - 66.0°F </td> </tr> </table>	Adsorption: Cooling water Initial - 64.5°F Final - 54.9°F	Desorption: Hot water Initial - 179.3°F Final - 166.6°F Cooling water Initial - 55.7°F Final - 66.0°F	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;"> References </div> Figure B-5-a. Zeolite Isobars Figure B-5-b. Data Run Temperatures Figure B-5-c. Desorption Response Figure B-5-d. Data Printout										
Adsorption: Cooling water Initial - 64.5°F Final - 54.9°F	Desorption: Hot water Initial - 179.3°F Final - 166.6°F Cooling water Initial - 55.7°F Final - 66.0°F												
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;"> Key Results </div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Actual water processed:</td> <td style="width: 50%;">6.4 pounds</td> </tr> <tr> <td>Cooling:</td> <td>6825 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td>5.3 pounds</td> </tr> <tr> <td>Cooling:</td> <td>5652 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td>1.21</td> </tr> <tr> <td>Time for 90% desorption:</td> <td>47 minutes</td> </tr> </table>		Actual water processed:	6.4 pounds	Cooling:	6825 Btu/cycle	Theoretic water processed:	5.3 pounds	Cooling:	5652 Btu/cycle	Actual/theoretical:	1.21	Time for 90% desorption:	47 minutes
Actual water processed:	6.4 pounds												
Cooling:	6825 Btu/cycle												
Theoretic water processed:	5.3 pounds												
Cooling:	5652 Btu/cycle												
Actual/theoretical:	1.21												
Time for 90% desorption:	47 minutes												
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px; text-align: center;"> Comments </div> <p>The first 237 minutes of this test run were used for zeolite adsorption of water. There was an 8-hour period of vacuum pumping on February 9, with the vacuum valve closed to remove any "poisoning" which may have accumulated. This was the first long dry cycle (3-inch vacuum valve closed) vacuum pumping since January 29. The ice tank was filled to the half full condition with tap water preceding this test run. There was violent boiling (ferocious roar) when the cooling water filled the zeolite tank and the 3-inch vacuum valve was opened. The system pressure during adsorption started at 6.28 torr and ended at 8.58 torr (0.121 psia to 0.166 psia). There was no ice formation. This may have been due to the large amount of water in the ice tank and that the ice tank was still uninsulated. The cooling water input to the zeolite tank was initially 64.5°F and the evaporative water cooling system had not been operating. It was started about the time of the adsorption cycle initiation. The evaporative water chiller kept up with the adsorption heat load and cooled down to 54.9°F.</p> <p>The desorption cycle ran for 58 minutes. The last data points plotted on figure B-5-b are for measurements which occurred after shut down and there was a flow of hot water into condenser tank. The hot water started at 179.3°F and cooled to 166.6°F prior to the end of the desorption cycle. The condenser mix temperature was 69.5°F just prior to shifting to the desorption cycle. There was then a 9.3°F rise due to hot water infiltration which was cycled out and the temperature dropped to 66.6°F.</p> <p>Figure B-5-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 27.2 lbs/100 lbs based on measured temperature of the ice tank, (b) 26.7 lbs/100 lbs based on pressure gauge measurements.</p> <p>Figure B-5-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 21.4 lbs/100 lbs based on pressure gauge measurements, (d) 20.0 lbs/100 lbs based on temperature of the condensate receiver. The desorbed water based on gauge pressures was 5.3 pounds. The measured water was 6.4 pounds. The measured water was 121 percent of that based on the zeolite manufacturers data, system pressure measurements and zeolite temperatures.</p>													

<div style="display: flex; justify-content: space-between;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Test Run</div> <div>Test Run 6: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Date</div> </div> <div style="text-align: right; margin-top: 5px;">February 14, 1984</div>													
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Test Conditions</div> <div style="display: flex;"> <div style="flex: 1;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 62.9°F</p> <p>Final - 52.0°F</p> </div> <div style="flex: 1;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 185°F</p> <p>Final - 163.7°F</p> <p>Cooling water</p> <p>Initial - 57.4°F</p> <p>Final - 64.6°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">References</div> <p>Figure B-6-a. Zeolite Isobars</p> <p>Figure B-6-b. Data Run Temperatures</p> <p>Figure B-6-c. Desorption Response</p> <p>Figure B-6-d. Data Printout</p>												
<div style="border: 1px solid black; padding: 2px; text-align: center; margin-bottom: 5px;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Actual water processed:</td> <td style="width: 50%; text-align: right;">6.8 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">7167 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">4.4 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">4638 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.55</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">36 minutes</td> </tr> </table>		Actual water processed:	6.8 pounds	Cooling:	7167 Btu/cycle	Theoretic water processed:	4.4 pounds	Cooling:	4638 Btu/cycle	Actual/theoretical:	1.55	Time for 90% desorption:	36 minutes
Actual water processed:	6.8 pounds												
Cooling:	7167 Btu/cycle												
Theoretic water processed:	4.4 pounds												
Cooling:	4638 Btu/cycle												
Actual/theoretical:	1.55												
Time for 90% desorption:	36 minutes												
<div style="border: 1px solid black; padding: 2px; text-align: center; margin-bottom: 5px;">Comments</div> <p>The first 275 minutes of this test run were used for zeolite adsorption of water. This was preceded by a 30-minute vacuum pumping with the 3-inch vacuum valve open. The evaporative water chiller was started up at the initiation of the adsorption cycle. The cooled water started at 62.9°F and dropped to 52°F by the end of adsorption.</p> <p>The water cooler readily handled the adsorption heat but did not cool all the way to the ambient air wet bulb temperature. The system pressure during the adsorption phase started at 4.3 torr and increased to 7.6 torr at the end of adsorption (0.83 psia to 0.146 psia). There was no ice formation which was partially due to the large amount of water in the ice tank and its initial temperature.</p> <p>The hot water started at 185°F and quickly dropped to 167.2°F during the desorption cycle. The system pressure started at 26 torr and ended at 27.3 torr during desorption (0.503 psia to 0.528 psia).</p> <p>Figure B-6-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 26.8 lbs/100 lbs based on measured temperature of the ice tank water. This measured temperature is thought to be high, (b) 26.3 lbs/100 lbs based on pressure gauge measurements.</p> <p>Figure B-6-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 21.9 lbs/100 lbs based on pressure gauge measurements, (d) 20.9 lbs/100 lbs based on the measured temperature of the condensate receiver.</p> <p>The desorbed water based on gauge pressures was 4.4 pounds. The measured water was 6.8 pounds. The measured water was 155 percent of that based on the zeolite manufacturers data, system pressure measurements, and zeolite temperatures.</p>													

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Run</div> <div>Test Run 7: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Date</div> </div> <div style="text-align: right; margin-top: 5px;">February 18, 1984</div>													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Test Conditions</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; vertical-align: top;"> Adsorption: Cooling water Initial - 55.4°F Final - 48.8°F </td> <td style="width: 50%; vertical-align: top;"> Desorption: Hot water Initial - 162.9°F Final - 152.3°F Cooling water Initial - 50.5°F Final - 56.6°F </td> </tr> </table>	Adsorption: Cooling water Initial - 55.4°F Final - 48.8°F	Desorption: Hot water Initial - 162.9°F Final - 152.3°F Cooling water Initial - 50.5°F Final - 56.6°F	<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">References</div> <p>Figure B-7-a. Zeolite Isobars Figure B-7-b. Data Run Temperatures Figure B-7-c. Desorption Response Figure B-7-d. Data Printout</p>										
Adsorption: Cooling water Initial - 55.4°F Final - 48.8°F	Desorption: Hot water Initial - 162.9°F Final - 152.3°F Cooling water Initial - 50.5°F Final - 56.6°F												
<div style="border: 1px solid black; padding: 2px; font-weight: bold;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 40%;">Actual water processed:</td> <td style="text-align: right;">5.15 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5485 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">4.2 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">4473 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.23</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">52 minutes</td> </tr> </table>		Actual water processed:	5.15 pounds	Cooling:	5485 Btu/cycle	Theoretic water processed:	4.2 pounds	Cooling:	4473 Btu/cycle	Actual/theoretical:	1.23	Time for 90% desorption:	52 minutes
Actual water processed:	5.15 pounds												
Cooling:	5485 Btu/cycle												
Theoretic water processed:	4.2 pounds												
Cooling:	4473 Btu/cycle												
Actual/theoretical:	1.23												
Time for 90% desorption:	52 minutes												
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Comments</div> <p>The first 277 minutes of this test run were used for zeolite adsorption of water. There was a 30-minute vacuum pumping which preceded the test run. The 3-inch vacuum valve was open during this period. The evaporative water chiller was started about the same time as the filling of the zeolite tank with cooling water. The cooling water started at 55.4°F and dropped to 42.2°F while removing the heat of adsorption. The temperature of the water warmed somewhat as the day warmed. The pressure varied from 4.8 torr to 7.3 torr at the end of adsorption (0.092 to 0.141 psia). There was no ice formation which was due to the large amount of water in the ice tank and its initial temperature.</p> <p>The hot water (desorption cycle) started at 162.9°F and quickly dropped to 150.2°F. The temperature warmed somewhat as the desorption load dropped.</p> <p>Figure B-7-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 26.7 lbs/100 lbs based on measured temperature of the ice tank water, (b) 26.4 lbs/100 lbs based on pressure gauge measurements, (d) 20.8 lbs/100 lbs based on the temperature of the condensate receiver.</p> <p>The desorbed water based on gauge pressures was 4.2 pounds. The measured water was 5.15 pounds. The measured water was 123 percent of that based on the zeolite manufacturers data, system pressure measurements, and zeolite temperatures.</p> <p>Figure B-7-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 22.2 lbs/100 lbs based on pressure gauge measurements.</p>													

<div style="display: flex; justify-content: space-between;"> <div style="width: 60%;"> Test Run Test Run 8: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility. </div> <div style="width: 35%;"> Date February 24, 1984 </div> </div>	
Test Conditions <div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> Adsorption: Cooling water Initial - 66.2°F Final - 50.3°F </div> <div style="width: 48%;"> Desorption: Hot water Initial - 166.6°F Final - 152.8°F Cooling water Initial - 59.2°F Final - 64.0°F </div> </div>	References Figure B-8-a. Zeolite Isobars Figure B-8-b. Data Run Temperatures Figure B-8-c. Desorption Response Figure B-8-d. Data Printout
Key Results <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Actual water processed:</div> <div style="width: 50%;">6 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Cooling:</div> <div style="width: 50%;">6402 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Theoretic water processed:</div> <div style="width: 50%;">4.3 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Cooling:</div> <div style="width: 50%;">4588 8tu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Actual/theoretical:</div> <div style="width: 50%;">1.4</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 45%;">Time for 90% desorption:</div> <div style="width: 50%;">55 minutes</div> </div>	
Comments <p>The first 238 minutes of this test run were used for adsorption of water. There was a 35-minute vacuum pumping cycle with the 3-inch vacuum valve open which preceded the adsorption cycle. The temperature logging was started before the evaporative water cooler and zeolite tank filling were initiated. The zeolite tank filling was started at 10:35 and the zeolite tank initially cooled the water. The evaporative cooling was initiated at about 10:50 and the 3-inch vacuum was opened at 11:02. This sequence shows on figure B-8-b as first a decreasing cooling of the water by the cooling equipment while the sun was adding heat. There was an overall trend up in temperature with the zeolite tank cooling the water. The evaporative cooler was turned on and the temperature of the water started dropping. This was followed by opening the 3-inch vacuum valve; adsorption started, and the zeolite heated the circulating cooling water. The evaporative cooling exceeded the adsorptive heating and the cooling water dropped from 66.2°F to 49.7°F. It stayed near the 50°F level for the remainder of the adsorption cycle. The pressure during adsorption started at 6.4 torr and ended at 8.0 torr (0.124 to 0.154 psia). There was no ice formation as the weight of water in the ice tank, the starting temperature and the pressure were all too high. The hot water cycle started at 166.6°F, dropped to 156.1°F as heat went in to desorption, held somewhat steady, and ended at 152.2°F. The last point plotted on figure B-8-b was after shut down. The pressure started at 25 torr and at the end of the desorption cycle was 30.7 torr (0.483 to 0.518 psia). The evaporatively cooled water started at 59.2°F and was at 64°F at the end of the desorption phase. The temperature of the condensate ended at 67.6°F (0.335 psi saturation pressure).</p> <p>Figure B-8-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 27.1 lbs/100 based on the measured temperature of the water in the ice tank, (b) 26.7 lbs/100 lbs based on pressure gauge measurements.</p> <p>Figure B-8-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 22.4 lbs/100 lbs based on pressure gauge measurements, (d) 21.0 lbs/100 lbs based on the temperature of the condensate. The desorbed water based on gauge pressures was 4.3 pounds. The desorbed water based on direct measurement was 6 pounds. The measured water was 140 percent of that based on zeolite manufacturers data, system pressure measurements, and zeolite temperatures.</p>	

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Run</div> <div>Test Run 9: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Date</div> </div> <div style="text-align: right; margin-top: 5px;">February 28, 1984</div>													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Test Conditions</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; vertical-align: top;"> Adsorption: Cooling water Initial - Final - </td> <td style="width: 50%; vertical-align: top;"> Desorption: Hot water Initial - Final - Cooling water Initial - Final - </td> </tr> </table>	Adsorption: Cooling water Initial - Final -	Desorption: Hot water Initial - Final - Cooling water Initial - Final -	<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">References</div> <p>Figure B-9-a. Zeolite Isobars Figure B-9-b. Data Run Temperatures Figure B-9-c. Desorption Response Figure B-9-d. Data Printout</p>										
Adsorption: Cooling water Initial - Final -	Desorption: Hot water Initial - Final - Cooling water Initial - Final -												
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Actual water processed:</td> <td style="width: 50%;">pounds</td> </tr> <tr> <td>Cooling:</td> <td>Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td>pounds</td> </tr> <tr> <td>Cooling:</td> <td>Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td></td> </tr> <tr> <td>Time for 90% desorption:</td> <td>minutes</td> </tr> </table>		Actual water processed:	pounds	Cooling:	Btu/cycle	Theoretic water processed:	pounds	Cooling:	Btu/cycle	Actual/theoretical:		Time for 90% desorption:	minutes
Actual water processed:	pounds												
Cooling:	Btu/cycle												
Theoretic water processed:	pounds												
Cooling:	Btu/cycle												
Actual/theoretical:													
Time for 90% desorption:	minutes												
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Comments</div> <p>Previous data indicated that the system could be cycled at 1-hour intervals for each adsorb and desorb phase with good results. This did not happen. Each phase was far from complete at the end of 1-hour. There was insufficient to determine completeness of each phase which makes the data of little value.</p>													

Test Run Test Run 10: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.		Date March 1, 1984
Test Conditions <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> Adsorption: Cooling water Initial - 64.6°F Final - 56.9°F </div> <div style="width: 45%;"> Desorption: Hot water Initial - 162.4°F Final - 150.9°F Cooling water Initial - 59.4°F Final - 58.7°F </div> </div>	References Figure B-10-a. Zeolite Isobars Figure B-10-b. Data Run Temperatures Figure B-10-c. Desorption Response Figure B-10-d. Data Printout	
Key Results <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Actual water processed:</div> <div style="width: 55%;">6.15 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 55%;">6507 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Theoretic water processed:</div> <div style="width: 55%;">4 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 55%;">4243 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Actual/theoretical:</div> <div style="width: 55%;">1.54</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div style="width: 40%;">Time for 90% desorption:</div> <div style="width: 55%;">56 minutes</div> </div>		
Comments <p>The first 184 minutes of this test run were used for adsorption of water. This cycle was preceded by 40 minutes of vacuum pumping with the 3-inch vacuum valve open. The data logger was started after the adsorption cycle was started so the initial conditions are not know. The cooling water was at about 66°F at the time the evaporative water cooler was turned on and the adsorption cycle started. The temperature was 64.6°F when the data logger started. The evaporative water cooler cooled down to 56.9 by the end of the adsorption cycle. The pressure during the adsorption cycle started at 8.15 torr and ended at 11.6 torr (0.157 to 0.223 psia). There was no ice in the ice tank as the weight of water in the ice tank, the starting temperature, and the pressure were all too high.</p> <p>The hot cycle (desorption) started with 162.4°F water which quickly dropped to 150.9°F. The pressure started at 19.6 torr and increased to 26 torr by the end of the cycle (0.380 to 0.503 psia). The evaporatively cooled water was 58.8°F at the end of the desorption cycle and the condensate receiver was 63.8°F (0.2933 psia saturation pressure).</p> <p>Figure B-10-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 26.9 lbs/100 lbs based on the measured temperature of the ice tank, (b) 26.3 lbs/100 lbs based on the pressure gauge measurement.</p> <p>Figure B-10-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 22.3 lbs/100 lbs based on pressure gauge measurement, (d) 21 lbs/100 lbs based on the temperature of the condensate.</p> <p>The desorbed water based on gauge pressures and zeolite temperatures was four pounds. The desorbed water based on direct measurement was 6.15 pounds. The measured water was 154 percent of that based on zeolite manufacturer's data, system pressure measurements, and zeolite temperatures.</p>		

<div style="display: flex; justify-content: space-between;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Test Run</div> <div>Test Run 11: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> </div>		<div style="border: 1px solid black; padding: 2px; display: inline-block;">Date</div> March 6, 1984												
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">Test Conditions</div> <div style="display: flex;"> <div style="flex: 1;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 53.1°F</p> <p>Final - 43.3°F</p> </div> <div style="flex: 1;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 152.5°F</p> <p>Final - 145.9°F</p> <p>Cooling water</p> <p>Initial - 44.6°F</p> <p>Final - 49.2°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px;">References</div> <p>Figure B-11-a. Zeolite Isobars</p> <p>Figure B-11-b. Data Run Temperatures</p> <p>Figure B-11-c. Desorption Response</p> <p>Figure B-11-d. Data Printout</p>													
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px; text-align: center;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">Actual water processed:</td> <td style="text-align: right;">5.5 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5915 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">4.2 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">4517 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.31</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">80 minutes</td> </tr> </table>			Actual water processed:	5.5 pounds	Cooling:	5915 Btu/cycle	Theoretic water processed:	4.2 pounds	Cooling:	4517 Btu/cycle	Actual/theoretical:	1.31	Time for 90% desorption:	80 minutes
Actual water processed:	5.5 pounds													
Cooling:	5915 Btu/cycle													
Theoretic water processed:	4.2 pounds													
Cooling:	4517 Btu/cycle													
Actual/theoretical:	1.31													
Time for 90% desorption:	80 minutes													
<div style="border: 1px solid black; padding: 2px; display: inline-block; margin-bottom: 5px; text-align: center;">Comments</div> <p>The first 246 minutes of this test run were used for adsorption of water by the zeolite. This was preceded by a 48-minute vacuum pumping period of which the 3-inch vacuum valve was open for 8 minutes. The temperature the night before was down to 20°F and there was ice in the uninsulated ice tank. Adsorption was initiated at 0815. The data logger showed a starting time of 0820. It was determined from previous tests that the thermowell was mounted such that a packet of air was trapped and the temperature of this air packet was being measured instead of the water. A second thermowell was mounted 180° to the original mounting. This thermocouple and the one on the input to the zeolite tank both measure the cooled water during the adsorption cycle. The condenser input thermocouple consistently measured 2°F below the zeolite tank input thermocouple. A review of the data indicates that the condenser input thermocouple was primarily the one in error. The cooling water was 53.1°F just prior to opening the 3-inch vacuum valve. The evaporative water cooling lowered it to 42.3 during the adsorption cycle. The pressure during the adsorption cycle started below 3.9 torr and ended at 4.8 torr (<0.075 to 0.094 psia). There was ice in the ice tank during this test so the water was 32°F and the zero vapor flow pressure range was 0.0887 psia and above. At the end of the adsorption cycle was a time of quiet in the ice tank so the pressure readings versus the calibrated pressures were plotted with the Figure B-3 calibration curve.</p> <p>The hot cycle (desorption) started with water above 152.5°F cooled quickly to 143.9°F and ended at 145.9°F. The last point plotted occurred after the end of the cycle. The pressure started at 14.0 torr and ended at 14.2 torr (0.271 psia to .274 psia). The evaporatively cooled water started at 50.6°F, dropped to 45.6°F and ended at 48.5°F. The condensate receiver temperature ended at 49.9°F (0.1778 psia saturation pressure).</p> <p>Figure B-1-a plots the water in the zeolite at the end of the adsorption cycle and desorption cycle: (a) 26.3 lbs/100 lbs based on the measured temperature of the ice tank, (b) 25.7 lbs/100 lbs based on the pressure gauge measurement, (c) 25.5 lbs/100 lbs based on the ice in the ice tank holding the water at 32°F, (d) 21.5 lbs/100 lbs based on the pressure gauge measurement, (e) 20.5 lbs/100 lbs based on the temperature of the condensate receiver. The desorbed water based on gauge pressures and zeolite temperatures was 4.2 pounds. The desorbed water based on direct measurement was 5.5 pounds or 131 percent.</p>														

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Test Run</div> <div>Test Run 12: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> <div style="border: 1px solid black; padding: 2px; display: inline-block;">Date</div> </div> <div style="text-align: right; margin-top: 5px;">March 11, 1984</div>													
<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">Test Conditions</div> <div style="display: flex;"> <div style="flex: 1;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 58.2°F</p> <p>Final - 53.8°F</p> </div> <div style="flex: 1;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 142.7°F</p> <p>Final - 138.8°F</p> <p>Cooling water</p> <p>Initial - 57.7°F</p> <p>Final - 54.0°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; margin-bottom: 5px;">References</div> <p>Figure B-12-a. Zeolite Isobars</p> <p>Figure B-12-b. Data Run Temperatures</p> <p>Figure B-12-c. Desorption Response</p> <p>Figure B-12-d. Data Printout</p>												
<div style="border: 1px solid black; padding: 2px; text-align: center; margin-bottom: 5px;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 40%;">Actual water processed:</td> <td style="text-align: right;">1.64 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">1746 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">3.2 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">3408 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">0.51</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">59 minutes</td> </tr> </table>		Actual water processed:	1.64 pounds	Cooling:	1746 Btu/cycle	Theoretic water processed:	3.2 pounds	Cooling:	3408 Btu/cycle	Actual/theoretical:	0.51	Time for 90% desorption:	59 minutes
Actual water processed:	1.64 pounds												
Cooling:	1746 Btu/cycle												
Theoretic water processed:	3.2 pounds												
Cooling:	3408 Btu/cycle												
Actual/theoretical:	0.51												
Time for 90% desorption:	59 minutes												
<div style="border: 1px solid black; padding: 2px; text-align: center; margin-bottom: 5px;">Comments</div> <p>The first 249 minutes of this run were used for adsorption of water by the zeolite. This was preceded by a 10-minute vacuum pumping of which the 3-inch vacuum valve was open for 5 minutes. The cooling water was 58.2°F 7 minutes after the adsorption cycle was initiated. It dropped to 52.6°F and the cycle ended with the temperature at 53.8°F. The pressure during the adsorption cycle started at 6.11 torr dropped slightly and rose to 6.20 torr at the end (0.118 to 0.120 psia). There was no ice in the ice tank.</p> <p>The hot cycle (desorption) started with water at 142.7°F. The water cooled to 137.8°F and was 138.8°F at the end of the cycle. The pressure was 13.3 torr at the start of desorption and 18.4 torr at the end (0.256 to 0.355 psia). The temperature of the evaporatively cooled water rose over 6°F after the desorption cycle was initiated and then cooled to 54°F by the end of the cycle. The condensate receiver temperature ended at 66.6°F (0.3128 psia saturation pressure).</p> <p>Figure B-12-a plots the water in the zeolite at the end of the adsorption cycle: (a) 26.5 lbs/100 lbs based on the measured temperature of the ice tank, (b) 25.7 lbs/100 lbs based on the pressure gauge measurement. For the desorption cycle: (c) 22.2 lbs/100 lbs based on the pressure gauge measurement, (d) 22.2 lbs/100 lbs based on the temperature of the condensate receiver.</p> <p>The desorbed water based on zeolite manufacturer data gauge pressures and zeolite temperatures was 3.2 pounds. The desorbed water based on direct measurement was 1.64 pounds or 51 percent. The average figure for 14 test runs was 141 percent. The possibility of zeolite "poisoning" is suspected. There had been an overnight vacuum pumping preceding the March 1 test. Its performance was 154 percent of theoretical. There was only minor vacuum pumping between the March 1 and March 6 tests. The March 6 performance was 131 percent. There was 32 minutes of pumping before the March 11 test, including 2 minutes of vapor pumping from the ice tank. It had been 10 days since the last major vacuum pumping.</p>													

<div style="display: flex; justify-content: space-between;"> <div style="width: 60%;"> Test Run Test Run 13: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility. </div> <div style="width: 35%;"> Date March 12, 1984 </div> </div>	
Test Conditions	References
<div style="display: flex;"> <div style="flex: 1;"> Adsorption: Cooling water Initial - 62.2°F Final - 55.2°F </div> <div style="flex: 1;"> Desorption: Hot water Initial - 128.9°F Final - 131.8°F Cooling water Initial - 57.2°F Final - 56.0°F </div> </div>	Figure B-13-a. Zeolite Isobars Figure B-13-b. Data Run Temperatures Figure B-13-c. Desorption Response Figure B-13-d. Data Printout
Key Results	
<div style="display: flex; justify-content: space-between;"> <div style="width: 40%;">Actual water processed:</div> <div style="width: 60%;">4.74 -pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 60%;">5065 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Theoretic water processed:</div> <div style="width: 60%;">1.6 pounds</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Cooling:</div> <div style="width: 60%;">1710 Btu/cycle</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Actual/theoretical:</div> <div style="width: 60%;">2.96</div> </div> <div style="display: flex; justify-content: space-between; margin-top: 5px;"> <div style="width: 40%;">Time for 90% desorption:</div> <div style="width: 60%;">80 minutes</div> </div>	
Comments	
<p>The first 255 minutes of this test run were used for adsorption of water by the zeolite. This was preceded by a 32-minute vacuum pumping the morning of the test and a long vacuum pumping during the previous night. The cooling water was 62.2°F 18 minutes after test initiation, dropped to 54.5°F, and rose to 55.2°F at the end of the adsorption cycle. The pressure during the adsorption cycle was below the zero of the mechanical pressure gauge until the end when it rose to 4.5 torr (0.0886 psia). There was no ice noted in the tank. The ice tank was in the low 40°F range which precluded any freezing (0.142 psia saturation pressure).</p> <p>The hot cycle (desorption) started with water at 128.9°F, which quickly dropped to 124.5°F, and then rose gradually to 131.8°F. The pressure during desorption started at 14.5 torr and finished at 19.2 torr (0.280 to 0.371 psia). The temperature of the evaporatively cooled water started at 57.2°F, rose to 60.2°F during heavy condensation, and dropped to 56°F by the end of the test run. The condensate receiver temperature was 66°F (0.317 psia saturation pressure) at the end of the desorption.</p> <p>Figure B-13-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 26.0 lbs/100 lbs based on the measured temperature of the ice tank, (b) 23.0 lbs/100 lbs based on the pressure gauge measurements.</p> <p>Figure B-13-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 23.0 lbs/100 lbs based on the pressure gauge measurement, (d) 22.7 lbs/100 lbs based on the temperature of the condensate receiver.</p> <p>The desorbed water based on the zeolite manufacture data, gauge pressures, and zeolite temperatures was 1.6 pounds. The desorbed water based on direct measurement was 4.74 pounds. The measured water was 296 percent of that based on zeolite manufacturers data, system pressure measurements, and the zeolite temperature measurements.</p>	

<div style="display: flex; justify-content: space-between;"> <div style="width: 60%;"> Test Run Test Run 14: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility. </div> <div style="width: 35%;"> Date March 13, 1984 </div> </div>													
Test Conditions <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> Adsorption: Cooling water Initial - 60.5°F Final - 55.1°F </div> <div style="width: 45%;"> Desorption: Hot water Initial - 154.0°F Final - 156.6°F Cooling water Initial - 69.6°F Final - 59.9°F </div> </div>	References Figure B-14-a. Zeolite Isobars Figure B-14-b. Data Run Temperatures Figure B-14-c. Desorption Response Figure B-14-d. Data Printout												
<div style="text-align: center; border: 1px solid black; margin-bottom: 5px;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 40%;">Actual water processed:</td> <td style="text-align: right;">4.75 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5084 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">3.15 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">3371 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.51</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">76 minutes</td> </tr> </table>		Actual water processed:	4.75 pounds	Cooling:	5084 Btu/cycle	Theoretic water processed:	3.15 pounds	Cooling:	3371 Btu/cycle	Actual/theoretical:	1.51	Time for 90% desorption:	76 minutes
Actual water processed:	4.75 pounds												
Cooling:	5084 Btu/cycle												
Theoretic water processed:	3.15 pounds												
Cooling:	3371 Btu/cycle												
Actual/theoretical:	1.51												
Time for 90% desorption:	76 minutes												
<div style="text-align: center; border: 1px solid black; margin-bottom: 5px;">Comments</div> <p>The first 212 minutes of this test run were used for adsorption of water by the zeolite. This was preceded by 46 minutes of vacuum pumping. The cooling water was 60.5°F 7 minutes after test initiation, dropped to 54.7°F, and ended at 55.1°F. The pressure during the adsorption phase stayed below the zero (3.9 torr calibrated) level on the vacuum gauge during the entire adsorption period. The ice tank was at 43.6°F 7 minutes after initiation of adsorption, dropped to 38.3°F and gradually rose to 41°F (0.127 psia saturation pressure). The plot of zeolite water content based on gauge pressure at the end of adsorption was 0.087 psia.</p> <p>The hot cycle (desorption) started with water at 159.0 F, which quickly dropped to 150.1°F, and rose to 156.1°F by the end of desorption. The pressure during desorption started at 16.7 torr and finished at 17.6 torr (0.323 to 0.340 psia). The temperature of the evaporatively cooled water started at 59.1°F rose to 69.6°F and dropped to 59.9°F by the end of the test run. The condensate receiver temperature was 69.4°F (0.3565 psia saturation pressure) at the end of desorption.</p> <p>Figure B-14-a plots the water in the zeolite at the end of the adsorption cycle as follows: (a) 25.3 lbs/100 lbs based on the measured temperature of the ice tank, (b) 24.3 lbs/100 based on the pressure gauge measurements.</p> <p>Figure B-14-a also plots the water in the zeolite at the end of the desorption cycle as follows: (c) 21.15 lbs/100 lbs based on the pressure gauge measurement, (d) 21.25 lbs/100 lbs based on the temperature of the condensate receiver.</p> <p>The desorbed water based on the zeolite manufacturers data, gauge pressures, and zeolite temperatures was 3.15 pounds. The desorbed water based on direct measurement was 4.75 pounds. The measured water was 151 percent of that based on zeolite manufacturers data, system pressure measurements, and the zeolite temperature measurements.</p>													

<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Run</div> <div>Test Run 15: To determine the chill generation, and operational characteristics of the zeolite chill augmented test facility.</div> </div>		<div style="border: 1px solid black; padding: 2px; font-weight: bold;">Date</div> <div>March 14, 1984</div>												
<div style="border: 1px solid black; padding: 2px; font-weight: bold;">Test Conditions</div> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Adsorption:</p> <p>Cooling water</p> <p>Initial - 52.7°F</p> <p>Final - 59.3°F</p> </div> <div style="width: 45%;"> <p>Desorption:</p> <p>Hot water</p> <p>Initial - 177.9°F</p> <p>Final - 165.3°F</p> <p>Cooling water</p> <p>Initial - 67.8°F</p> <p>Final - 58.7°F</p> </div> </div>	<div style="border: 1px solid black; padding: 2px; font-weight: bold;">References</div> <div> <p>Figure B-15-a. Zeolite Isobars</p> <p>Figure B-15-b. Data Run Temperatures</p> <p>Figure B-15-c. Desorption Response</p> <p>Figure B-15-d. Data Printout</p> </div>													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Key Results</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">Actual water processed:</td> <td style="text-align: right;">5.06-pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">5413 Btu/cycle</td> </tr> <tr> <td>Theoretic water processed:</td> <td style="text-align: right;">3.61 pounds</td> </tr> <tr> <td>Cooling:</td> <td style="text-align: right;">3862 Btu/cycle</td> </tr> <tr> <td>Actual/theoretical:</td> <td style="text-align: right;">1.4</td> </tr> <tr> <td>Time for 90% desorption:</td> <td style="text-align: right;">63 minutes</td> </tr> </table>			Actual water processed:	5.06-pounds	Cooling:	5413 Btu/cycle	Theoretic water processed:	3.61 pounds	Cooling:	3862 Btu/cycle	Actual/theoretical:	1.4	Time for 90% desorption:	63 minutes
Actual water processed:	5.06-pounds													
Cooling:	5413 Btu/cycle													
Theoretic water processed:	3.61 pounds													
Cooling:	3862 Btu/cycle													
Actual/theoretical:	1.4													
Time for 90% desorption:	63 minutes													
<div style="border: 1px solid black; padding: 2px; font-weight: bold; text-align: center;">Comments</div> <p>The first 255 minutes was used for adsorption of water into the zeolite. This adsorption period was preceded by 10-minute and 8-minute vacuum pumping periods. The 3-inch vacuum valve was opened for 3 minutes at the end of vacuum pumping. For this test, the data logging was in 5-minute intervals, the ice tank was insulated with two layers of 3-inch aluminized fiberglass bats. Data recording started 45 minutes prior to filling the zeolite tank with cooling water.</p> <p>During the 3-minute interval when the 3-inch vacuum valve was first opened (prior to filling the zeolite tank with cooling water) the water at the bottom of the ice tank dropped 9°F in temperature. Within 10 minutes after the second opening of the valve, the ice tank water dropped another 8.5°F. The zeolite was then close to saturation.</p> <p>The cooling water was 52.7°F at the start of adsorption and ended at 59.3°F. The pressure gauge gave below zero reading until the end of adsorption when it increased to zero (3.9 torr). The ice tank was 45.9°F at the first vacuum valve opening, it dropped to 37.5°F within 25 minutes and was 41.6°F at the end of adsorption (0.130 psia saturation pressure). The plots on Figure 19 for the end of adsorption are at 0.130 psia and 0.083 psia.</p> <p>The hot cycle (desorption) started with water at 177.9°F, which cooled to 163.8°F and warmed to 165.3°F by the end of the cycle. The pressure started at 17.3 torr and finished at 16.2 torr. The temperature of the cooling water started at 60.6°F and ended at 58.7°F. The condensate receiver temperature at the end of the cycle was 70.7°F (0.373 psia saturation pressure).</p> <p>Figure 19 plots the water in the zeolite at the end of adsorption cycle and desorption cycle as follows: (a) 25.7 lbs/100 lbs based on the measured temperature of the ice tank, (b) 24.2 lbs/100 lbs based on the pressure gauge data, (c) 21.2 lbs/100 lbs based on the condensate receiver temperature, (d) 20.7 lbs/100 lbs based on the pressure gauge estimate. The desorbed water based on the zeolite manufacturers data, gauge pressures, and the zeolite temperatures was 3.5 pounds. The desorbed water based on direct measurement was 5.06 pounds or 144 percent.</p>														

APPENDIX B

EXHIBIT OF DATA FROM TEST RUNS

EXHIBIT 1 OF 101 - FROM JESS KINGS

EXHIBIT OF DATA FROM TEST RUNS

Description of figures

Zeolite Isobars

The isobars were extracted from data published by Linde, a Division of Union Carbide. A chart is included to give saturated pressures for eight different temperatures. A chart is also included giving the zeolite water content based on:

- a. Ice tank temperature and zeolite temperature at the end of adsorption
- b. System pressure and zeolite temperature at the end of adsorption
- c. System pressure and zeolite temperature at the end of desorption
- d. Condensate receiver temperature and zeolite temperature at the end of desorption

Data Run

These are plots of the temperature data logged during the test runs and a summary of the hand recorded data.

Desorption Response

These are plots of the levels of condensate drained from the condensate receiver (see figure C-2) versus time of the draining. There are also one or two points (circled points) plotted for each showing the actual measurements of the condensate by means of a graduated cylinder.

Data Printout

This printouts give the calibrated temperature data for both hot (desorption) and cold (adsorption) cycles as follows:

Time of measurements

Condenser:

in, channel 00
out, channel 01
mix, channel 17

Z-tank:

- in, channel 02
- out, channel 03
- mix, channel 18

Condensate Receiver:

1. CI, input cooling water around the receiver, channel 04
2. CO, output cooling water around the receiver, channel 05
(channels 04 and 00 are nominally the same temperature)
3. SUR, temperature of condensate, channel 06
4. BR, bottom right on ice tank, channel 19
5. TR, top right on ice tank, channel 20

Date: January 30, 1984

a 26.7 lbs/100 lbs

b 26.6 lbs/100 lbs

c 20.8 lbs/100 lbs

d 19.8 lbs/100 lbs

b-c = 5.8 lbs

a-d = 6.9 lbs

measured 10.4 lbs

FIGURE B-1-a. Zeolite Isobars

Start Z-tank filling	0935	Start Z-tank filling	1410	Drain:	1.34 lbs	1438	Drain:	0.23 lb	1632
Full of cold water	0943	Full of hot water	1420	Drain:	2.64 lbs	1517	Measured:	10.4 lbs	1632
Open 3" valve	0943	Start condenser flow	1427	Drain:	0.46 lb	1530	Adsorption:	cold water flow, 3.3 gpm	
Start Z-tank drain	1400	Drain:	2.22 lbs	1420	Drain:	0.57 lb	1613	Desorption:	cold water flow, 3.5 gpm
Close 3" valve	1400	Drain:	2.68 lbs	1432	Drain:	0.14 lb	1624		hot water flow, 3 gpm

FIGURE B-1-b. Data Run, January 30, 1984

FIGURE B-1-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-2-84

DATE DATA COLLECTED: 1-30-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:10		64.9	49.7	52.2	52.8	50.8	50.7	50.0	47.9	49.1
10:30		64.9	47.2	50.3	50.0	48.4	48.1	51.3	48.0	49.8
10:50		64.6	46.3	48.2	48.2	47.5	47.0	51.0	47.5	49.3
11:10		64.7	45.0	47.1	46.3	46.1	45.7	50.9	47.6	47.2
1:50		64.0	43.1	44.1	43.3	43.9	43.8	49.7	48.4	46.6
2:10		64.5	45.0	44.4	43.2	43.6	44.0	49.0	48.4	52.5

Time Pressure (psia)
2:02 0.1864

Average Flowrates (gpm)
Spray: 0.5 Cold: 3.3

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
2:30	79.5	81.5	180.9	156.3	165.2	47.7	46.8	68.1	50.2	54.2
2:40	66.5	63.5	176.5	167.5	172.0	56.5	59.2	66.3	51.5	54.8
2:50	63.6	61.4	163.3	164.4	166.1	59.3	59.6	62.1	51.5	55.2
3:00	61.3	60.0	164.1	160.9	162.5	57.8	58.3	60.0	51.5	54.9
3:10	59.8	58.6	164.4	162.5	164.3	57.4	57.5	58.8	52.1	55.2
3:20	59.7	57.2	163.6	163.0	164.8	56.6	56.8	57.9	52.2	55.1
3:30	58.1	57.6	163.5	162.1	164.7	56.6	56.4	56.9	52.8	55.2
3:40	55.8	56.1	163.4	162.0	164.7	55.1	54.1	55.9	52.7	54.7
3:50	54.5	54.2	163.0	162.9	164.9	53.5	53.2	55.2	52.9	55.2
4:00	52.6	53.1	163.3	161.9	164.9	52.0	51.9	54.2	52.7	55.2
4:10	50.6	51.5	163.2	162.2	165.0	51.2	50.6	53.5	53.0	54.8
4:20	53.3	50.6	163.2	162.6	165.4	49.5	49.5	52.6	52.8	54.1
4:30	51.7	50.5	148.4	157.5	160.4	49.2	49.7	51.5	52.7	54.3

Time Pressure (psia)
2:37 0.1020

Average Flowrates (gpm)
Spray: 0.5 Condenser: 3.4 Hot: 3
Total condensate removed this hot cycle (lbs): 10.417

FIGURE B-1-d. Data Printout

Date: January 31, 1984

a 26.3 lbs/100 lbs

b 26.2 lbs/100 lbs

c 21.1 lbs/100 lbs

d 19.7 lbs/100 lbs

e 25.3 lbs/100 lbs based
on ice in tank

b-c = 5.1 lbs

a-d = 6.6 lbs
measured 6.85 lbs

FIGURE B-2-a. Zeolite Isobars

Start Z-tank filling 0845
Full of cold water 0913
Open 3" valve 0913
Start Z-tank drain 1406
Start Z-tank filling 1417

Full of hot water 1427
Drain: 1 lb 1427
Drain: 1.77 lbs 1431
Drain: 1.77 lbs 1440
Drain: 1.7 lbs 1500

Measured: 6.85 lbs 1710
Drain Z-tank fill with cold 1715
Adsorption: cold water flow, 3.3 gpm
Desorption: cold water flow, 3.5 gpm
hot water flow, 3.1 gpm

FIGURE B-2-b. Data Run, January 31, 1984

B.11

FIGURE B-2-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-2-84

DATE DATA COLLECTED: 1-31-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:00		61.4	54.9	55.7	57.4	55.7	56.1	47.2	36.1	42.1
9:20		62.0	54.8	56.5	57.6	54.4	55.8	49.0	36.5	38.0
9:40		62.3	59.4	61.4	62.1	58.9	59.6	49.8	35.7	39.6
10:11		62.1	61.4	62.1	62.5	61.5	61.9	50.5	36.5	43.0
10:30		62.6	56.5	60.1	59.9	57.2	57.3	52.8	38.3	47.2
10:50		63.1	51.7	55.2	54.8	52.2	52.1	51.5	38.6	47.6
11:10		63.1	49.5	52.2	51.2	49.2	49.2	50.7	39.9	49.9
11:30		62.7	47.1	50.1	48.6	47.4	47.6	51.0	39.7	52.0
11:50		63.3	46.7	48.9	47.7	46.3	46.6	50.3	39.6	53.3
12:10		63.4	45.7	47.4	46.4	45.6	45.5	50.4	40.5	56.3
12:30		63.0	44.8	46.9	45.6	45.1	45.3	51.3	41.2	55.9
12:50		63.2	45.4	46.5	45.5	44.8	45.1	50.9	41.9	55.1
1:10		62.9	45.7	46.5	45.7	45.3	45.4	51.7	41.5	54.5
1:30		62.7	45.8	46.1	45.9	45.3	45.3	51.5	42.0	54.3
1:50		63.0	46.5	47.2	46.5	46.1	46.0	51.4	41.4	56.3
2:10		62.8	50.2	47.7	46.7	46.3	46.9	52.2	41.8	58.4

Time Pressure (psia)
2:10 0.0964

Average Flowrates (gpm)
Spray: 0.9 Cold: 3.3

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
2:30	61.9	73.1	167.5	131.7	139.4	47.9	47.8	62.5	44.0	60.9
2:50	70.4	60.0	157.9	157.9	158.5	54.1	55.9	60.8	45.1	62.5
3:10	61.1	59.8	158.2	153.6	156.1	59.6	59.7	62.1	45.6	62.1
3:30	60.7	59.1	159.0	157.3	158.2	58.1	58.3	61.6	46.3	62.3
3:50	59.1	58.0	160.0	159.4	160.1	57.1	57.8	61.3	43.0	62.4
4:10	57.9	57.0	161.6	160.8	161.9	56.5	56.5	62.1	51.1	62.8
4:30	55.8	55.7	163.1	160.2	162.8	54.7	54.9	61.4	53.2	62.3
4:50	53.7	53.2	162.4	157.9	163.4	53.0	52.6	60.6	53.2	57.7

Time Pressure (psia)
3:30 0.1647

Average Flowrates (gpm)
Spray: 0.9 Cold: 3.5 Hot: 3.1
Total condensate removed this hot cycle (lbs): 6.853

FIGURE B-2-d. Data Printout

Date: February 2, 1984

a 26.5 lbs/100 lbs

b 26.0 lbs/100 lbs

c 21.1 lbs/100 lbs

d 20.3 lbs/100 lbs

e 25.2 lbs based on
ice in the tank

b-c = 4.9 lbs

a-d = 6.2 lbs
measured 5.64 lbs

FIGURE B-3-a. Zeolite Isobars

B.14

Drain: 0.123 1612
Measured: 1.3 lbs 1612
Adsorption: cold water flow, 3.3 gpm
Desorption: cold water flow, 3.5 gpm
hot water flow, 3.2 gpm

B.15

FIGURE B-3-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-5-84

DATE DATA COLLECTED: 2-2-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:20		55.3	52.0	55.6	55.6	51.8	52.8	51.7	37.0	33.4
9:40		55.6	52.7	55.1	53.7	52.4	53.2	54.2	37.8	35.4
10:00		56.0	52.0	54.6	53.5	52.0	51.7	53.9	38.8	38.7
10:20		56.3	52.0	53.1	52.8	51.2	51.6	54.1	39.8	41.9
10:40		56.7	51.8	52.2	52.0	51.1	51.3	54.0	39.6	45.0
11:00		56.6	50.8	51.7	51.5	50.6	51.0	54.1	40.1	48.7
11:20		56.5	50.7	51.8	50.9	49.8	50.4	53.9	39.5	51.8
11:40		56.5	49.9	51.8	51.0	49.5	50.5	54.4	40.5	55.3
12:00		56.5	50.3	50.8	49.8	49.7	50.4	54.4	41.8	58.7
12:20		56.5	50.3	51.0	50.4	49.8	50.3	55.0	43.3	62.4
12:40		56.7	50.4	50.9	49.6	49.8	49.8	54.9	41.6	63.4
1:00		57.0	51.6	51.2	50.5	50.0	50.1	55.1	43.5	61.2

Time Pressure (psia)
12:59 0.112

Average Flowrates (gpm)
Spray: 0.7 Cold: 3.3

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
1:20	64.5	66.1	162.7	127.6	136.9	50.5	50.5	59.8	46.9	59.4
1:40	67.5	59.1	156.3	148.5	155.0	58.3	59.1	59.5	50.2	62.4
2:00	61.1	60.6	155.3	152.5	153.1	59.3	59.2	60.0	53.1	65.4
2:20	60.4	59.0	156.0	154.6	155.7	58.3	58.3	61.2	55.6	67.7
2:40	60.4	57.5	158.1	156.0	157.3	57.6	57.4	61.4	58.0	67.4
3:00	60.4	56.7	159.3	158.0	158.8	56.6	57.1	61.4	59.4	69.5
3:20	57.5	56.4	160.0	159.4	160.3	56.6	56.2	60.9	61.1	69.4
3:40	56.7	55.3	161.3	161.2	162.4	55.7	55.8	60.4	62.7	68.1
4:00	55.8	55.3	163.6	162.8	163.6	55.1	55.4	61.3	62.8	67.9
4:20	60.2	61.5	60.0	69.8	67.9	54.2	54.4	52.5	63.9	67.4

Time Pressure (psia)
4:12 0.37

Average Flowrates (gpm)
Spray: 0.55 Condenser: 3.6 Hot: 3
Total condensate removed this hot cycle (lbs): 5.995

FIGURE B-3-d. Data Printout

Date: February 7, 1984

a 26.6 lbs/100 lbs

b 26.1 lbs/100 lbs

c 21.2 lbs/100 lbs

d 20.4 lbs/100 lbs

b-c = 4.9 lbs

a-d = 6.2 lbs
measured 4.3 lbs

FIGURE B-4-a. Zeolite Isobars

Start Z-tank filling	1219	Drain: 1.17 lbs	1649	Drain: 0.08 lbs	1730
Open 3" valve	1230	Drain: 1.34 lbs	1700	Measured: 1.1	
Start Z-tank drain	1630	Measured: 3.2 lbs	1700	Hot and cold mixed about	1730
Full of hot water	1646	Drain 0.46 lbs	1706	Adsorption: cold water flow, 3.4 gpm	
Condenser flow on	1646	Drain 0.36 lbs	1715	Desorption: cold water flow, 3.5 gpm	
Drain 0.5 lbs	1646	Drain 0.18 lbs	1724	hot water flow, 3.0 gpm

FIGURE B-4-b. Data Run, February 7, 1984

FIGURE B-4-c. Desorption Response

SOLAR ZEOLITE SYTEM DATA

DATE PROGRAMMED:

DATE DATA COLLECTED:

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:00		56.7	53.6	57.8	56.3	54.4	54.3	49.2	39.4	37.6
9:20		58.0	51.4	54.4	54.2	52.2	52.5	53.0	39.2	35.8
1:02		57.0	62.4	66.0	64.8	62.0	62.5	53.3	53.0	50.2
1:20		57.0	63.5	65.6	64.8	60.5	60.9	57.7	53.0	50.2
1:40		57.8	61.5	63.5	63.0	66.5	66.2	60.2	53.7	52.1
2:00		58.0	60.0	61.9	61.4	63.7	63.7	62.2	54.7	51.9
2:20		58.7	58.4	60.4	59.5	59.2	59.0	61.9	55.6	53.2
2:40		58.2	57.1	58.8	57.1	56.9	56.7	61.6	55.7	54.3
3:00		58.7	55.4	57.2	56.5	56.1	55.4	61.1	53.9	52.8
3:20		58.7	54.3	55.8	55.2	54.6	55.1	61.0	54.3	52.0
3:40		59.1	53.5	55.5	54.6	54.9	55.9	60.5	54.3	52.1
4:20		59.0	56.3	55.5	57.7	56.7	57.3	61.6	56.8	54.6

Time Pressure (psia)
3:55 0.2206

Average Flowrates (gpm)
Spray: 0.79 Cold: 3.4

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
4:40	61.5	59.5	165.3	58.7	129.3	54.6	54.7	61.7	55.8	59.1
5:00	63.2	58.9	176.0	166.5	170.5	59.1	59.7	62.6	56.5	61.7
5:20	65.3	63.1	165.3	163.7	164.6	63.7	63.2	62.7	57.5	62.7
5:40	77.2	123.8	127.2	128.3	158.4	63.3	63.1	61.7	57.8	62.3

Time Pressure (psia)
5:30 0.6052

Average Flowrates (gpm)
Spray: 0.7 Condenser: 3.5 Hot: 3
Total condensate removed this hot cycle (lbs): 4.29

FIGURE B-4-d. Data Prinout

Date: February 10, 1984

a 27.2 lbs/100 lbs

b 26.7 lbs/100 lbs

c 21.4 lbs/100 lbs

d 20.0 lbs/100 lbs

b-c = 5.3 lbs

a-d = 7.2 lbs
measured 6.4 lbs

FIGURE B-5-a. Zeolite Isobars

Start Z-tank filling 1045
Full of cold water 1053
Open 3" valve 1053
Start Z-tank drain 1450
Close 3" valve 1450
Start Z-tank filling 1500
Full of hot water 1510

Drain: 1.385 lbs 1510
Drain: 1.385 lbs 1520
Drain: 1.385 lbs 1530
Measured: 5.09 lbs 1530
Drain: 0.568 lbs 1540
Drain: 0.568 lbs 1555
Drain: 0.227 lbs 1608

Drain: 0.123 lbs 1621
Measured: 7.265 lbs 1621
Adsorption: cold water flow, 3.5 gpm
Desorption: cold water flow, 3.6 gpm
hot water flow, 3.0 gpm

FIGURE B-5-b. Data Run, February 10, 1984

FIGURE B-5-c. Desorption Response

SOLAR ZEOLITE SYTEM DATA

DATE PROGRAMMED: 3-6-84

DATE DATA COLLECTED: 2-10-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:50		69.0	64.5	62.0	64.1	64.6	65.1	59.1	56.9	60.3
11:10		69.5	57.4	61.9	61.9	58.0	57.9	60.5	49.3	44.8
11:30		69.4	55.6	58.9	58.6	55.8	55.3	60.4	49.8	45.8
11:50		69.5	53.7	56.7	55.0	54.2	54.1	61.0	51.3	47.0
12:10		70.4	53.1	55.1	53.8	52.7	53.3	60.9	53.0	49.6
12:30		70.4	52.3	54.7	54.5	53.1	53.3	62.8	55.6	52.6
12:50		70.4	53.3	54.9	53.5	53.9	53.4	62.7	56.2	53.3
1:10		70.3	53.1	54.3	53.3	53.4	53.1	63.8	57.1	54.4
1:30		70.0	53.3	54.0	53.0	53.9	53.1	64.7	58.0	54.6
1:50		70.2	53.0	54.7	53.1	53.5	53.1	64.2	59.1	55.8
2:10		69.9	52.9	54.5	53.3	53.8	53.7	54.5	59.0	56.2
2:30		70.3	53.6	54.4	53.7	53.8	53.0	65.4	57.9	53.7
2:50		69.5	54.9	55.7	54.2	55.5	54.9	66.3	58.6	54.7

Time Pressure (psia)
2:50 0.2164

Average Flowrates (gpm)
Spray: 0.75 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
3:10	67.3	78.8	179.3	124.5	139.2	55.9	55.5	71.8	63.1	66.3
3:30	69.8	66.6	172.7	172.5	177.4	67.5	67.7	68.6	65.1	70.1
3:50	66.8	66.7	166.6	163.5	166.9	65.8	65.2	68.8	66.8	69.8
4:10	90.1	85.6	155.4	166.8	167.4	66.5	66.4	69.3	66.9	69.7

Time Pressure (psia)
4:05 0.5382

Average Flowrates (gpm)
Spray: 0.78 Condenser: 3.7 Hot: 3
Total condensate removed this hot cycle (lbs): 6.358

FIGURE B-5-d. Data Prinout

Date: February 14, 1984

a 26.8 lbs/100 lbs

b 26.3 lbs/100 lbs

c 21.9 lbs/100 lbs

d 20.9 lbs/100 lbs

b-c = 4.4 lbs

a-d = 5.9 lbs

measured 6.8 lbs

FIGURE B-6-a. Zeolite Isobars

Start Z-tank filling 0900
Open 3" valve 0908
Full of cold water 0908
Start Z-tank drain 1343
Close 3" valve 1343
Start Z-tank filling 1353
Start condenser water 1402

Drain: 1.386 lbs 1402
Drain: 1.342 lbs 1409
Drain: 1.342 lbs 1418
Measured: 4.65 lbs 1425
Drain: 1.17 lbs 1425
Drain: 0.568 lbs 1540
Drain: 0.227 lbs 1540

Drain: 0.074 lbs 1552
Measured: 2.15 lbs 1552
Adsorption: cold water flow, 3.5 gpm
Desorption: cold water flow, 3.5 gpm
hot water flow, 3.0 gpm

FIGURE B-6-b. Data Run, February 14, 1984

B.27

FIGURE B-6-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-6-84

DATE DATA COLLECTED: 2-14-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
9:10		64.2	62.9	64.8	65.8	58.5	60.2	54.1	41.1	45.0
9:30		64.5	56.9	60.2	60.1	57.5	58.2	56.9	42.0	37.9
9:50		64.8	54.6	57.5	57.5	54.5	55.1	55.5	42.6	38.9
10:10		64.9	52.5	54.8	54.8	53.0	52.6	58.6	43.9	40.0
10:30		65.2	51.6	53.3	52.6	51.3	51.8	61.0	44.5	42.3
10:50		65.3	50.1	52.1	51.2	50.5	50.8	60.7	46.2	44.0
11:10		65.2	49.5	51.6	50.5	49.5	50.0	61.9	45.9	43.4
11:30		64.6	49.6	50.6	49.6	49.3	49.4	65.3	46.7	45.2
11:50		65.3	50.2	51.2	49.9	49.5	49.5	65.7	48.5	46.7
12:10		65.1	49.6	51.2	50.0	50.4	50.4	67.2	52.3	51.1
12:30		65.3	50.8	51.9	50.4	51.4	51.1	68.5	53.6	52.2
12:50		65.3	51.4	51.7	51.2	52.4	51.5	67.5	54.5	54.0
1:10		65.2	52.0	52.7	52.0	53.4	51.6	68.3	56.5	55.8
1:30		65.1	52.7	53.2	52.3	52.7	52.5	69.4	57.1	55.9

Time Pressure (psia)
1:43 0.146

Average Flowrates (gpm)
Spray: 0.75 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
2:10	76.1	66.6	185.0	158.9	168.0	57.6	57.2	70.4	61.8	67.3
2:30	72.5	64.3	167.2	164.2	171.5	67.7	67.8	71.3	63.6	70.4
2:50	68.7	68.3	167.5	158.1	168.2	68.0	67.5	72.4	66.1	72.3
3:10	66.7	66.1	164.9	175.5	166.8	66.3	66.0	68.0	67.8	73.7
3:30	66.7	64.2	163.7	164.3	165.9	64.6	63.7	68.2	69.5	73.7

Time Pressure (psia)
3:40 0.53

Average Flowrates (gpm)
Spray: 0.75 Cold: 3.5 Hot: 3
Total condensate removed this hot cycle (lbs): 6.798

FIGURE B-6-d. Data Printout

Date: February 18, 1984

a 26.7 lbs/100 lbs

b 26.4 lbs/100 lbs

c 22.2 lbs/100 lbs

d 20.8 lbs/100 lbs

b-c = 4.2 lbs

a-d = 5.9 lbs
measured 5.15 lbs

FIGURE B-7-a. Zeolite Isobars

Start Z-tank filling 1015
 Full of cold water 1030
 Open 3" valve 1030
 Start Z-tank drain 1507
 Close 3" valve 1507
 Start Z-tank filling 1514

Full of hot water 1524
 Drain: 1.342 lbs 1524
 Drain: 1.386 lbs 1536
 Drain: 0.847 lbs 1551
 Drain: 0.568 lbs 1606
 Drain: 0.361 lbs 1623

Drain: 0.123 lbs 1633
 Measured: 5.15 lbs
 Adsorption: cold water flow, 3.5 gpm
 Desorption: cold water flow, 3.8 gpm
 hot water flow, 3.0 gpm

FIGURE B-7-b. Data Run, February 18, 1984

FIGURE B-7-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-5-84

DATE DATA COLLECTED: 2-18-84

Corrected Cold Cycle Temperature

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:50		53.9	55.4	58.5	58.4	45.2	46.2	49.3	43.2	38.6
11:10		55.2	53.6	55.9	56.4	50.6	51.9	50.2	43.9	39.8
11:30		55.3	50.8	54.0	52.9	51.0	51.1	51.0	45.3	41.1
11:50		55.8	49.5	51.6	51.2	49.4	49.6	51.7	45.8	42.4
12:10		55.8	48.4	50.1	49.7	49.0	48.4	50.5	47.2	44.6
12:30		56.3	47.6	49.3	48.6	47.6	47.4	50.9	47.6	44.5
12:50		56.1	47.7	48.8	48.2	47.7	47.6	51.0	48.6	45.4
1:10		56.2	47.2	48.4	47.2	47.2	47.5	50.9	49.6	45.9
1:30		55.9	47.5	48.7	47.6	47.2	47.5	52.0	49.4	47.1
1:50		56.2	47.5	48.6	47.9	47.5	47.1	52.3	50.5	48.1
2:10		56.4	47.5	48.2	47.5	47.8	47.8	52.3	51.2	48.8
2:30		56.4	48.2	49.0	47.5	48.5	48.1	53.2	52.1	50.4
2:50		56.9	48.0	48.8	47.7	48.8	48.2	53.5	52.7	51.1
3:10		56.6	48.8	48.6	47.6	49.1	48.2	54.6	52.9	55.9

Time Pressure (psia)
3:07 0.1829

Average Flowrates (gpm)
Spray: 0.6 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
3:30	59.7	55.7	162.9	141.1	148.7	50.5	52.4	58.7	54.6	58.5
3:50	59.5	56.4	150.2	151.0	151.3	57.4	57.2	57.4	56.2	59.7
4:10	61.0	57.4	152.2	150.5	151.9	57.9	57.7	58.5	56.9	60.0
4:30	59.0	57.1	152.3	150.2	152.2	56.9	56.2	60.0	58.0	60.7

Time Pressure (psia)
4:33 0.4580

Average Flowrates (gpm)
Spray: 0.6 Cold: 3.8 Hot: 3
Total condensate removed this hot cycle (lbs): 5.148

FIGURE B-7-d. Data Printout

Date: February 24, 1984

a 27.1 lbs/100 lbs

b 26.7 lbs/100 lbs

c 22.4 lbs/100 lbs

d 21 lbs/100 lbs

b-c = 4.3 lbs/100 lbs

a-d = 6.1 lbs/100 lbs
measured 6 lbs

FIGURE B-8-a. Zeolite Isobars

Start Z-tank filling	1035	Start condenser water flow	1516	Drain:	0.847 lbs	1556
Full of cold water	1100	Drain:	1.306 lbs	1516	Drain:	0.568 lbs
Open 3" valve	1102	Drain:	1.386 lbs	1526	Drain:	0.145 lbs
Start Z-tank drain	1500	Drain:	1.386 lbs	1536	Measured:	1.6 lbs
Close 3" valve	1500	Drain:	1.342 lbs	1536	Adsorption:	cold water flow, 3.5 gpm
Start Z-tank filling	1506	Measured:	4.4 lbs	1536	Desorption:	cold water flow, 3.6 gpm
						hot water flow, 3.0 gpm

FIGURE B-8-b. Data Run, February 24, 1984

B.35

FIGURE B-8-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-5-84

DATE DATA COLLECTED: 2-24-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:30		68.4	62.0	57.9	63.4	47.1	48.7	53.8	51.1	47.9
10:50		67.7	66.2	64.2	67.8	64.9	66.4	57.7	50.5	54.5
11:10		67.7	58.0	62.2	61.4	58.9	59.0	58.3	51.0	46.6
11:30		67.5	54.9	58.0	57.3	55.1	54.9	58.2	51.3	47.3
11:50		68.3	52.2	55.3	54.8	52.4	52.8	57.2	52.2	48.9
12:30		67.9	50.1	51.9	51.1	50.0	49.8	55.7	53.2	50.7
12:50		67.6	49.7	51.4	50.7	50.0	49.7	57.0	54.3	51.6
1:10		68.3	49.8	51.0	50.8	49.5	50.1	56.2	54.3	51.6
1:30		68.3	49.9	51.1	50.4	50.8	50.6	56.6	55.0	52.4
1:50		68.1	49.8	51.2	50.1	50.0	49.8	57.5	55.4	52.9
2:10		68.1	50.2	50.8	50.0	50.4	50.1	58.0	56.7	53.6
2:30		68.5	50.3	51.4	50.3	51.1	50.7	59.1	56.5	55.0
2:50		67.9	50.3	51.1	50.7	50.9	50.8	59.0	57.0	54.4

Time Pressure (psia)
11:51 0.1922

Average Flowrates (gpm)
Spray: 0.55 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
3:10	69.8	68.8	157.0	54.4	123.4	51.9	51.2	61.8	58.9	62.8
3:30	66.6	60.2	166.6	156.0	160.1	59.5	60.1	66.1	60.6	65.0
3:50	65.8	63.5	156.1	154.5	555.4	63.6	63.7	65.5	62.7	66.3
4:10	62.7	62.9	157.8	152.7	157.5	63.1	62.0	66.0	63.9	67.2
4:30	65.5	61.6	156.5	155.8	156.6	62.7	62.7	66.8	65.4	68.3
4:50	63.5	62.6	157.8	151.4	157.7	64.3	63.1	67.6	65.5	68.4
5:10	62.7	68.8	152.2	159.5	159.8	61.4	60.8	65.6	65.8	67.9

Time Pressure (psia)
5:06 0.1829

Average Flowrates (gpm)
Spray: 0.55 Condenser: 3.6 Hot: 3
Total condensate removed this hot cycle (lbs): 5.995

FIGURE B-8-d. Data Printout

Date: February 28, 1984

a 26.6 lbs/100 lbs	a" 2.67 lbs/100 lbs	a' 26.6 lbs/100 lbs
b 26.2 lbs/100 lbs	b" 26.0 lbs/100 lbs	b' 26.0 lbs/100 lbs
c 22.6 lbs/100 lbs	c" 22.6 lbs/100 lbs	c' 22.3 lbs/100 lbs
d 19.7 lbs/100 lbs	d" 20.4 lbs/100 lbs	d' 20.4 lbs/100 lbs
b-c = 3.6 lbs	b"-c" = 3.7 lbs	b'-c' = 3.7 lbs
a-d = 6.9 lbs	a"-d" = 6.2 lbs	a'-d' = 6.3 lbs
measured 0.76 lbs	measured 1.43 lbs	measured 1.24 lbs

FIGURE B-9-a. Zeolite Isobars

Start Z-tank filling	0915
Full of cold water	0925
Open 3" valve	0925
Start Z-tank drain	1030
Close 3" valve	1030
Start Z-tank filling	1037
Full of hot water	1047
Condenser flow	1047
Drain: 0.36 lbs	1101
Drain: 0.36 lbs	1111
Drain: 0.18 lbs	1123
Drain: 0.8 lbs	1147
Measured: 0.76 lbs	1147
Start Z-tank drain	1147
Start Z-tank filling	1152
Full cold water	1202
Open 3" valve	1204
Start Z-tank drain	1306
Close 3" valve	1306
Start Z-tank filling	1314
Full of hot water	1323
Condenser flow	1323
Drain: 0.70 lbs	1338
Drain: 0.51 lbs	1358
Drain: 0.18 lbs	1428
Measured: 1.24 lbs	1428
Start Z-tank filling	1434
Full of cold water	1443
Open 3" valve	1443
Start Z-tank drain	1600
Start Z-tank filling	1609
Full of hot water	1617
Condenser flow	1617
Drain: 1.01 lbs	1643
Drain: 0.23 lbs	1700
Drain: 0.13 lbs	1720
Measured: 1.43 lbs	1720
Drain Z-tank	1720
Adsorption:	
cold water flow, 3.5 gpm	
Desorption:	
cold water flow, 3.6 gpm	
hot water flow, 3.0 gpm

FIGURE B-9-b. Data Runs, February 28, 1984

Date: February 28, 1984

Zeolite: Run 1 - 157.7/155.9°F

Run 2 - 155.8/156.0°F

Run 3 - 149.4/150.3°F

Condenser Mix: Run 1 - 49°F

Run 2 - 55.1°F

Run 3 - 50.6°F

Figure B-9-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-5-84

DATE DATA COLLECTED: 2-28-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:20	48.8	48.3	49.8	45.0	45.4	51.3	47.6	50.6	45.6	40.0	48.9
9:40	54.0	53.6	52.6	53.2	56.1	54.9	54.2	54.5	50.9	42.8	54.3
10:00	54.7	55.5	53.5	49.6	51.7	52.4	50.5	50.8	51.8	44.9	52.9
10:20	51.8	54.7	54.0	47.4	50.2	50.1	48.7	58.5	51.3	47.1	53.8

Time	Pressure (psia)
10:30	0.1829

Average Flowrates (gpm)
 Spray: 0.55 Cold: 3.6

Corrected Hot Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:40	52.6	55.4	54.1	149.1	50.3	139.5	47.8	48.2	51.3	48.7	53.4
11:00	52.6	49.0	50.2	169.0	159.6	167.8	48.8	48.6	51.7	49.9	55.4
11:20	51.9	50.2	51.1	155.4	157.0	162.2	50.8	50.7	52.7	51.3	55.8
11:40	52.6	49.6	49.0	157.7	155.9	160.0	48.9	48.8	51.9	53.0	57.6

Time	Pressure (psia)
11:23	0.5086

Average Flowrates (gpm)
 Spray: 0.55 Condenser: 3.6 Hot: 3
 Total condensate removed this hot cycle (lbs): 0.759

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:40	54.0	53.6	52.6	53.2	56.1	54.9	54.2	54.5	50.9	42.8	54.3
10:00	54.7	55.5	53.5	49.6	51.7	52.3	50.5	50.8	51.8	44.9	52.9
12:00	53.2	61.1	57.6	58.9	82.1	69.7	55.5	55.8	54.9	54.5	58.3
12:20	54.6	61.2	60.8	62.7	67.9	67.9	62.1	62.8	54.0	55.0	54.6
12:40	55.6	61.3	62.0	59.8	62.8	62.4	60.4	60.0	52.6	53.7	54.8
1:00	56.1	60.5	62.5	57.2	60.1	58.8	57.5	57.2	53.0	54.0	54.5

Time	Pressure (psia)
12:04	0.1690

Average Flowrates (gpm)
 Spray: 0.55 Cold: 3.5

FIGURE B-9-d. Data Printout

FIGURE B-9-d. (continued)

Corrected Hot Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
1:20	58.2	61.1	62.7	156.5	61.3	124.4	56.0	56.2	54.5	56.0	59.4
1:40	61.1	56.4	54.8	162.9	154.6	161.5	55.3	54.5	56.3	57.7	61.6
2:00	61.9	56.3	55.1	152.5	154.6	156.0	55.0	55.0	56.7	58.4	62.4

Time	Pressure (psia)
1:58	0.5168

Average Flowrates (gpm)

Spray: 0.55 Condenser: 3.6 Hot: 3

Total condensate removed this hot cycle (lbs): 1.243

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:40	54.0	53.6	52.6	53.2	56.1	54.9	54.2	54.5	50.9	42.8	54.3
10:00	54.7	55.5	53.5	49.6	51.7	52.4	50.5	50.8	51.8	44.9	52.9
2:40	66.5	56.5	54.7	56.0	93.7	70.0	53.6	53.2	57.1	61.7	62.8
3:00	67.0	60.6	55.7	63.0	68.8	68.5	61.6	62.4	55.3	56.5	53.3
3:20	66.2	61.6	56.6	61.4	64.9	63.9	61.7	61.5	55.5	56.2	54.6
3:40	63.6	62.2	57.1	58.5	61.6	59.9	58.9	58.6	56.8	55.9	50.8
4:00	62.6	61.4	57.3	55.2	57.9	56.5	56.4	55.7	57.0	56.1	54.2

Time	Pressure (psia)
4:00	0.1685

Average Flowrates (gpm)

Spray: 0.5 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
4:20	61.2	59.5	58.0	161.7	121.4	136.9	55.0	54.4	56.9	56.8	58.9
4:40	59.9	54.0	54.3	158.8	151.6	162.0	53.4	53.3	56.6	57.5	59.3
5:00	58.5	50.6	51.1	149.8	140.2	150.8	51.0	51.1	55.2	57.8	59.1
5:20	57.8	51.8	50.6	149.4	150.3	152.4	51.2	50.7	53.5	58.3	59.2

Time	Pressure (psia)
5:00	0.5168

Average Flowrates (gpm)

Spray: 0.5 Condenser: 3.6 Hot: 3

Total condensate removed this hot cycle (lbs): 1.4322

FIGURE B-9-d. Data Printout (continued)

Date: March 1, 1984

a 26.9 lbs/100 lbs

b 26.3 lbs/100 lbs

c 22.3 lbs/100 lbs

d 21.0 lbs/100 lbs

b-c = 4 lbs

a-d = 5.9 lbs

measured 6.15 lbs

FIGURE B-10-a. Zeolite Isobars

Start Z-tank filling	1300	Full of hot water	1643	Drain: 0.286 lbs	1745
Full of cold water	1320	Drain: 1.36 lbs	1643	Drain: 0.286 lbs	1802
Open 3" valve	1320	Drain: 1.36 lbs	1654	Measured: 957 lbs	1802
Start Z-tank drain	1624	Drain: 1.36 lbs	1711	Adsorption: cold water flow, 3.8 gpm	
Close 3" valve	1624	Measured: 5.19 lbs	1711	Desorption: cold water flow, 3.6 gpm	
Start Z-tank filling	1633	Drain: 0.563 lbs	1734	hot water flow, 3.0 gpm

FIGURE B-10-b. Data Run, March 1, 1984

FIGURE B-10-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-6-84

DATE DATA COLLECTED: 3-1-84

Corrected Cold Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
1:30		58.7	64.6	67.3	67.6	64.3	64.3	64.0	63.9	60.3
1:50		59.8	63.0	65.8	65.1	64.1	63.2	65.6	62.8	59.0
2:10		59.7	61.5	63.8	63.4	62.5	62.3	66.6	63.3	60.3
2:30		59.8	59.8	62.1	61.6	61.1	60.6	67.6	62.9	60.8
2:50		60.6	58.7	61.0	59.9	60.5	60.1	67.3	64.0	61.6
3:10		61.7	57.8	60.2	59.3	58.9	59.0	66.9	63.3	60.7
3:30		60.8	58.6	59.1	58.5	58.8	58.2	66.8	63.1	61.4
3:50		60.9	57.3	58.8	57.3	57.4	57.9	66.9	62.7	60.8
4:10		61.4	56.9	57.9	57.0	57.6	57.3	66.7	63.1	61.4

Time	Pressure (psia)
1:20	0.1576
1:21	0.2234
4:24	0.1905

Average Flowrates (gpm)
Spray: 0.475 Cold: 3.7

Corrected Hot Cycle Temperatures

Time	Condenser		Z-Tank			Receiver			Ice Tank	
	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
4:50	70.0	63.7	162.4	130.4	138.9	59.6	59.3	67.9	67.1	69.6
5:10	64.7	62.2	150.9	154.2	155.3	63.3	63.2	66.4	67.9	69.9
5:30	62.3	61.9	150.5	146.9	149.7	61.2	61.0	65.1	68.6	69.3
5:50	61.6	58.6	150.7	148.9	150.3	59.0	59.0	63.8	67.3	66.8
6:10	61.5	58.8	150.9	148.0	150.7	58.9	58.3	63.8	66.4	65.9

Time	Pressure (psia)
6:02	0.5028

Average Flowrates (gpm)
Spray: 0.45 Condenser: 3.5 Hot: 3
Total condensate removed this hot cycle (lbs): 6.149

FIGURE B-10-d. Data Printout

Date: March 6, 1984

a 26.3 lbs/100 lbs

b 25.7 lbs/100 lbs

c 21.5 lbs/100 lbs

d 20.5 lbs/100 lbs

b-c = 4.2 lbs

a-d = 5.8 lbs

measured 5.5 lbs

FIGURE B-11-a. Zeolite Isobars

Start Z-tank filling 0730
 Full of cold water 0815
 Open 3" valve 0815
 Start Z-tank drain 1221
 Close 3" valve 1221
 Start Z-tank filling 1231

Full of hot water 1239
 Drain: 0.847 lbs 1239
 Drain: 1.353 lbs 1256
 Drain: 1.008 lbs 1313
 Measured: 4.5
 Drain: 0.70 lbs 1350

Drain: 0.286 lbs 1407
 Drain: 0.145 lbs 1417
 Measured: 0.97 lbs
 Start Z-tank drain 1414
 Adsorption: cold water flow, 3.6 gpm
 Desorption: cold water flow, 3.6 gpm
 hot water flow, 2.9 gpm

FIGURE B-11-b. Data Run, March 6, 1984

B.50

Figure B-11-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-8-84

DATE DATA COLLECTED: 3-6-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
8:20	50.6		36.5	53.1	49.3	49.8	50.3	52.8	42.7	33.4	25.4
8:40	46.9		37.6	48.7	51.4	51.7	48.3	49.0	45.9	33.7	36.7
9:00	45.6		38.2	47.9	49.9	50.2	47.3	48.4	45.9	33.3	43.6
9:20	45.3		38.9	47.9	48.9	48.9	46.9	47.2	47.7	34.0	47.6
9:40	44.2		38.5	46.0	47.6	47.4	46.0	45.9	47.2	34.3	51.7
10:00	43.0		38.7	45.5	46.7	47.4	45.1	45.3	46.4	35.5	51.1
10:20	42.0		38.6	44.7	45.9	46.0	44.5	44.8	45.1	37.0	51.2
10:40	42.0		38.7	43.9	44.7	45.8	43.9	44.2	45.0	37.0	51.5
11:00	41.1		39.7	43.6	44.8	45.2	43.1	43.1	44.5	37.6	51.5
11:20	41.3		39.4	43.1	44.3	44.5	42.8	43.7	44.0	37.9	52.0
11:40	41.8		40.2	42.3	43.4	44.4	42.7	43.2	44.4	38.9	52.4
12:00	42.3		40.2	44.2	43.5	43.6	43.7	43.6	44.5	39.7	52.3
12:20	41.7		40.1	43.3	44.4	44.1	43.4	43.5	45.1	41.6	53.5

Time	Pressure (psia)
12:21	0.0935
12:31	0.1067

Average Flowrates (gpm)
 Spray: 0.4 Cold: 3.6

Corrected Hot Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
12:40	46.0	51.7	45.7	150.8	48.8	108.7	43.7	44.3	49.7	42.4	54.6
1:00	46.0	50.0	50.3	152.5	144.6	147.4	47.1	47.9	48.7	42.5	55.6
1:20	48.5	50.1	49.9	143.9	140.4	141.9	48.4	50.1	49.3	43.6	56.5
1:40	48.2	50.1	49.4	145.5	142.9	144.9	49.4	49.7	49.8	44.3	56.1
2:00	48.5	49.9	49.4	145.9	144.4	146.3	49.3	49.2	49.9	45.5	56.4
2:20	51.1	51.1	50.9	130.4	141.4	145.5	49.2	50.2	47.5	46.2	54.4

Time	Pressure (psia)
12:39	0.2135
12:56	0.2711
1:13	0.2743
1:23	0.2743
1:41	0.2776
1:50	0.2776
2:07	0.2730
2:14	0.2743
2:17	0.2743

Average Flowrates (gpm)
 Spray: 0.4 Condenser: 3.5 Hot: 2.9
 Total condensate removed this hot cycle (lbs): 5.489

FIGURE B-11-d. Data Printout

Date: March 11, 1984

a 26.5 lbs/100 lbs

b 25.7 lbs/100 lbs

c 22.5 lbs/100 lbs

d 22.2 lbs/100 lbs

b-c = 3.2 lbs

a-d = 4.3 lbs

measured 1.64 lbs

FIGURE B-12-a. Zeolite Isobars

Start Z-tank filling 0922
Full of cold water 0932
Open 3" valve 0933
Close 3" valve 1342
Start Z-tank filling 1351

Full hot water 1401
Condenser flowing 1401
Drain: 0.85 lbs 1413
Drain: 0.67 lbs 1439
Drain: 0.23 lbs 1526

Drain: 0.12 lbs 1601
Measure: 1.64 lbs
Adsorption: cold water flow, 3.5 gpm
Desorption: cold water flow, 3.6 gpm
hot water flow, 3.0 gpm

FIGURE B-12-b. Data Run, March 11, 1984

B.54

FIGURE B-12-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMED: 3-11-84

DATA DATA COLLECTED: 3-11-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
9:40	56.9	60.3	57.8	58.2	60.2	60.3	57.6	59.3	60.6	48.4	41.9
10:00	54.6	62.6	58.7	57.1	59.5	59.2	57.8	58.0	61.4	47.8	41.6
10:20	53.5	62.4	59.0	55.0	57.7	56.3	56.8	56.4	62.0	47.4	42.8
10:40	52.4	58.2	59.8	54.3	56.1	55.3	55.4	55.1	60.5	47.8	43.9
11:00	51.3	54.8	59.8	53.3	55.1	54.2	54.1	53.6	60.5	48.0	44.5
11:20	49.1	54.1	60.0	52.6	54.1	53.4	53.3	53.0	59.8	47.3	45.0
11:40	54.3	57.0	60.4	55.5	56.6	55.8	56.4	56.0	61.4	47.3	46.2
12:00	53.9	61.4	60.1	55.5	55.9	55.2	58.2	58.0	62.8	47.2	47.4
12:20	52.1	64.2	60.6	54.0	55.1	54.1	54.0	54.0	61.8	48.0	48.4
12:40	52.9	66.1	60.6	53.7	54.0	53.3	54.6	53.7	62.2	48.4	49.4
1:00	51.8	66.6	60.8	53.9	54.2	53.2	54.5	53.8	62.5	48.8	49.9
1:20	52.2	66.5	61.0	53.3	53.9	52.5	54.8	53.1	63.8	49.3	50.3
1:40	52.1	67.5	61.2	53.8	54.5	53.0	55.1	54.0	63.6	50.5	51.6

Time	Pressure (psia)
9:32	0.0886
9:33	0.1182
11:22	0.1165
1:42	0.1198

Average Flowrates (gpm)
Spray: 0.9 Cold: 3.5

Corrected Hot Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
2:00	57.7	65.4	61.7	142.7	100.1	112.6	55.2	54.4	65.0	50.6	53.2
2:10	56.4	60.1	58.4	140.9	130.0	135.6	57.3	56.8	64.9	50.7	53.9
2:30	56.5	58.4	58.5	137.8	135.7	137.7	59.2	58.5	65.8	50.7	54.7
2:50	56.2	58.2	57.9	138.6	136.5	138.0	59.5	57.6	66.8	51.5	55.9
3:10	55.5	57.6	56.3	139.6	133.7	139.4	58.7	57.0	66.3	51.0	56.9
3:30	54.7	56.7	55.8	138.9	135.0	139.6	57.3	56.5	67.0	51.7	57.8
3:50	54.0	55.8	55.3	138.8	136.4	139.4	58.2	56.5	66.6	52.8	59.1

Time	Pressure (psia)
2:01	0.2563
2:06	0.3039
2:13	0.3302
2:39	0.3434
3:26	0.3549

Average Flowrates (gpm)
Spray: 0.95 Condenser: 3.5 Hot: 3
Total condensate removed this hot cycle (lbs): 1.639

FIGURE B-12-d. Data Printout

Date: March 12, 1984

a 26.0 lbs/100 lbs

b 24.6 lbs/100 lbs

c 23 lbs/100 lbs

d 22.7 lbs/100 lbs

b-c = 1.6 lbs

a-d = 3.3 lbs

measured 4.74 lbs

Adsorption pressure below
mech. gauge scale.

FIGURE B-13-a. Zeolite isobars

Start Z-tank filling 1114
Open 3" valve 1122
Start Z-tank drain 1537
Close 3" valve 1537
Start Z-tank filling 1547
Full of hot water 1554

Condenser flowing 1554
Drain: .85 lbs 1606
Drain: 1.01 lbs 1620
Drain: .85 lbs 1652
Drain: .37 lbs 1717
Drain: .46 lbs 1804

Measures: 3.03 lbs 1804
Ice tank vapor between
29.8°F and 41.2°F
Adsorption: cold water flow, 3.5 gpm
Desorption: cold water flow, 3.6 gpm
hot water flow, 3.0 gpm

FIGURE B-13-b. Data Run, March 12, 1984

B.58

FIGURE 8-13-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMED: 3-13-84

DATA DATA COLLECTED: 3-12-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
11:00	60.6	76.4	70.3	62.2	66.3	67.8	62.5	62.9	67.0	44.4	31.3
12:00	56.9	77.3	69.7	59.0	62.6	61.6	59.6	59.6	65.9	42.5	30.4
12:20	55.4	78.6	68.2	57.3	60.1	59.2	57.5	58.4	64.5	43.1	28.9
12:40	53.6	76.9	66.5	55.8	58.8	57.5	56.4	56.0	64.0	42.7	29.8
1:00	52.7	71.5	66.2	54.5	56.6	55.8	56.7	56.2	64.5	41.2	30.7
1:20	54.6	70.6	66.5	55.9	57.5	56.2	60.2	59.8	66.3	42.2	33.4
1:40	56.5	70.3	66.2	58.2	57.7	57.0	59.6	58.8	67.6	44.0	34.1
2:00	54.6	71.0	66.7	55.9	57.2	56.4	56.9	56.4	66.5	43.5	37.3
2:20	53.6	71.0	67.1	55.2	56.4	55.7	56.4	55.9	66.9	43.8	38.2
2:40	53.6	72.6	66.7	55.0	56.3	54.9	56.2	55.0	69.1	44.0	39.2
3:00	53.6	71.7	66.9	54.7	55.3	54.6	55.9	54.6	67.8	44.0	40.1
3:20	53.5	71.5	67.2	55.2	56.0	53.9	55.8	54.8	68.9	45.1	41.2

Time	Pressure (psia)
10:45	0.1001
3:37	0.0886

Average Flowrates (gpm)
Spray: 0.8 Cold: 3.5

CORRECTED HOT CYCLE TEMPERATURES

Time	Condenser			Z Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
4:00	57.2	68.9	66.1	128.9	104.3	110.6	57.9	57.9	68.5	47.1	49.2
4:20	60.2	63.9	61.6	124.5	123.6	125.4	62.4	61.6	68.8	47.1	51.1
4:40	60.0	63.2	61.5	125.5	122.6	123.2	61.8	61.1	68.2	48.0	53.0
5:00	59.3	62.7	60.5	127.9	124.5	126.2	60.8	60.6	67.5	48.7	54.3
5:20	58.2	61.5	60.0	129.9	127.1	128.0	60.4	60.2	67.4	49.7	55.6
5:40	57.2	60.2	59.2	131.8	129.5	130.3	59.1	58.6	66.8	50.1	56.2
6:00	56.0	59.4	58.1	127.8	129.2	129.8	58.3	57.2	66.0	50.5	56.8

Time	Pressure (psia)
3:54	0.2809
4:20	0.3648
6:04	0.3713

Average Flowrates (gpm)
Spray: 0.7 Condenser: 3.5 Hot: 3
Total condensate removed this hot cycle (lbs): 3.025

FIGURE B-13-d. Data Printout

Date: March 13, 1984

a 25.3 lbs/100 lbs

b 24.3 lbs/100 lbs

c 21.15 lbs/100 lbs

d 21.25 lbs/100 lbs

b-c = 3.15 lbs

a-d = 4.05 lbs
measured 4.75 lbs

FIGURE B-14-a. Zeolite Isobars

Start Z-tank filling	1004	Condenser flowing	1400	Drain: 0.458 lbs	1513
Full of cold water	1012	Drain: 0.568 lbs	1404	Drain: 0.363 lbs	1543
Open 3" valve	1013	Drain: 0.847 lbs	1407	Drain: 0.231	1601
Start Z-tank drain	1345	Drain: 1.010 lbs	1414	Measured: 1.485 lbs	1601
Close 3" valve	1345	Drain: 1.010 lbs	1424	Adsorption: cold water flow, 3.5 gpm	
Start Z-tank filling	1351	Measured: 3.256 lbs	1424	Desorption: cold water flow, 3.6 gpm	
Full of hot water	1400	Drain: 1.010 lbs	1449	hot water flow, 3.0 gpm

FIGURE B-14-b. Data Run, March 13, 1984

B.62

FIGURE B-14-c. Desorption Response

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-13-84

DATE DATA COLLECTED: 3-13-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
10:20	59.1	78.9	71.3	60.5	58.8	58.5	57.3	59.8	63.3	43.6	28.9
10:40	56.2	82.1	65.6	58.4	61.2	59.9	58.7	58.8	64.4	38.3	28.8
11:00	55.7	76.6	65.2	58.2	59.7	58.7	58.0	58.2	64.9	38.7	29.1
11:20	54.8	73.4	66.1	56.6	58.2	57.6	56.7	56.5	63.8	39.9	29.1
11:40	54.0	74.2	65.7	55.9	57.1	56.7	56.7	56.3	64.4	39.8	30.2
12:00	53.2	73.9	66.3	55.3	56.5	55.6	55.5	54.9	63.9	39.8	30.4
12:20	52.3	73.7	66.4	54.7	55.6	54.8	55.1	54.3	63.5	40.7	31.2
12:40	52.9	74.5	67.1	55.3	55.5	54.7	55.4	54.5	65.1	40.5	32.1
1:00	53.8	73.4	66.8	55.4	55.2	54.5	55.9	54.9	66.1	40.2	33.8
1:20	53.7	74.0	67.4	55.0	55.6	54.2	57.3	56.5	66.4	40.0	36.0
1:40	53.6	74.4	66.6	55.1	55.6	54.4	57.7	57.1	66.9	41.0	41.6

Time Pressure (psia)
1:40 0.0836

Average Flowrates (gpm)
Spray: 0.7 Cold 3.5

CORRECTED HOT CYCLE TEMPERATURES

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	CO	SUR	BR	TR
2:00	69.6	74.7	66.8	154.0	62.1	117.1	60.1	59.5	70.7	39.6	48.4
2:20	63.4	69.2	67.3	158.3	148.4	150.8	64.9	63.9	70.8	39.3	50.4
2:40	63.8	67.9	65.3	150.1	147.7	149.1	65.5	65.2	70.2	40.0	53.8
3:00	62.2	66.1	64.0	152.7	149.9	151.5	63.5	63.3	69.7	40.3	54.0
3:20	61.1	66.0	62.7	153.9	152.0	152.8	63.4	62.7	69.2	39.5	50.5
3:40	60.0	64.7	61.7	155.2	153.4	154.8	62.0	61.6	69.8	41.1	51.4
4:00	59.9	64.2	60.6	156.6	156.1	156.8	61.5	60.5	69.4	43.6	52.8

Time Pressure (psia)
2:00 0.3220
4:01 0.3401

Average Flowrates (gpm)
Spray: 0.8 Condenser: 3.6 Hot: 3
Total condensate removed this hot cycle (lbs): 4.741

FIGURE B-14-d. Data Printout

SOLAR ZEOLITE SYSTEM DATA

DATE PROGRAMMED: 3-15-84

DATE DATA COLLECTED: 3-14-84

Corrected Cold Cycle Temperatures

Time	Condenser			Z-Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
8:18	48.7	51.0	66.8	55.1	53.2	83.4	49.7	50.5	54.1	52.2	52.5
8:23	52.2	52.2	67.3	56.3	54.3	83.6	51.4	52.7	55.1	52.6	52.8
8:28	54.5	53.3	68.4	57.6	54.8	83.7	52.6	53.2	56.7	53.0	53.1
8:33	55.9	55.6	70.5	59.7	56.3	84.2	52.6	53.5	58.0	53.3	53.2
8:38	57.1	58.1	72.4	62.2	57.9	82.6	53.3	53.5	59.4	53.0	53.4
8:43	58.5	60.6	75.5	64.7	58.5	83.9	53.5	54.3	59.2	53.0	53.7
8:48	59.2	61.0	76.0	66.0	59.5	83.5	53.5	53.9	60.4	53.4	54.2
8:53	60.8	63.4	76.8	67.9	60.6	89.8	53.7	54.2	59.8	45.9	33.7
8:58	51.7	64.8	76.0	53.8	66.8	57.7	53.5	53.3	60.9	45.2	41.5
9:03	50.7	66.4	74.5	52.7	65.2	57.6	52.9	52.9	62.1	45.9	44.1
9:08	51.5	68.0	72.7	53.7	60.3	58.9	53.1	53.4	62.1	41.4	23.5
9:13	53.8	69.5	71.8	54.6	60.4	59.1	53.9	54.8	61.8	37.5	25.4
9:18	55.0	69.5	70.5	55.8	60.6	60.2	55.3	55.8	62.1	37.9	28.1
9:23	55.7	70.0	70.0	57.2	60.5	59.5	56.0	57.2	63.3	38.1	28.0
9:28	55.9	71.3	69.8	57.3	60.2	59.8	56.5	57.4	63.5	37.6	27.3
9:33	55.6	71.4	69.1	57.5	61.1	60.6	57.5	58.0	64.4	38.1	26.9
9:38	56.8	73.2	69.6	58.3	60.6	59.8	57.7	58.4	65.1	37.9	28.1
9:43	56.9	74.0	70.0	58.8	60.6	59.5	58.1	58.2	65.1	37.3	26.9
9:48	56.7	75.5	70.5	58.4	60.2	59.3	58.4	58.4	66.0	37.5	28.0
9:53	56.5	76.6	70.3	58.2	60.2	59.2	58.2	58.6	65.1	38.4	28.0
9:58	56.2	76.8	69.4	57.6	60.1	59.5	58.5	58.4	65.5	37.0	28.0
10:03	55.7	77.9	69.1	58.2	59.6	58.5	58.4	58.5	65.2	37.8	27.3
10:08	56.1	78.4	68.2	57.7	59.6	58.5	58.2	57.9	65.7	37.9	28.5
10:13	55.9	78.4	67.6	57.5	59.2	58.3	57.6	57.8	65.4	37.9	28.9
10:18	56.1	78.7	67.0	57.3	58.9	57.9	58.0	58.0	65.6	38.8	28.9
10:23	55.5	79.0	66.5	57.5	58.5	57.7	57.8	57.4	66.3	39.0	28.8
10:28	55.7	80.8	63.4	57.3	58.8	57.1	57.7	57.6	66.2	38.9	29.1
10:33	56.2	81.1	62.5	57.4	58.3	57.5	57.4	57.8	66.9	38.8	29.8
10:38	62.2	82.1	62.1	63.6	60.6	59.3	62.5	63.8	67.7	39.2	31.6
10:43	58.8	82.3	62.8	60.8	62.4	62.1	60.9	61.1	67.6	39.3	33.0
10:48	58.5	76.9	62.7	60.9	61.4	60.9	60.7	60.8	67.1	39.7	33.5
10:53	58.2	75.1	63.2	59.6	61.3	60.1	60.4	60.0	66.9	39.6	33.2
10:58	58.2	73.8	63.1	59.6	60.6	59.9	59.6	59.9	67.7	40.0	33.7
11:03	57.6	73.2	62.8	59.4	60.2	59.8	59.6	59.2	68.6	40.1	34.4
11:08	57.8	72.0	63.1	58.9	60.0	59.2	59.8	59.3	69.6	39.2	34.5
11:03	57.2	71.4	63.4	58.7	59.9	59.1	59.3	59.0	70.3	40.0	34.5
11:18	57.3	70.7	63.3	58.4	59.7	59.2	59.6	58.8	70.2	40.7	34.9
11:23	57.0	70.3	62.8	59.1	59.8	58.4	59.8	59.0	69.9	40.0	36.3
11:28	56.7	70.2	63.2	58.2	59.2	58.5	59.5	59.1	70.5	40.1	37.0
11:33	56.8	70.6	63.7	58.4	59.1	58.1	59.2	58.9	68.5	39.6	38.1
11:38	61.6	70.9	63.2	64.1	59.3	58.6	63.6	64.0	69.7	39.9	37.3
11:43	59.3	69.2	63.6	61.5	61.1	61.5	61.9	62.0	69.0	39.4	39.7
11:48	59.0	66.9	63.6	61.1	61.5	60.5	61.0	60.8	70.4	39.8	42.5
11:53	58.9	66.3	63.5	59.9	62.0	60.1	60.4	60.3	70.1	39.9	45.2
11:58	58.7	66.0	63.3	60.0	60.8	59.5	60.9	60.8	71.1	40.7	46.5
12:03	58.2	66.3	63.2	59.2	60.2	59.6	61.0	59.4	71.2	41.4	47.7
12:08	58.4	66.1	63.6	59.7	60.6	59.4	60.6	59.8	71.5	42.4	49.0
12:13	58.5	66.7	63.7	58.6	60.8	58.9	60.9	60.2	72.0	43.1	49.5
12:18	57.8	68.6	63.7	59.3	60.3	59.0	60.7	60.0	71.7	43.0	50.8

FIGURE B-15-d. Data Printout

Corrected Cold Cycle Temperatures

Time	Condenser			Z Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
12:23	63.2	69.8	63.9	64.0	59.6	59.0	61.7	62.8	72.4	43.4	52.2
12:28	59.1	70.4	63.6	53.7	61.1	59.9	62.6	61.6	71.9	44.1	53.4
12:33	58.8	71.3	64.3	60.2	60.7	60.3	61.5	60.6	72.0	43.0	53.7
12:38	59.2	71.7	64.0	60.0	60.6	60.0	61.1	60.6	72.8	42.4	54.5
12:43	58.5	72.4	64.0	60.0	60.6	59.8	61.4	60.9	73.0	41.7	55.4
12:48	58.4	72.3	63.9	60.6	61.0	59.2	61.5	60.9	72.6	41.8	56.6
12:53	58.7	72.7	63.8	60.3	60.3	59.6	61.2	60.4	72.6	42.3	57.2
12:58	58.8	72.7	64.0	60.0	60.3	58.7	61.4	60.9	73.3	42.1	57.1
1:03	58.0	72.7	64.0	59.8	60.0	59.4	61.1	60.5	71.9	41.7	58.2
12:58	58.8	72.7	64.0	60.0	60.3	58.7	61.4	60.9	73.3	42.1	57.1
1:03	58.0	72.7	64.0	59.8	60.0	59.4	61.1	60.5	71.9	41.7	58.2
1:08	58.1	72.4	63.8	59.7	59.6	59.3	60.7	60.5	72.6	41.3	57.6
1:13	58.1	73.4	64.0	59.8	59.7	59.1	61.1	60.0	72.5	41.1	55.0
1:18	58.3	72.9	64.7	59.3	61.1	59.2	61.0	60.3	72.9	42.4	52.0
1:23	62.6	73.6	64.8	63.2	60.2	59.5	61.2	60.0	72.6	42.7	52.1
1:28	65.1	73.2	64.7	67.6	62.1	59.7	61.0	60.0	71.5	41.6	50.2

Time	Pressure (psia)
1:19	0.0771
1:29	0.0836

Average Flowrates (gpm)
 Spray: 0.6 Cold 3.5

CORRECTED HOT CYCLE TEMPERATURES

Time	Condenser			Z Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
1:33	67.8	73.4	63.9	169.3	64.6	133.8	61.9	61.0	73.0	41.4	50.2
1:38	60.6	71.7	68.5	175.0	124.0	140.2	61.4	60.4	71.9	40.8	48.1
1:43	60.6	71.3	68.2	177.1	143.4	151.8	62.3	61.5	71.9	40.6	48.5
1:48	63.4	70.4	67.4	177.9	158.3	164.5	63.8	63.6	70.3	40.8	48.7
1:53	64.3	70.2	67.3	177.1	159.6	168.6	65.3	65.6	70.7	40.2	49.9
1:58	64.4	69.7	68.4	174.6	167.1	171.5	66.2	65.7	71.5	39.8	46.8
2:03	65.0	69.4	67.7	167.1	166.7	171.4	66.7	66.2	71.2	40.4	47.3
2:08	64.4	68.2	66.4	163.5	163.5	167.7	67.0	66.5	71.3	41.2	48.7
2:13	64.6	68.1	66.6	164.2	162.9	165.8	66.9	66.1	71.7	41.7	48.8
2:18	63.6	67.4	65.3	164.8	159.8	165.0	66.6	65.6	72.0	41.7	48.7
2:23	63.6	67.4	65.5	165.0	159.2	164.8	66.1	64.6	70.6	42.3	49.0
2:28	63.5	66.7	64.9	165.2	159.8	164.6	65.5	64.6	72.1	41.8	49.7
2:33	62.4	66.5	64.9	164.4	160.2	165.4	64.8	64.6	71.6	41.7	51.4
2:38	61.7	65.9	64.1	165.1	162.6	165.7	64.0	63.6	71.1	41.6	50.2
2:43	61.9	65.3	63.6	164.0	162.5	166.1	64.8	63.0	71.2	42.2	46.5
2:48	61.1	64.9	62.6	163.8	162.4	165.7	64.4	63.3	70.0	42.0	45.5
2:53	61.1	64.8	62.6	163.9	162.3	166.1	63.7	62.8	72.6	42.4	46.4
2:58	60.6	64.5	62.3	164.0	162.1	165.0	63.9	62.1	70.2	43.0	47.9
2:33	62.4	66.5	64.9	164.4	160.2	165.4	64.8	64.6	71.6	41.7	51.4
2:38	61.7	65.9	64.1	165.1	162.6	165.7	64.0	63.6	71.1	41.6	50.2
2:43	61.9	65.3	63.6	164.0	162.5	166.1	64.8	63.0	71.2	42.2	46.5

FIGURE B-15-d. Data Printout (continued)

CORRECTED HOT CYCLE TEMPERATURES

Time	Condenser			Z Tank			Receiver			Ice Tank	
	In	Out	Mix	In	Out	Mix	C1	C0	SUR	BR	TR
2:48	61.1	64.9	62.6	163.8	162.4	165.7	64.4	63.3	70.0	42.0	45.5
2:53	61.1	64.8	62.6	163.9	162.3	166.1	63.7	62.8	72.6	42.4	46.4
2:58	60.6	64.5	62.3	164.0	162.1	165.0	63.9	62.1	70.2	43.0	47.9
3:03	60.4	64.1	61.7	164.2	162.6	165.3	63.1	61.8	70.2	42.7	48.9
3:08	60.0	64.1	61.8	164.6	162.2	165.4	63.0	61.8	69.9	42.0	48.6
3:13	60.0	63.1	61.2	163.9	162.7	165.3	62.4	61.6	69.4	43.5	49.8
3:18	59.5	63.5	60.7	164.0	162.6	165.5	62.3	61.2	69.9	43.3	50.3
3:23	59.4	62.3	60.4	164.3	163.0	165.7	61.8	61.2	70.2	43.0	51.2
3:28	58.7	62.9	59.9	164.7	163.0	166.2	63.2	60.4	69.2	43.2	51.3
3:33	59.4	63.1	60.0	165.1	163.7	165.7	61.7	61.1	71.9	42.8	52.0
3:38	59.5	62.4	59.9	165.4	163.6	166.1	61.5	60.5	71.4	42.2	51.1
3:43	58.7	62.9	59.9	165.3	164.0	165.1	61.8	60.3	70.7	43.0	51.9
3:48	62.6	63.0	59.5	158.7	163.5	166.8	62.1	60.6	70.7	43.3	52.0

Time	Pressure (PSIA)
1:38	0.3352
2:54	0.3237
3:15	0.3187
3:46	0.3138

Average Flowrates (GPM)
 Spray: 0.6 Condenser: 3.6 Hot: 2.8
 Total condensate removed this hot cycle (lbs): 5.06

FIGURE B-15-d. Data Printout (continued)

APPENDIX C

CALIBRATIONS

APR 1964

NOTAR

FIGURE C-1. Temperature Calibrations

```

560 LET SUM7=SUM7+T(1.7)
570 LET SUM8=SUM8+T(1.8)
580 LET SUM9=SUM9+T(1.9)
590 LET SUM10=SUM10+T(1.10)
600 LET SUM11=SUM11+T(1.11)
610 NEXT I
615 REM *****AVERAGE THE TEMPERATURES AT EACH POINT*****
620 LET C42=SUM1/N
630 LET C41=SUM2/N
640 LET C43=SUM3/N
650 LET C38=SUM4/N
660 LET C40=SUM5/N
670 LET C39=SUM6/N
680 LET C36=SUM7/N
690 LET C37=SUM8/N
700 LET C44=SUM9/N
710 LET C46=SUM10/N
720 LET C45=SUM11/N
725 REM *****USE LINEAR CLIBRATION TO CORRECT TEMPS*****
730 LET TIWB=.9910389*C42+1.8749241
740 LET TIDB=.9901562*C41+1.9097596
750 LET BDWB=.9933127*C43+1.6809583
760 LET BDDB=.9872468*C38+1.903992
770 LET OWB=.9996835*C40+.8920704
780 LET ODB=.9881693*C39+1.5892001
790 LET BWB=.9893211*C36+1.8437028
800 LET BWD=.9873368*C37+1.903992
810 LET TLI=.9922119*C44+1.6784763
820 LET TLO=.9919257*C46+1.3890396
830 LET PT=.9890487*C45+1.6226466
840 LET AVGOB=(ODB+TIDB)/2
845 REM *****CALCULATE THE AVG. HEAT OF EVAPORATION FOR THE SYSTEM*****
850 LET HOEVAP=-(.5639753*AVGOB)+1093.4376
855 REM ***** CALCULATE THE SATURATION PRESSURES AT WET & DRY BULB TEMPS***
860 LET PWSI=FNPS(TIWB)
870 LET PWSDI=FNPS(TIDB)
880 LET PWSB=FNPS(BDWB)
890 LET PWSDB=FNPS(BDDB)
900 LET PWSO=FNPS(OWB)
910 LET PWSDO=FNPS(ODB)
920 LET PWSBW=FNPS(BWB)
930 LET PWSDBW=FNPS(BWD)
935 REM *****CALCULATE THE SATURATION HUMIDITY RATIOS (WET&DRY)*****
940 LET WSI=FNWS(PWSI)
950 LET WSDI=FNWS(PWSDI)
960 LET WSB=FNWS(PWSB)
970 LET WSD=FNWS(PWSDB)
980 LET WSO=FNWS(PWSO)
990 LET WSDO=FNWS(PWSDO)
1000 LET WSBW=FNWS(PWSBW)
1010 LET WSDBW=FNWS(PWSDBW)
1015 REM *****CALCULATE THE HUMIDITY RATIO AT EACH POINT *****
1020 LET HRI=FNHR(TIWB,TIDB,WSI)
1030 LET HRB=FNHR(BDWB,BDDB,WSD)
1040 LET HRO=FNHR(OWB,ODB,WSO)
1050 LET HRBW=FNHR(BWB,BWD,WSBW)
1055 REM *****CALCULATE THE DEGREE OF SATURATION*****
1060 LET UI=FNU(HRI,WSDI)
1070 LET UBD=FNU(HRB,WSD)
1080 LET UO=FNU(HRO,WSDO)
1090 LET UEW=FNU(HRBW,WSDBW)
1095 REM *****CALCULATE THE RELATIVE HUMIDITY AT EACH POINT*****

```



```

1100 LET RHI=FNRH(UI,PWSDI)
1110 LET RHBD=FNRH(UBD,PWSDBD)
1120 LET RHO=FNRH(UO,PWSDO)
1130 LET RHBW=FNRH(UBW,PWSDBW)
1135 REM *****CALCULATE LOG OF WATER VAPOR PARTIAL PRESSURE*****
1140 LET VI=FNV(PWSDI)
1150 LET VBW=FNV(PWSDBW)
1160 LET VO=FNV(PWSDO)
1170 LET VBD=FNV(PWSDBD)
1175 REM *****CALCULATE THE DEW POINT TEMPERATURE AT EACH POINT ***
1180 LET DPTI=FNDPT(VI)
1190 LET DPTBW=FNDPT(VBW)
1200 LET DPTO=FNDPT(VO)
1210 LET DPTBD=FNDPT(VBD)
1215 REM *****CALCULATE THE TOTAL WATER FLOW *****
1220 LET TWF=WF(IP+WFLR)
1225 REM *****CALCULATE THE AMOUNT OF WATER CHILLING*****
1230 LET WC=TWF*60*8.34*(TLO-PT)
1235 REM *****CALCULATE THE AMOUNT OF AIR CHILLING*****
1240 LET AC=(TIDB-ODB)*411.16*60*.0155
1245 REM *****CALCULATE THE TOTAL LATENT HEAT *****
1250 LET LH=(HRO-HRI)*HOEVAP*411.16*60*.0648
1255 REM *****PERFORM SIMILAR CALCULATIONS FOR AMBIENT SLING DATA*****
1260 FOR I=1 TO NAS
1270 LET PWSAS=FNPWS(ASWB(I))
1280 LET PWDAS=FNPWS(ASDB(I))
1290 LET WSAS=FNWS(PWSAS)
1300 LET WSDAS=FNWS(PWDAS)
1310 LET HRAS(I)=FNRH(ASWB(I),ASDB(I),WSAS)
1320 LET UAS=FNU(HRAS(I),WSDAS)
1330 LET IRHAS(I)=FNRH(UAS,PWDAS)
1340 LET VAS=FNV(PWSAS)
1350 LET DPTAS(I)=FNDPT(VAS)
1360 NEXT I
1370 DISP
1380 DISP
1390 PRINTER IS 1
1400 FOR I=1 TO N
1410 PRINT USING 130 : T(I,1);T(I,2);T(I,3);T(I,4);T(I,5);T(I,6);T(I,7);T(I,8);T
(I,9);T(I,10);T(I,11)
1420 NEXT I
1430 DISP
1440 PRINT " AVERAGE CORRECTED TEMPERATURES"
1450 PRINT USING 130 : TIWB;TIDB;BOWB;BODB;OWB;ODB;BWWB;BWDB;TLI;TLO;PT
1460 DISP
1470 PRINT "WATER CHILLING":WC
1480 PRINT "AIR CHILLING":AC
1490 PRINT "LATENT HEAT":LH
1500 DISP
1510 DISP "DO YOU WANT TO CHANGE ANY TEMPERATURES ? (Y OR N)"
1520 INPUT ANS#
1530 IF ANS#="Y" THEN 1550
1540 GOTO 1610
1550 DISP "ENTER THE ROW NUMBER AND COLUMN NUMBER OF THE TEMP. YOU WANT TO CHANG
E."
1560 INPUT I,J
1570 DISP "ENTER THE NEW TEMPERATURE"
1580 INPUT ERROR
1590 LET T(I,J)=ERROR
1600 GOTO 380
1610 DISP "DO YOU WANT A PRINTOUT OF THE RESULTS ? (Y OR N)"
1620 INPUT ANS#

```

```

1630 IF ANS2#="Y" THEN 1650
1640 GOTO 2180
1650 PRINTER IS 701
1660 PRINT
1670 PRINT
1680 PRINT "                EVAPORATIVE WATER CHILLER DATA"
1690 PRINT
1700 PRINT "DATE PROGRAMED: ";MO;"-" ;DA;"-" ;YR
1710 PRINT
1720 PRINT "DATE DATA COLLECTED: ";MO;"-" ;DA;"-" ;YR1
1730 PRINT
1740 PRINT "WEATHER CONDITIONS: ";WEATH$
1750 PRINT
1760 PRINT "TYPE OF HEAT EXCHANGER: ";UNIT$
1770 PRINT
1780 PRINT "AMBIENT SLING DATA"
1790 PRINT " TIME WET    DRY    HUMIDITY (LB/LB)  REL. HUMIDITY (%)  DEWPOINT"

1800 FOR I=1 TO NAS
1810 PRINT USING "2D.2D.1X.2D.D.2X.3D.D.8X.D.6D.12X.3D.D.10X.3D.D" : T1(I),ASWB(
I),ASDB(I),HRAS(I),RHAS(I),DPTAS(I)
1820 NEXT I
1830 PRINT
1840 PRINT "HEAT EXCHANGER FLOW RATE: ";HEFR
1850 PRINT "UPPER FLOW RATE: ";WFUP
1860 PRINT "LOWER FLOW RATE: ";WFLR
1870 PRINT
1880 PRINT "   INPUT      BOTTOM DRY   OUTPUT      BOTTOM WET      LOAD      PAN"
1890 PRINT " WET  DRY    WET  DRY    WET  DRY    WET  DRY    IN   OUT   TEMP."
1900 PRINT
1910 FOR I=1 TO N
1920 PRINT USING 130 : T(1,1);T(1,2);T(1,3);T(1,4);T(1,5);T(1,6);T(1,7);T(1,8);T
(1,9);T(1,10);T(1,11)
1930 NEXT I
1940 PRINT
1950 PRINT "                AVERAGE CORRECTED TEMPERATURES"
1960 PRINT
1970 PRINT USING 130 : TIWB;TIDB;BDWB;BDOB;OWB;ODB;BWDB;BWDB;TLI;TLO;PT
1980 PRINT
1990 PRINT "                HUMIDITY RATIO (LB/LB)"
2000 PRINT
2010 PRINT USING "1X.D.6D.4X.D.6D.4X.D.6D.4X.D.6D" : HRI;HRBD;HRO;HREW
2020 PRINT
2030 PRINT "                RELATIVE HUMIDITY (%)"
2040 PRINT
2050 PRINT USING "3X.3D.D.7X.3D.D.7X.3D.D.7X.3D.D" : RH1;RHBD;RHO;RHBW
2060 PRINT
2070 PRINT "                DEWPOINT TEMPERATURES"
2080 PRINT
2090 PRINT USING "3X.2D.D.8X.2D.D.8X.2D.D.8X.2D.D" : DPT1;DPTBD;DPTO;DPTBW
2100 PRINT
2110 PRINT
2120 PRINT "WATER CHILLING IN BTU/HR = ";WC
2130 PRINT
2140 PRINT "AIR CHILLING IN BTU/HR = ";AC
2150 PRINT
2160 PRINT "LATENT HEAT IN BTU/HR = ";LH
2170 PRINT
2180 PRINTER IS 1
2190 DISP

```

2200 DISP "DO YOU WANT TO RUN MORE DATA FOR THIS DAY (SAME WEATHER CONDITIONS)?"

2210 INPUT ANS3\$

2220 IF ANS3\$="Y" THEN 290

2230 BEEP

2240 END

147469

FIGURE C-2. Condensate Receiver Calibration

FIGURE C-3. Mechanical Pressure Gauge Calibration

Figure 1. A linear relationship between the variables shown on the axes.

APPENDIX D

DETAILS OF CONSTRUCTION

APR 19 1964

RECEIVED

APPENDIX D

DETAILS OF CONSTRUCTION

Figures D-1 through D-3 give the physical arrangement of the ZCAT system. Copper and stainless steel were used in the manufacture of the system because contamination of the zeolite is known to be a critical problem. The zeolite tubes, manifold, condenser, condensate receiver, and connection to the ice tank are all copper except the 5-inch diameter cap, tee, coupler, and 3-inch vacuum valve, which are brass. The ice tank is constructed from 12-inch diameter 304 stainless steel. All copper connections were made with Sil-Fos brazing. Parts other than those in the zeolite section can probably be made of less costly materials as long as the material does not outgas under vacuum conditions.

The zeolite tubes, condenser tubes, and manifold are mounted within an 18-inch by 7-foot fiberglass tank (see Figure D-1). The evaporative water chiller is mounted on the north of the sealed system, and the solar water heating panel is mounted just south of the sealed system. Drainback tanks are installed to conserve hot and cold water and allow repetitive cycling during a day. An 80-gallon, 4500-watt electric water heater was added to expedite testing.

Evaporative Water Chiller

The chilled water system consists of a Des Champs Z-Duct heat exchanger mounted with blower on an airflow turn-around duct. A block of Munters CELdek installed in the turn-around duct furnishes an air-water interface where both are evaporatively cooled. Ambient air is blown into one side of the Z-Duct then to the CELdek. The evaporatively cooled air then is exhausted through the second side of the Z-Duct. The evaporatively cooled air cools the dry ambient input air via heat exchange. As the wet air extracts heat from the dry air, additional water is evaporated from water sprayed into the exhaust side of the Z-Duct, which further extracts heat out of the input side air. This heat exchange lowers the wet bulb and dry bulb temperature of the dry air, which then allows the evaporative cooling in the CELdek to approach lower temperatures. Figure D-4 presents a psychrometric plot of the evaporative water cooling. The dry cooling of

DETAILS OF SYSTEM

The system is a closed loop system. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter.

The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter.

The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter. The water is pumped from the reservoir through a pump and into a distribution system. The distribution system consists of a main line and several branch lines. The main line is 12 inches in diameter and the branch lines are 6 inches in diameter.

FIGURE D-1. Solar Zeolite System, Looking East

FIGURE D-2. Solar Zeolite System, Looking North

FIGURE D-3. Plan View of System

the air is line 12. Line 12 sensible cooling must equal line 34 sensible and latent heat change. Line 23 has an energy balance between the air cooling, water cooling, and latent heat. In the water chiller system are two Richdel Model R798A water circulating pumps, two water flow meters (Dwyer Models RMC142SSV and RMC 145SSV), a drainback tank, four thermowells, valves, fittings, and interconnecting plumbing.

Zeolite Tank

The zeolite tank and condenser tanks share the same 7-foot fiberglass tank. An aluminum plate and 3 inches of foam insulation separate the top 54 inches (the zeolite tank) from the bottom 30 inches (the condenser tank). This arrangement is shown in Figures D-1 and D-2. The separating plates restrict water flow between the zeolite section and the condenser manifold section but do not completely block it. An operational procedure was established that minimized any water flow across the separating plates.

Figure D-5 shows the details of the zeolite tank cross section. The fiberglass tank is a nominal 18 inches in diameter. The Solar Components Corporation makes the tanks out of 5-foot widths of fiberglass but uses four diameters in increments of $\frac{3}{8}$ inches to allow stacking four tubes for shipping. An aluminum plate along with eight $\frac{1}{2}$ -inch diameter threaded rods support the 64 zeolite filled tubes. The plumbing is arranged to enter hot or chilled water in the top of this section and return it to the heating or cooling system at the bottom.

For the zeolite tubes, a $\frac{1}{2}$ -inch copper tube was cut $51\frac{1}{4}$ inches long (Figure D-9). Starting 1 inch from one end, $\frac{1}{8}$ -inch holes were drilled at $\frac{1}{2}$ -inch intervals along the tube to $2\frac{1}{2}$ inches from the opposite end. Four rows were drilled symmetrically around the tube. Thirty-mesh copper cloth was then wrapped around the tube over the holes and held in place with fine copper wire. A $1\frac{1}{2}$ -inch bell reducer was then brazed to one end of a 48-inch section of $1\frac{1}{2}$ -inch copper pipe. The $2\frac{1}{2}$ -inch hole-free end of the $\frac{1}{2}$ -inch pipe was then brazed to the bell (Figure 2). A $1\frac{1}{2}$ -inch bell reducer was then slipped over the opposite end of the tube assembly and brazed to the $1\frac{1}{2}$ -inch tube leaving the $\frac{1}{2}$ -inch tube extending into the neck of the bell but not brazed to it.

FIGURE D-5. Geometry of Zeolite Tubes in Zeolite Tank

Bell reducers typically have a small lip extending around the inside of the small end. This lip was removed to allow the 1/2-inch pipe to extend through it. A 4-inch long section of 1/2-inch pipe was then brazed in place and capped. The 4-inch section became the top of the assembly. The main 1/2-inch tube was free to move in the top bell reducer. This allowed for differential expansion between the 1-1/2-inch and the 1/2-inch pipes. The tube system was sealed except for the open bottom end. It was then tested for air leaks by connecting a vacuum pump to the open end. After a 1/4-inch hole was drilled in the tube assembly, it was flushed with distilled water and filled with molecular sieve 13X zeolite through the 1/4-inch hole. The system was then flushed again with distilled water and a 1/4-inch plug brazed into the hole. Sixty-four tube assemblies were constructed.

Condenser Manifold

In this application, vapor desorbed from the zeolite must be condensed to keep internal pressure low while heating the zeolite. Each zeolite tube was connected through a silicone tube thermal break to a 1/2-inch condenser tube. The 64 condenser tubes were then manifolded into one vertical 5-inch copper pipe to allow condensate to flow readily downward to the bottom of the condensate collector. An acrylic viewing window on a 45° bevel and a condensate drain with vacuum valve were installed on the condensate receiver. The window was for observation of condensate. The purpose of the bevel is to allow freezing of up to 1.8 pounds of condensate without straining the pipe. There is a 5-inch by 5-inch by 3-inch copper tee between the manifold and condensate receiver. The third outlet is connected, through a vacuum valve, to the ice tank.

Figure D-6 gives the plan view of the manifold. The 64 condenser tubes were connected (brazed) to the manifold as shown by the small circles or ellipses. Eight condenser tubes were brazed to the cap of the 5-inch diameter pipe. Seven 1-1/2-inch pipes radiate from the 5-inch pipe. Each of the seven pipes has eight 1/2-inch condenser pipes brazed as shown. A conflict between two 1-1/2-inch pipes and the 1/2-inch threaded rods caused a shortening of the pipes and a change in where the condenser pipes were

FIGURE D-6. Plan View, Manifold

brazed. Figure D-7 shows the tank and table cut along condenser-manifold section DD (of Figure D-6). Figure D-8 shows the tank and table cut along condenser-manifold section EE (of Figure D-6).

The central part of the manifold, condensate receiver, and connecting tee are made of 5-inch plumbing. A brass cap at the top was brazed to 5-inch copper pipe which in turn was brazed to a brass coupler. The coupler was then brazed to another short section of pipe, for a total length of 20-15/16 inches. A flange of 1/2-inch brass was then brazed onto the low part of the section 3-1/2 inches from the end. The brass flange has six symmetrical holes for 5/16-inch bolts for clamping to the lower section. Eight 0.625-inch holes were drilled in the brass cap for condenser tubes as shown in Figure D-6. The 5-inch coupler had seven 1.625-inch holes drilled symmetrically around it. Seven 1-1/2-inch diameter pipes 7 inches long were inserted into these holes and brazed at a 5° angle (Figures D-7 and D-8) to assure good draining of the condensate. The 1-1/2-inch pipes were inserted into the 5-inch pipe to avoid exceeding a radius of 8-5/8 inches. Two were inserted further in to 5-inch pipe to clear the 1/2-inch threaded rods that hold the system together. Each 1 1/2-inch pipe was capped and drilled for 1/2-inch copper pipe as shown in Figure D-6.

Three vacuum valves are shown in Figures D-7 and D-8. The main valve, or 3-inch valve, is in the 3-inch piping between the 5-inch by 5-inch by 3-inch brass tee in the condensate receiver and the ice tank. This valve is in a 3-inch pipe section, has two 90° bends. One bend is required, but because of the way the valve was designed, second bend was made to allow for other equipment not involved in this project. This valve was available and was used as built. Included in the valve was a flexible section to allow some flexing between the ice tank and the condensate receiver. However, the flexible section was made of stainless steel and was found to leak. It was replaced with a flexible copper section. A second vacuum valve, a 1-inch valve mounted above the tee, is used to pump air from the system. The third valve is described below.

FIGURE D-8. Cut-Away of Condenser-Manifold, Section EE

Condensate Receiver

The condensate receiver is a 7.8-inch section of 5-inch copper pipe with a 45° bevel on the bottom and a view window with 15 fiducial marks for estimating the amount of water. A 5/16-inch copper line with vacuum valve extends from the bottom of the receiver to allow condensate to be drained.

Solar System

The solar water heating system, which is not optimized for this project, is adequate for daily cycling. The solar water heating system includes a locally fabricated solar panel, circulating water pump, and drainback tank. A 4500-watt electric water heater is included to expedite desorption speed of response testing.

Vacuum Gauges

During initial vacuum testing of the system, three vacuum gauges were installed as shown in Figure D-7. One, a General Instrument Corporation 6001 gauge (with a scale of -30 inches of mercury to 0 to +15 psia) was used to give a rough measurement. This gauge is noted as the 2-1/2-inch vacuum gauge on Figure D-7. The second was a mechanical gauge with a 7-inch diameter and a nonlinear scale of 1.0 torr to 400 torr with 30 torr at the one-half scale position. The third was a pirani gauge, which gives good readings from 0 to 4 torr. The electronics for the pirani gauge failed when there was not sufficient time for repair and recalibration, so the mechanical gauge was utilized.

Ice Tank

Figure D-9 gives construction details of the ice tank. The tee in the vertical 5-inch diameter pipe system connects through the 3-inch diameter port, bellows section (flexible), and vacuum valve to the ice tank. The 10-inch long bellows section relieves any mechanical strain between the tank and the 5-inch pipe. The valve allows testing without the ice tank and isolates the ice tank while vapor is being condensed in the condenser manifold. Acrylic windows at each end of the ice tank allow monitoring of the inside of the tank.

FIGURE D-9. Construction Details, Ice Tank

A fiberglass tank 5 feet high and 18 inches in diameter and a circulating system with antifreeze solution allow extraction of daily use cooling in summer and extraction of heat in winter to freeze the water in the ice tank. The circulating system includes an 18-square foot unglazed solar panel to radiate heat from the system.

The stainless steel ice tank was constructed to assure that no air leaks existed. Because the ice tank was fastened to the rest of the system by flanges and is remote from the zeolite, other materials should be applicable as long as no outgassing occurs and the ice tank does not collapse under 14 psi pressure in compression. The ends were beveled at 45° and capped with flat stainless steel welded to the bevel. The 1-inch by 10-inch windows at each end were covered with a gasket and acrylic. A 1/2-inch stainless steel pipe runs the 15-foot length of the center line of the tank with a tee at the center for support. This pipe allows freezing of water concentrically so that the tank can be mostly filled with ice without stressing the pipe. Four stainless steel pipes were spot welded the length of the pipe to the bottom of the tank at about 4-inch intervals. They were manifolded at each end to 1/2-inch headers. This set of four pipes allows heat exchange with the tank to give a more efficient heat transfer than would a single pipe.

Figure D-10 gives details of the ice tank system in a plan view. The ice tank has a drain or fill via vacuum valve V_1 . The ice tank drain/fill and each heat exchanger are connected through valves V_1 , V_2 , and V_3 to the ice tank circulating pump PI, which circulates an antifreeze solution through the 66-gallon fiberglass tank, the heat-radiating unglazed solar panel, and the heat exchangers. Valve V_1 and valve V_4 are normally closed. Valves V_2 and V_3 are set according to which heat exchangers are in use. Valves V_4 and V_5 allow the ice tank circulating pump PI to operate in series with hot water circulating pump PH. Opening valves V_1 , V_4 , and V_5 and closing valves V_2 , V_3 , V_6 , V_7 , allows the two pumps to operate in series and work against atmospheric pressure to evacuate water from the ice tank.

Figure D-11 gives temperatures of a black absorber, tar coating, and clear fiberglass with respect to ambient air temperature and time over a

FIGURE D-10. Ice Tank System, Plan View

FIGURE D-11. Variation of ΔT Versus Time for Miscellaneous Material Samples

24-hour period. This data was measured by George Conrad of the Physical Science Laboratory of New Mexico State University. The samples tested were insulated on the back side and placed on the roof horizontally so that the test surface faced zenith. Each of the three sample materials went to about 10°F below ambient at night. The 97.5 percent winter design temperature for Las Cruces is 20°F; for Santa Fe, 10°F. This indicates that use of radiation cooling in Las Cruces should give about the same freezing degree days as air cooling will furnish in Santa Fe, which is 280 miles north of Las Cruces and 3,000 feet higher.

Figures D-12, D-13, D-14, D-15, and D-16 are photographs of the ZCAT facility. The tall object in the center of each photograph is the translucent fiberglass tank encompassing the 64 zeolite tubes in the top two-thirds of the tank and the condenser-manifold in the bottom third. The tubes are partially visible. The evaporative water chiller can be identified by the presence of the blower. The long slender horizontal tank is the ice tank.

Labor and Material Breakdown

The material breakdown is furnished in Table D1. A total of \$18,800 was spent for equipment, material, and supplies. Labor for construction was about \$8,904. Construction, except for the ice tank, was performed by NMSU students.

FIGURE D-12. System, Looking East

FIGURE D-13. System, Looking West

FIGURE D-14. System, Looking North

FIGURE D-15. System, Looking Northwest

FIGURE D-16. Zeolite Tubes and Condenser

TABLE D-1. Materials Breakdown, ZCAT Facility

<u>Qty</u>	<u>Zeolite Tank</u>
2	1/4" x 18" aluminum plate
64	1 1/2" x 4' copper pipe
64	1/2" x 5' copper tubing
64	1/2" copper caps
15'	30 mesh x 4' copper screen
16'	3/4" I.D. silicon tubing
100#	13 x molecular sieve zeolite

	<u>Condenser Tank</u>
64	1/2" x 18" copper tubing
1	1/2" x 7" x 7" brass plate
1	5" ϕ brass cap
1	5" ϕ copper coupler
1	5" ϕ x 9" copper pipe
7	1-1/2" x 6" copper pipe
7	1-1/2" copper caps
1	3/16" x 17-3/4" steel plate
1	7/8" x 15" neoprene gasket
1	3/16" x 6" neoprene gasket

	<u>Receiver Section</u>
1	5" ϕ x 9" copper pipe
1	5" ϕ x 12" copper pipe
2	1/2" x 7" x 7" brass flange
1	1-1/2" brass vacuum valve
1	5" x 5" x 3" brass tee
1	1/2" x 7" ϕ neoprene gasket
8	3/16" bolts and nuts
1	3/16" x 7" x 4" aluminum plate
1	3/16" x 7" ϕ neoprene gasket
1	3/16" 7" x 4" acrylic plate

TABLE D-1. (continued)

2	5/16" vacuum vale
1	3" ϕ copper bellows
2	1/2" x 6" ϕ brass flanges
1	3" ϕ vacuum valve
1	3" ϕ x 6" copper pipe
1	3" ϕ copper elbow
1	1/2" x 6" ϕ brass flange
1	5/16" brass tee
1	5/16" vacuum valve
1	3/8" x 10' copper tubing

Ice Tank

1	12" ϕ x 15" stainless steel tank w/bevel cut edges, 3" ϕ stack w/flange
2	3/16" x 7" x 4" aluminum plate
2	3/16" x 6" ϕ neoprene gasket
2	3/16" x 7" x 4" acrylic plate

Exterior Tanks

1	18" ϕ x 10' fiberglass tank
3	18" ϕ 5' fiberglass tank
1	18" ϕ 5' steel tank

Misc. Plumbing, Parts and Systems

7	3/4" thermal wells
10	3/4" valves
1	1/2" vacuum valve
10	PVC pipe 3/4" x 10'
1	Evaporative water chiller
10	2' x 8' aluminum covered insulation batts
2	3' x 6' solar collector
1	80 gallon hot water heater

TABLE D-1. (continued)

4	Richdel circulating pumps
3	Flow rate meter
12	3' x 8' x 1 1/2" sheets foam insulation
4	2" x 3" x 8' slotted angle
150'	1/8" diameter stranded metal cable

PVC (3/4")	Copper (3/4")
------------	---------------

Elbows (90°)	- 22	- 10
Tees	- 11	- 12
Couplers	- 9	- 1
Quick Release		
Couplers	6	
Caps	- 3	- 2

Wood

1	4' x 8' x 3/4" plywood
3	4" x 4" x 8' posts
10	2" x 4" x 8' studs

Misc.

6 lb.	Sil-Fos #5 brazing alloy
1	2-1/2" vacuum guage
6	5/16" pirani transducer
1	Televac pirani vacuum guage electronics
1	1 torr to 400 torr vacuum gauge
1	OMEGA 24 TX20PP, 24 pair thermocouple cable 125 ft.
1	Austron data logger
1	Vacuum pump
1	Mass spectrometer helium leak detector

Data Collection

All temperature measurements were tabulated automatically by a data logger manufactured by Austron, Inc. Flows of hot water and chilled water were set according to specific test requirements and the information hand recorded. The pirani and dial pressure gauges were monitored and readings hand recorded. The airflow in the evaporative water chiller was measured with a TSI anemometer and hand recorded. Climatological data were obtained from the office of the state climatologist at the New Mexico Department of Agriculture at Las Cruces, New Mexico.

The Physical Science Laboratory at New Mexico State University maintains a secondary standard quartz thermometer for calibration of thermocouples. This secondary standard was used to measure the temperature of a water bath. Test tubes with silicon oil were immersed in the water bath and the thermocouples were immersed in the oil. The thermocouples were calibrated at 15 temperatures.

Pressure gauge calibration in vapor was performed in the ZCAT facility by pumping the pressure down until water in the condensate receiver started to boil. The temperature of the water was then related to the saturation line on the steam chart, and the pressure at that point was recorded. The pirani gauge was calibrated in air at the NASA White Sands Test Facility.

Transducer locations are shown in Figures 1, 8, 9, 10, and 14. A list of all measurements is given in Table D-2.

The initial proposal for this project did not include any electrical power consumption measurements since the main concern was for the performances of the zeolite, condenser, manifold, and ice tank. However, a Watt Probe 2,000 A was procured and used to measure the power used by the circulating pumps and the blower. These pumps and blower were designed to be cost competitive and are very inefficient. The Richdel Model R798A pumps were rated at 80 watts in company literature. It took 86 watts to circulate water through the solar panel, electric hot water heater, drainback tank, and related plumbing. Adding the zeolite tank to the water loop raised the power used to 95 watts. The chilled water spray pump used 80 watts to circulate water through the condensate receiver cooling coils, plumbing, and sprays. The chilled water circulating pump used 85 watts to

TABLE D-2. System Performance Measurements

<u>Channel</u>	<u>Parameter</u>
<u>Number</u>	
<u>Air Temperatures</u>	
07	Chiller air output, wet bulb
08	Chiller air output, dry bulb
09	Chiller air input, wet bulb
10	Chiller air input, dry bulb
11	Chiller air, bottom, wet bulb
12	Chiller air, bottom, dry bulb
13	Chiller air, bottom, wet bulb
14	Chiller air, bottom dry, dry bulb
15	Ambient air, wet bulb
16	Ambient air, dry bulb
<u>Water Temperatures</u>	
00 (T_0)	Condenser tank input
01 (T_1)	Condenser tank output
02 (T_2)	Zeolite tank, input
03 (T_3)	Zeolite tank, output
04 (T_4)	Condensate cooler, input
05 (T_5)	Condensate cooler, output
06 (T_6)	Condensate receiver
17 (T_{17})	Condenser tank mix ¹
18 (T_{18})	Zeolite tank mix ²
19	Ice tank, bottom north west
23	Ice tank, bottom south west
<u>Vapor Temperatures</u>	
20	Ice tank vapor exit, north
21	Ice tank vapor exit, south ³
22	Ice tank vapor, east of exit ³

TABLE D-2. (continued)

<u>Water Flow</u>	
(F ₁)	Chilled water supply
(F ₂)	Condensate receiver cooling
(F ₃)	Hot water flow
<u>Air Flow</u>	
F ₄	Air flow through evaporative water cooler
<u>Pressure</u>	
P ₁	Sealed system pressure measurement

- 1 The condenser mix thermocouple was placed 3 inches from the top center of the condenser tank for purposes of monitoring the condenser water before any hot water could infiltrate from the zeolite tank.
 - 2 The zeolite tank mix thermocouple was placed 3 inches from the bottom center of the zeolite tank for purposes of monitoring the zeolite water before any cooling water could infiltrate from the condenser tank.
 - 3 These transducers were later moved to check the condenser input water temperature.
- () Transducer designations in parenthesis correspond to Figure 1. Transducer designations without parentheses correspond to data logger channels.

circulate water through the condenser tank, chilled water evaporation CELdek, and plumbing and 87 watts to circulate water through the zeolite tank. The ice tank circulating pump used 81 watts to circulate water through the ice tank center-line heat exchanger, radiating panel, and storage tank. The blower used 285 watts to drive air through both sides of the Z-Duct and the CELdek; the air flow was 485 cubic feet per minute. The static pressure of the Z-Duct CELdek and ducting was 1 inch of water pressure. The efficiency of the blower was 40 percent, based on the above

figures. The impedances of the water flow paths were not measured. For a measured rate of 3 gallons per minute of hot water flow through the zeolite tank and based on information from the manufacturer's literature, the pumping head would be 12 feet. Thus the pump had an efficiency of 7 percent. A good electrically driven pump can be over 60 percent efficient.

Test Control

Two parameters can be partially controlled, the temperature of the heated water and the temperature of the chilled water. However, the temperature of the evaporatively chilled water is subject to ambient atmosphere dew point and dry bulb temperatures. Likewise, the temperature of the solar-heated water is subject to insolation, air temperature, and wind. An 80-gallon 4500-watt electrical hot water heater was added to speed testing.

It was difficult to obtain the desired higher water temperatures needed to dry the zeolites because the fiberglass tanks used would not hold up if the water exceeded 175°F and the volume of water in the system was not adequate for the necessary heat storage. There were 80 gallons of water stored in the electric hot water heater, 50 gallons in the drainback tank (the original 66-gallon fiberglass tank was replaced with a 60-gallon iron tank) and about 5 gallons in the plumbing and solar water heater. Total weight of water was 1126, pounds which stores 1126 Btu/°F. Heating the mass of the zeolite tubes required 71.7 Btu/°F as calculated and somewhat less according to test data. Heating the zeolite tubes by 100°F between the adsorption and desorption phases, therefore, required 7170 Btu and a 6.3°F drop in stored water temperature. Desorption during the first 10 minutes of that phase typically dropped the water temperature another 3.5. These elements combined to drop the temperature about 10°F and limited the testing to 165°F or below. Desorption testing was performed with hot water varying from 130°F to 165°F.

Chilled water storage furnished 440 Btu/°F, which limited the adsorption and condensation operation of the lower matrix points.

The volumes of storage of hot and cold water, while limiting the magnitude of speed of response testing, were still adequate to allow acquisition of good speed of response testing.

the volume of steam of hot and cold water, while testing the
resistance of steam of various temperatures, was used to allow
comparison of good steam of various temperatures.

DISTRIBUTION

No of
Copies

No of
Copies

OFFSITE

US Department of Energy Attn: I. Gyuk Office of Energy Systems Res. Forrestal Bldg, CE-141 5E-052 Washington, DC 20585	10	Charles F. Meyer 1141 Cima Linda Lane Santa Barbara, CA 93108 New Mexico Solar Energy Institute Attn: V.V. Risser New Mexico State Univ. PO Box 3, SOL Las Cruces, NM 88003 New York State Energy Research & Development Agency Attn: Director Rockefeller Plaza Albany, NY 12223 New York State Energy Research & Development Agency Attn: Gunnar Walmet Rockefeller Plaza Albany, NY 12223 Oak Ridge National Laboratory Attn: J. F. Martin PO Box Y Oak Ridge, TN 37830 Office of Congressman Sid Morrison Kevin Billings Legislative Assist. 1330 Longworth Bldg. Washington, DC 20515 Rocket Research Attn: L. B. Katter York Center Redmond, WA 98052
US Department of Energy Attn: R. Shivers Office of Energy Systems Res. Forrestal Bldg, CE-141 5E-052 Washington, DC 20585		
27 DOE Technical Information Center		
Argonne National Laboratory Solar Thermal Storage Program Attn: A. Michaels Building 362 9700 S. Cass Avenue Argonne, IL 60439		
Auburn University Attn: F. J. Molz School of Engineering Auburn, AL 36830		
Walter Hausz 4520 Via Vistosa Santa Barbara, CA 93110		
Lawrence Berkeley Laboratory Attn: C. F. Tsang University of California Bldg. 90, Room 1012-H 1 Cyclotron Road Berkeley, CA 94720		

No of
Copies

Union Carbide Corporation
Nuclear Division
Attn: Library
Y-12 Plant
PO Box Y
Oak Ridge, TN 37830

US Army Corps of Engineers
Attn: Library
PO Box 59
Louisville, KY 40202

US Department of Interior
Attn: Natural Resources
Library
Serials Branch (G/E)
Washington, DC 20240

FOREIGN

Bengt Hidemark Gosta Danielson
Arkitekter SAR
Attn: A. Boysen
Jarntorget 78
S-11 29 Stockholm
Sweden

Public Works of Canada
Attn: E. L. Morofsky
C456 Sir Charles Tupper Bldg.
Riverside Dr. and Heron Rd.
Ottawa, Ontario
K1A 0M2 Canada

ONSITE

DOE Richland Operations Off.

H. E. Ransom/D. R. Segna

22 Pacific Northwest Laboratory

L. D. Kannberg (15)
Technical Information (5)
Publishing Coordination (2)