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COLORADO STATE UNIVERSITY PROGRAM FOR
DEVELOPING, TESTING, EVALUATING AND OPTIMIZING
SOLAR HEATING AND COOLING SYSTEMS

PROJECT STATUS REPORT FOR THE MONTHS OF
JANUARY AND FEBRUARY 1992

Prepared for the

U.S. Department of Energy
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Under Grant DE-FG03-86-SF16306

Submitted by

Solar Energy Applications Laboratory
Colorado State University

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MASTER

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Report No: SF-16306-33

Report Period: 1 January 1992 to 29 February 1992

PROJECT TITLE:

Developing, Testing, Evaluating and Optimizing Solar Heating and Cooling Systems

GRANT NUMBER: DE-FG03-86-SF16306

GRANTEE NAME: Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado 80523

GRANT PERIOD: 1 June 1986 to 29 February 1992

GENERAL STATUS:

1. Project Objective:

The objective is to develop and test various integrated solar heating, cooling and domestic hot water systems, and to evaluate their performance.

2. Technical Approach:

Systems composed of new, as well as previously tested, components are carefully integrated so that effects of new components on system performance can be clearly delineated. The SEAL-DOE program includes six tasks which have received funding for the 1991-92 fifteen-month period. These include: (1) a project employing isothermal operation of air and liquid solar space heating systems, (2) a project to build and test several generic solar water heaters, (3) a project that will evaluate advanced solar domestic hot water components and concepts and integrate them into solar domestic hot water systems, (4) a liquid desiccant cooling system development project, (5) a project that will perform system modeling and analysis work on solid desiccant cooling systems research, and (6) a management task. The objectives and progress in each task are described in this report.

3. Project Tasks:

SOLAR HEATING WITH ISOTHERMAL COLLECTOR OPERATION AND ADVANCED CONTROL STRATEGY

Status: Activity during January and February was devoted to analysis and plans for presentation of results from the TRNSYS heating simulations. Time and effort of the project staff was primarily devoted to cooling simulation due to the contract sequence.

GENERIC SOLAR DOMESTIC WATER HEATING SYSTEMS

Status: Discussions at the 1992 SOLTECH meeting in Albuquerque with project members from University of Wisconsin, Solar Rating and

Certification Corp., Florida Solar Energy Center, National Renewable Energy Laboratory and the Department of Energy established future experimental needs for the in-collector storage solar DHW systems. In particular, plans are now underway to develop a testing plan to determine incidence angle modifiers, effects of background reflectance, tank stratification and heat-loss. Experimental analyses during the current funding period will focus on the NEG system. Additional tests with thermosiphon systems will be delayed until the next project period beginning March 1, 1992. Progress continues on construction of the solar simulator.

ADVANCED DOMESTIC HOT WATER (DHW) SYSTEMS

Status: Activities in the Advanced SDHW Systems Task focused on preparations for and attendance at the January 27 through 31 International Energy Agency Solar Heating and Cooling Program (IEA) Task XIV (Advanced Solar Energy Systems) Experts meeting. Other activities in this period included: 1) modeling the American Solar Network (ASN) SDHW system, 2) meeting with Al Rich of American Solar Network regarding technical aspects of ASN SDHW systems, 3) organizing two papers on results of the Task for the June 1992 ASES meeting, 4) serving on the technical Committee for the June ASES meeting, 5) meeting with Konrad Schreitmüller, Associate Director of the Institut für Solarenergieforschung in Hanover regarding advanced SDHW modeling, and 6) attending the SRCC and SEIA meetings at SOLTECH.

LIQUID DESICCANT COOLING SYSTEM DEVELOPMENT

Status: During this period permission was obtained from the department of Environmental Health Services to carry out diffusivity studies using tritiated water.

A survey of standard diffusivity measurement methods was carried out and a suitable combination of these methods was developed to meet the requirements. The method proposed is similar to the twin bulb method; however, the design of the apparatus is based on the criteria used for the diaphragm cell. The volume of each bulb was chosen to be 5 ml to reduce the duration of the experiment and a capillary of 1.47 mm diameter and 30 mm length was chosen to satisfy the design criteria. A known amount of TOH will be used along with water to prepare the LiBr solution in one of the bulbs to eliminate the need for large volumes. A constant temperature bath with high accuracy is being purchased to maintain a uniform temperature in both the bulbs and thus eliminate thermal diffusion.

ANALYSIS OF ADVANCED SOLID DESICCANT SOLAR COOLING SYSTEMS

Status: Activities during January and February were devoted to development of a TRNSYS simulation deck for the Pennington (ventilation) solar desiccant cooling cycle. This simulation

SOLAR HEATING WITH ISOTHERMAL COLLECTOR OPERATION AND ADVANCED CONTROL STRATEGY

Research Team:

Charles C. Smith, Task Leader
George O.G. Löf, Senior Advisor
Douglas C. Hittle, Advisor
Ihsan A. Abbud, Graduate Research Assistant

Objectives:

As principally a systems performance laboratory, an objective in recent years at the Colorado State University Solar House I has been to increase overall system performance at negligible added cost. This effort has proven most successful in the areas of improved control strategy and temperature stratification in the water storage tank. Seasonal system efficiency, the ratio of useful energy to space heating divided by solar energy on the collector surface, increased from 36 to 50 percent. Or, in economic terms, the value added to the system is 39 percent without appreciable cost increase.

While increased system efficiencies continues to be an important objective of this task, it is recognized that other factors are critical to owner acceptance of solar heating. Comfort, convenience, and physical compactness of systems are equally important and shall be addressed in the project.

A companion objective is the improvement of indoor air quality by use of increased ventilation levels to the space while it is heated. Awareness of radon, formaldehyde, and other pollutants within tightly constructed buildings has brought this matter to a new importance.

The principal objectives of the 1991 solar heating project are to develop control options and to model the use of flat plate collectors and dual temperature zone, single tank storage for isothermal operation.

Work Plan:

1. Model the effects of employing commercial type flat plate collectors in isothermal operation under different load patterns and solar availability.

It is proposed to model the performance of flat plate collectors under isothermal operation. The flat plate collector will respond somewhat differently to isothermal control due to greater environmental sensitivity of flat plates compared with the presently employed evacuated tube type. We expect that isothermal control will benefit flat plate systems even more than evacuated tube systems.

2. Model the effects of a single storage volume capable of maintaining two temperature zones of 25 C (or greater) difference.

The use of a single, but highly stratified, storage unit will be modelled. This will be performed in order to specify the best

design, geometry, or configuration such as multiple smaller tanks in series.

3. Simulate and assess the use of solar (radiation) sensor controlled collector pump as a means of approximate isothermal collector operation without temperature feedback control.

Perfecting this control strategy could simplify the hardware and/or permit the use of a PV-powered pump.

4. Identify motor/pump units which will provide variable volume flow efficiently and economically.

Under this effort, we will collaborate with motor and pump manufacturers to select or develop an appropriate variable speed pumping system for typical solar heating systems.

5. Introduce advanced control strategies to control collector loop flow.

The present system will be operated with a newly installed PC computer data acquisition/control system. This system will be used to test the best strategies for pump control for isothermal operation. Problems associated with pump start-up for the drainback system need to be resolved and tuning criteria need to be developed.

Progress:

Activity during January and February was devoted to analysis and plans for presentation of results from the TRNSYS heating simulations. Time and effort of the project staff was primarily devoted to cooling simulation due to the contract sequence.

GENERIC SOLAR DOMESTIC WATER HEATING SYSTEMS

Research Team: Jane H. Davidson, Task Leader
William S. Duff, Co-Task Leader
Mark Thornbloom, Graduate Research Assistant
Steve Kenny, Graduate Research Assistant

Objectives:

Certification of any solar domestic hot water (DHW) system by the Solar Rating and Certification Corporation (SRCC) currently requires an extensive laboratory system test in addition to the collector test. This procedure places a significant economic burden on a low sales volume industry and reduces the overall cost competitiveness of solar DHW versus gas and electric systems.

A research program supported by the Department of Energy to investigate the feasibility of a more cost effective rating method for solar DHW systems is now in progress at the Solar Energy Applications Laboratory (SEAL) at Colorado State University in conjunction with the University of Wisconsin, Solar Energy Research Institute (SERI) and SRCC. The main thrust of the research is to determine if ratings of solar DHW systems can be accurately based on computer simulations. The immediate goal is to determine if the simulation program, TRNSYS, can accurately predict the performance of drain-back, recirculation, anti-freeze, thermosiphon and internal collector storage solar DHW systems.

Work Plan:

1. Experimental study of the anti-freeze system is currently underway and results will be presented in July at a group meeting to be held in Washington, D.C. Study will focus on heat exchanger design and operation and system flow rates.
2. The single test of the recirculation system will be completed later in the summer. This delay is due to an agreement by project participants that additional study of flow rates in the anti-freeze system are needed.
3. A generic systems program for thermosiphon and internal collector storage (ICS) SDHW systems will be initiated. Colorado State, in cooperation with SRCC, representatives from the U.S. solar industry, SERI, and University of Wisconsin, will develop and carry out an experimental study of these systems. A solar simulator will be added to current outdoor testing facilities at SEAL to accomplish this phase of the project.
4. Thermosiphon system performance will be investigated for a system using a wrap-around heat exchanger. Stratification in horizontal tanks will also be explored. It is expected that the thermosiphon work will be completed during this project period.
5. Study of the ICS system will focus on determining if an analytical ray trace can be used to accurately predict incidence angle modifiers

for three complex geometries (tube storage tank in a "bread box", tube storage tank with parabolic shaped collector, and tube storage tank in a tubular collector). The ICS experimental results will be completed in the 1992 budget period.

6. Additional efforts in the 1992 budget period include validation of an analytical approach for predicting performance of non-generic DHW systems such as the Copper Cricket.

Progress:

Discussions at the 1992 SOLTECH meeting in Albuquerque with project members from University of Wisconsin, Solar Rating and Certification Corp., Florida Solar Energy Center, National Renewable Energy Laboratory and the Department of Energy established future experimental needs for the in-collector storage solar DHW systems. In particular, plans are now underway to develop a testing plan to determine incidence angle modifiers, effects of background reflectance, tank stratification and heat-loss. Experimental analyses during the current funding period will focus on the NEG system. Additional tests with thermosiphon systems will be delayed until the next project period beginning March 1, 1992. Progress continues on construction of the solar simulator.

The paper "INFLUENCE OF HEAT EXCHANGER EFFECTIVENESS AND SYSTEM FLOW RATES ON EXPERIMENTAL RATINGS OF A GENERIC ANTIFREEZE SDHW SYSTEM" is completed and will be presented at the 1992 American Solar Energy Society meeting. A copy of the paper is attached.

INFLUENCE OF HEAT EXCHANGER EFFECTIVENESS AND SYSTEM FLOW RATES ON EXPERIMENTAL RATINGS OF A GENERIC ANTIFREEZE SDHW SYSTEM

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ABSTRACT

Effects of heat exchanger design, collector-loop flow rate, and recirculation flow rate on the thermal rating of a generic antifreeze solar domestic hot water heating system are experimentally investigated in 11 Solar Rating and Certification Corporation OG-200 rating trials. Collector-loop flow rates are varied from 0.057 l/s to 0.228 l/s, and recirculation flow rates from 0.043 l/s to 0.176 l/s. Two double-walled heat exchanger designs are tested: a counter-flow U-shaped tube-in-tube with micro-fins and a counter-flow 8-pass tube-in-tube without fins. Heat exchanger effectiveness varies from 0.164 to 0.343. Collector area and tank volume are held constant at 5.56 m² and 246 l, respectively. Over the ranges examined, system performance is insensitive to changes in heat exchanger effectiveness above 0.17. In the absence of stratification, lower recirculation flow rates are not advantageous. Reductions in collector flow rate cause higher collector operating temperatures and reduced thermal output without any benefit to heat exchanger performance.

1. INTRODUCTION

Performance of a solar domestic hot water (SDHW) system is strongly dependent on operating parameters and component specifications. Collector performance and size have the largest impact on system energy output. However, tank stratification, parasitic power, and heat exchanger effectiveness, ϵ , can also influence system temperatures and overall efficiency. Antifreeze provides excellent protection against freezing and scale build-up. However, in many locations, its use requires the installation of a double-walled heat exchanger. In this case, lowered heat exchanger effectiveness may degrade system performance.

The Solar Rating and Certification Corporation (SRCC) OG-200 (1) rating test is used to study performance of a generic antifreeze (50%) SDHW system in a parametric study of system flow rates and heat exchanger design. Eleven rating trials are conducted for a fixed collector area of 5.56 m² and a constant tank volume of 246 l. Collector-loop flow rates are varied from 0.057 l/s

to 0.228 l/s. The collector manufacturer recommends a flow rate of 0.114 l/s for this collector area. Recirculation flow rates are varied from 0.043 l/s to 0.170 l/s. Conventional water flow rates are normally 0.19 to 0.25 l/s. Two double-walled heat exchanger designs are tested: 1) a counter-flow U-shaped tube-in-tube with micro-fins and a heat exchange area of 0.214 m², and 2) an 8-pass counter-flow tube-in-tube with heat exchange area of 0.279 m². The U-tube heat exchanger is also tested in an inverted orientation with the inlets at the bottom.

2. EXPERIMENTAL FACILITY

The SDHW rating facility is located in one of five 2-story residential style solar heated and cooled buildings at the Solar Energy Applications Laboratory. Water tanks, pumps, and heat exchanger are placed at ground level. Collectors are positioned at a 45 degree angle in a darkened, climate controlled space between an outer false roof and a weather-tight inner house roof. Solar radiation input is simulated by an in-line electric heater located downstream of the collectors. A detailed description of the facility is included in Carlson (2).

System control (including pumps, electric heater, and water draws) and data acquisition and analysis are integrated around a 80386-based personal computer system. Temperatures, temperature differences, flow rates and parasitic power are monitored throughout the facility as shown in Figure 1. Temperatures are measured with copper-constantan thermocouples (± 1 deg C) and temperature differences are determined with 5-junction thermopiles ($\pm (1\% \text{ of reading} + 0.05 \text{ deg C})$). Volumetric fluid flow rates are measured with turbine meters ($\pm 0.5\%$ linearity, standard error ≤ 0.001 l/s). Mass flow rates for water draws are also measured with turbine flow meters (standard error ≤ 0.0002 kg/s). Electrical energy consumption is measured using Watt transducers.

A description of the SDHW system is given in Table 1. Pump sizes vary due to higher pressure drops across the 8-pass heat exchanger at higher flow rates.

TABLE 1 COMPONENT SPECIFICATIONS

Component	Specification	Value	Notes
Collector loop fluid	50/50 ethylene glycol	Property values from ASHRAE Fundamentals	
Collector	Total Area	5.56 m ²	
	F _r α	0.602	
	F _r U _l	5.55 W/m ² /K	
	b _o	0.42	
	K ₁ α @ θ = 0	1.00	
		15	0.97
		30	0.90
		45	0.75
		60	0.58
	mC _p /Area (test)	74.0 W/m ² /K	1
Solar Storage Tank			
	Volume	246 liter	2
	R-Value	2.10 C m ² /W	
Auxiliary DHW	Volume	159 liter	2
	R-Value	2.10 C m ² /W	2
	Set Point	55 C	
Heat Exchanger			
1	Counter flow, copper, double wall, micro-finned		
	Heat exchange area	0.214 m ²	2
2	Counter flow, 8-pass, copper, double wall, no fins		
	Heat exchange area	0.279 m ²	2
Pumps:			
Collector	Type	Grunfus	2,4
		UP 15-42-F	
		Nominal 85 W	
		Grunfus	5,6
		UP 26-96F	
		Nominal 205 W	
Recirculation	Type	Grunfus	2,4
		UP 15-18SU	
		Nominal 85 W	
		Grunfus	5
		UP 15-42-F	
		Nominal 85 W	
		Grunfus	6
		UP 26-96F	
		Nominal 205 W	
Piping	Size and Type		
	Insulation Type	Closed Cell Foam 1.9 cm	
	Insulation R-Value	0.82 C m ² /W	
	Lengths:		
	Heat Exchanger to Collector	10.82 m	3
	Collector to Loop Heater	1.39 m	3
	Loop Heater to Heat Exchanger	11.71 m	3
	Heat Exchanger to Solar Storage Tank	2.90 m	3
	Solar Storage Tank to Heat Exchanger	3.15 m	3
Valves	Type	Gate	
	Size	19 mm	
Notes	1.	Value pertains to time of collector rating test.	
	2.	Manufacturer's rating.	
	3.	Value is based on measurements made in laboratory.	
	4.	Used in all Trials with HX 1, ie. Trial 1-4, and 9-10; and Trials 6 and 11 with HX 2.	
	5.	Used in Trial 8	
	6.	Used in Trials 5 and 7

Figure 1. Schematic of Antifreeze System

3. METHODOLOGY

The SRCC short-term rating procedure evaluates the steady-state performance of a SDHW system during four days. Environmental conditions and water load demands are specified as shown in Table 2. Daily hot water load is based on three equal draws at 8:00, 12:00, and 17:00. In these rating trials, the specified daily water draw is increased from 42.3 MJ to 49.8 MJ to conform with load specifications for conventional DHW systems (3). The in-line heater input is controlled according to the specified hourly solar profile and calculations outlined in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 95-1987 (4). Collector characteristics are determined in a separate ASHRAE Standard 93-1986 test (5).

TABLE 2 SRCC RATING SPECIFICATIONS

Quantity	Specification
Ambient Temperature	22 ±2 deg C
Mains Water Temperature	22 ±1 deg C
Total Daily Insolation	17.03 MJ / m ²
Total Daily Hot Water Load	42.3 MJ
Minimum Hot Water Temperature	35 deg C
Hot Water Draw Flow rate	0.2 kg/s
Auxiliary Heater Set Point	48.9 deg C

A schematic of most of the SRCC energy quantities is shown in Figure 2. Energy delivered by the solar

collectors is Q_u . Energy drawn from the solar storage tank, Q_s , minus the parasitic energy used by controllers and pumps, Q_{par} , is Q_{net} . Daily energy input into the auxiliary hot water heater is Q_{aux} . Daily energy delivered to the load is Q_{del} . Reserve energy left in the solar storage tank at the end of the test is Q_{res} . Capacity of the system, Q_{cap} , is the amount of energy the system can deliver without solar input.

Figure 2. Schematic of SRCC Energy Quantities

A system rating test is completed when the daily value of auxiliary energy, Q_{aux} , is within 3% of the previous day's value. The test is terminated after four days if convergence is not obtained. System thermal rating is based on daily energy quantities measured on the last day of testing if convergence is achieved. If a test does not converge, the average of daily quantities determined during the last two days is used to establish system rating. Daily energy quantities are calculated from measured temperature differences and flow rates as shown in the Appendix.

Heat exchanger effectiveness, the ratio of actual heat transfer across the heat exchanger to the maximum heat transfer possible between the hot and cold fluids, is given by,

$$\epsilon = \frac{(\rho(T_h)C_p(T_h)V_2(T_h - T_7))}{[(\rho(T)C_p(T)V)_{\min}(T_3 - T_7)]} \quad (1)$$

Number subscripts refer to the transducer locations shown in Figure 1. Effectiveness is calculated every fifteen minutes and averaged to provide a daily ϵ . Instabilities in ϵ that occur at the beginning and the end of the day are not included in the daily average.

4. RESULTS

Daily energy values and average daily heat exchanger effectivenesses are listed in Table 3 along with the flow rates and heat exchanger used in each of the 11 rating trials. The collector-loop antifreeze mixture is in the inner tube in the U-configuration and in the outer tube in the inverted position. The antifreeze flow is always in the outer tube of the 8-pass heat exchanger.

It is apparent in all 11 trials that use of a double-walled heat exchanger reduces heat exchanger effectiveness. In comparison to daily values of $\epsilon < 0.35$, effectiveness of a simple in-tank coiled copper tube heat exchanger, used in SRCC tests of a generic drain back SDHW system, never dropped below 0.40 and was as high as 0.60 (2).

Daily values of useful collected energy, Q_u , energy delivered from the solar storage tank, Q_s , and net energy delivered from the solar system, Q_{net} , are plotted as functions of heat exchanger effectiveness in Figures 3, 4 and 5, respectively. Data points are labeled by trial number. Measurement errors are calculated for each trial by combining transducer errors using a root sum

TABLE 3 SUMMARY OF EXPERIMENTAL RESULTS

Trial	Heat Exchanger Type	Collector Flow Rate [l/s]	Recirculation Flow Rate [l/s]	Effectiveness	Solar Fraction [%]	Q_s [MJ]	Q_{net} [MJ]	Q_{res} [MJ]	Q_{aux} [MJ]	Q_{par} [MJ]	Q_u [MJ]
1	1	0.114	0.170	0.308	41.2	24.8	20.5	18.0	29.9	4.3	31.1
2	1	0.114	0.085	0.266	39.6	24.0	19.7	17.3	30.6	4.2	30.0
3	1	0.228	0.170	0.242	44.3	26.4	22.0	19.6	28.7	4.4	31.2
4	1	0.228	0.085	0.324	41.7	25.2	20.8	18.2	29.7	4.4	29.7
5	2	0.114	0.170	0.226	36.2	24.3	18.0	18.5	31.8	6.3	29.3
6	2	0.114	0.085	0.343	42.0	25.2	20.9	18.0	29.8	4.3	30.6
7	2	0.228	0.170	0.180	37.8	25.5	18.8	19.1	30.1	6.6	30.0
8	2	0.228	0.085	0.290	34.6	23.6	17.3	18.1	31.8	6.3	29.9
9	1*	0.114	0.176	0.164	33.2	20.9	16.6	16.1	34.3	4.3	28.1
10	1*	0.114	0.095	0.167	33.8	21.1	16.8	15.8	33.8	4.3	27.8
11	2	0.057	0.043	0.316	36.1	22.4	18.0	15.1	32.6	4.4	28.5

* Inverted Heat Exchanger: Inlets are at the bottom

Figure 3. Useful Collected Energy as a Function of Effectiveness.

Figure 4. Solar Energy Supplied to Load as a Function of Effectiveness.

Figure 5. Net Solar Energy Supplied to Load as a Function of Effectiveness.

square method. Experimental error is assumed to be $\pm$ two standard deviations. Error bars for ϵ are daily averages of the 15 minute instantaneous errors. Caution must be taken in interpreting net energy delivered. Although this quantity is calculated by subtracting the thermal equivalent of electrical input to the two pumps from Q_u , only a portion of the pumping power is returned to the fluid as heat. Thus, in trials using larger pumps, i.e. Trials 5, 7 and 8, Q_{net} is reduced disproportionately compared to the other trials.

Only in Trials 9 and 10, in which effectivenesses are on the order of 0.17, is there a drop in energy output outside the error bands of the other trials. Low values of ϵ in these inverted heat exchanger trials are probably caused by air trapped at the top of the tube. Otherwise, the data do not show a strong correlation between ϵ and Q_u , Q_s or Q_{net} over the range of variables tested. However, a comparison of Trials 5 and 9, which have equivalent flow rates, shows that a 27% decrease in ϵ from 0.226 to 0.164 causes a 4% decrease in Q_u and a 14% decrease in Q_s . This trend is supported by comparison of Trials 2 and 10, which also have similar flow rates. With a 37% decrease in ϵ from 0.266 to 0.167, Q_u decreases by 7% and Q_s decreases 12%.

Reducing the recirculation flow rate from 0.170 l/s to 0.043 l/s does not affect tank stratification. With the lowest recirculation flow rate, Trial 11 has the greatest potential for stratification, yet the plot of tank temperatures, shown in Figure 6, indicates that the tank is fully mixed except during night hours. The lag in water temperature at the bottom of the tank (T32) results from incomplete circulation of the tank volume due to location of the drop tube 0.06 m above the bottom of the tank. Without tank stratification, there is no advantage to reducing storage-side flow rate unless pumping power can be reduced significantly.

Figure 6. Solar Storage Tank Temperatures for Trial 11.

The disadvantage of low flow rates when stratification is not achieved is evident in the Trial 11 results. Despite a relatively high average ϵ , this system is inferior to all the other configurations except those of Trials 9 and 10 in which the inverted heat exchanger is used. In Figure 7, comparison of collector inlet temperatures in Trials 1 and 11 with nearly equal values of ϵ but different collector-loop flow rates shows that in Trial 1, the higher collector-loop flow rate reduces collector operating temperatures throughout the day.

Figure 7. Collector Inlet Temperatures of Trials 1 and 11.

5. CONCLUSION

In a generic antifreeze SDHW system, thermal output is insensitive to changes in heat exchanger effectiveness from 0.18 to 0.35. With equivalent flow rates, system performance is only degraded when effectiveness drops below 0.18. In the absence of stratification, higher collector and recirculation flow rates lead to better system performance, in spite of lower effectiveness.

6. ACKNOWLEDGEMENT

The support of the U.S. Department of Energy through grant No. DE-FG03-SF-16306 is gratefully acknowledged.

7. NOMENCLATURE

b_o	=	dimensionless constant used in incident angle modifier calculation
C_p	=	specific heat, kJ/kg/K
F_r	=	collector heat removal factor
$K_{\tau,\alpha}$	=	empirical incident angle modifier
m	=	mass flow rate, kg/s
Q	=	daily energy, kJ
T	=	temperature, deg C

t	=	time, s
UA	=	overall heat transfer coefficient, W/C
U_1	=	collector heat loss coefficient, W/m ² /C
V	=	volumetric flow rate, l/s

Greek Letters

θ	=	incident angle
ρ	=	water density, kg/m ³
$\tau\alpha$	=	transmittance absorptance product for collector
ϵ	=	heat exchanger

Subscripts

a	=	ambient
aux	=	auxiliary
cap	=	refers to energy capacity of system without solar input
del	=	refers to hot water energy delivered by system
dl	=	refers to desired hot water energy load on system
l	=	laboratory
loss	=	energy loss
lh	=	loop heater, refers to collector loop heater energy input
main	=	water main
net	=	net energy delivered from preheat tank
p1	=	collector loop pump, energy consumed by collector loop pump
p2	=	recirculation loop pump, energy consumed by recirculation loop pump
par	=	parasitic energy consumption
res	=	reserve energy in preheat tank at end of test sequence
s	=	solar, refers to hot water energy delivered from preheat tank
u	=	useful, refers to useful energy gain of fluid through collector array

8. REFERENCES

- (1) Solar Rating Certification Corporation, Operating Guidelines for Certifying Solar Water Heating Systems, Document OG-200, Washington, D.C., (1984).
- (2) Carlson, W.T., Comparison of Experimental and TRNSYS SRCC Ratings of a Generic Drain Back Solar Water System, Master's Thesis, Colorado State University, Fort Collins Colorado (1990).
- (3) Federal Trade Commission, Uniform Test Method for Measuring the Energy Consumption of Water Heaters, Code of Federal Regulations, 10 CFR Ch. II, Part 430, Subpart B, Appendix E (1989).

(4) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems, Standard 95-1987, Atlanta, Georgia (1987).

(5) American Society of Heating, Refrigerating and Air-Conditioning Engineers, Methods of Testing to Determine the Thermal Performance of Solar Collectors, Standard 93-1986, Atlanta, Georgia (1986).

9. APPENDIX

The following equations are used to calculate the SRCC daily energy quantities.

$$Q_u = \int_{t=08:00}^{t=17:00} \rho(T_1) C_p(T_1) V_1 (T_4 - T_2) dt \quad (A.1)$$

$$Q_{del} = \int_{t=0}^{t=(Q_{del}-Q_u)} \rho(T_{15}) C_p(T_{15}) V_4 (T_{15} - T_{10}) dt \quad (A.2)$$

$$Q_s = \int_{t=0}^{t=(Q_{del}-Q_u)} \rho(T_{11}) C_p(T_{11}) V_3 (T_{12} - T_{11}) dt \quad (A.3)$$

$$Q_{res} = \int_{t=0}^{t=(T_{12}-T_{10}+3^\circ C)} \rho(T_{11}) C_p(T_{11}) V_3 (T_{12} - T_{11}) dt \quad (A.4)$$

$$Q_{comp} = \int_{t=0}^{t=(T_{15}-35^\circ C)} \rho(T_{15}) C_p(T_{15}) V_4 (T_{15} - T_{11}) dt \quad (A.5)$$

$$Q_{net} = Q_{del} - Q_{aux} + Q_{loss} - Q_{par} \quad (A.6)$$

$$= Q_s - Q_{par} \quad (A.7)$$

$$Q_{par} = Q_{p1} + Q_{p2}$$

ADVANCED SOLAR DOMESTIC HOT WATER (DHW) SYSTEMS

Research Team: William S. Duff, Task Leader
Jane H. Davidson, Co-Task Director
Ron Hill, Graduate Research Assistant

Objectives:

In the next few years, a renewed United States mass market for residential solar DHW systems is expected to develop as heightened environmental concerns spawn legislation and other incentives for alternative energies and energy conservation. This market will be accessible to products from other countries that are currently being developed with substantial research and development support from their governments. For United States manufactured solar DHW systems to remain competitive, cost effective solar DHW systems employing advanced materials, components, and concepts must be developed.

A research project funded by the Department of Energy to identify, analyze, design, build, and experimentally evaluate such solar DHW systems is currently underway at the Colorado State University Solar Energy Applications Laboratory. The objective of this project is to substantially lower costs and improve performance of commercial solar DHW systems in the United States. Several United States manufactured solar DHW systems with desirable features will be chosen as starting points for the design improvement process. As a means of identifying many promising materials, components, and concepts, this project is participating as the United States solar DHW installation in the International Energy Agency Task on Advanced Solar Energy Systems. Results from this project, as well as results from the International Energy Agency activities, will be disseminated to the United States solar energy industry.

Work Plan:

- 1) Represent the United States DOE as the United States Advanced DHW project leader in IEA Task XIV. This activity includes preparing reports on the United States single-pass and internal collector storage DHW systems work and discussing this and other United States solar DHW work at the meetings.
- 2) Represent the United States DOE as the leader of the IEA Task XIV working group. This activity includes preparing for and leading the working group meetings, summarizing the results, preparing the working group work plans, reminding participating countries of their deadlines, and working with the Task XIV Operating Agent to insure that working group goals are met. (In a later contract period this activity will include writing a Task XIV Advanced DHW Systems report.)
- 3) Report other information to working group participants as may be necessary.
- 4) Simulate the behavior of single-pass solar DHW system variable flow and radiation switch controllers. Study the effects of stratification and stratification enhancing devices. Develop a systems simulation for the single-pass DHW and baseline systems that incorporates component models developed by us, SERI, and other participating IEA countries. Develop an optimum design for the single-pass system based

on cost, performance and reliability. Prepare a plan for building and testing this system.

- 5) Assemble and integrate the Colorado State University Generic Systems incident angle modifier studies and other work for the Internal Collector Storage systems into IEA Task XIV activities.
- 6) Communicate the results and planned activities of the Colorado State University Advanced DHW task to the United States solar industry.

Progress:

Activities in the Advanced SDHW Systems Task focused on preparations for and attendance at the January 27 through 31 International Energy Agency Solar Heating and Cooling Program (IEA) Task XIV (Advanced Solar Energy Systems) Experts meeting. Other activities in this period included: 1) modeling the American Solar Network (ASN) SDHW system, 2) meeting with Al Rich of American Solar Network regarding technical aspects of ASN SDHW systems, 3) organizing two papers on results of the Task for the June 1992 ASSES meeting, 4) serving on the technical Committee for the June ASSES meeting, 5) meeting with Konrad Schreitmüller, Associate Director of the Institut für Solarenergieforschung in Hanover regarding advanced SDHW modeling, and 6) attending the SRCC and SEIA meetings at SOLTECH.

As a result of insufficient funding, experimental activities programmed for the next contract period will be delayed. As some of these activities were obligated as part of the United States participation in IEA Task XIV, renegotiation with IEA in regard to United States commitments will be necessary.

The following is a summary of activities at the January 27 through 31 IEA Task XIV meeting:

SOLAR DHW MODELING WORKSHOP

A pre-meeting workshop on SDHW modeling was held on the Monday before the task meeting. Dynamic collector models were the subject of much discussion. When collector fluid time constants are long, as they are in many matched flow SDHW systems, steady state collector models, such as those currently available in TRNSYS, are thought to be inaccurate. Sweden is in the final stages of developing a dynamic collector model for TRNSYS which will be evaluated by the United States and other Task XIV countries participating in the Advanced SDHW Working Group. Among other points, a successively more comprehensive sequence of collector modeling formulations was presented by Switzerland, with one intermediate formulation much like the inlet temperature/collector heat removal factor linear Hottel, Whillier, Bliss (HWB) relationship favored in the United States. The most comprehensive version collapses the dependence of the loss coefficient on a temperature difference back into a linear HWB form by redefining coefficients. An important point generally agreed upon was that the use of three arbitrary parameters in a second order model, or two in a first order model, tends to hide important physically interpretable attributes of the collection system.

ADVANCED SOLAR DHW PROJECT ACTIVITY REPORTS

Project activity reports by the participants in the Air Systems, Domestic Hot Water, and Large Systems Working Groups were presented in the main part of the meeting. Individual reports were distributed at that time.

ADVANCED SOLAR DHW WORKING GROUP MEETING

The meeting was led by Dr. William Duff. The primary emphasis of the meeting was on component development.

Daily and day-to-day load profiles and sensitivity analyses

USA: The United States presented a simulation of the effect of storage volume on solar fraction when the day-to-day load variations were unchanged, small, moderate, and severe. If the day-to-day load variation was unchanged, the same solar fraction was obtained with both the 190 and 300 liter storages. Substantially better solar fractions were obtained with the 300 liter storage when the day-to-day load variation was small or moderate. The 300 liter storage gave a somewhat better solar fraction with the severe variation.

Absorbers

NL: A low flow absorber has been designed, based on the available information of Terry Hollands and Heitech (Dutch consultant). The trade-off between material reduction, technical possibilities and price consequences resulted in an absorber design with the following specifications:

- o copper sheet, spectral selective: thickness 0.2 mm.
 - o piping: copper 6 mm ID, possible 8 mm because of the drainback function. There is no experience with 6 mm draindown tubing. This will be investigated.
 - o fin-width: 90 mm.
- absorber: serpentine configuration.

CH: Presently an MTI absorber is used. The Omegasun, as reported, turns out to be too expensive. There are some thoughts of making a fin-tube absorber by an extrusion process. The minimal thickness of the fin will be in the range of 0.7 mm due to the capabilities of the extrusion process. The group expressed concern that this will lead to much too great material content and therefore too high a price.

USA: A UV-protected polycarbonate collector with an EPDM absorber has been on the market for four years. This product seems to be durable and inexpensive. A passive venting device is used to prolong the lifetime. The United States is interested in this material because of its low cost potential. There are some concerns from the group about durability, heat conductivity, and efficiency. This will be a primary subject of further research by Colorado State University.

Piping

NL: A search has been conducted to find a suitable Dutch produced flexible piping material. There is no such material available at the moment.

USA: 1.2 cm polybutylene piping is currently used in installation of the ASN system. This material is somewhat flexible and installs quickly. Smaller diameters are thought to be available.

CH: In Switzerland the test facility has sometimes used Gerberit-Mepla 10 mm ID for the test systems. Occasional higher temperatures as allowed did occur without visible problems. However, there is some advice not to exceed 95 °C. The material is relatively cheap. There are three other options available: Teflon, Silicon and PVDF. These materials are supposed to withstand temperatures greater than 100°C. No durability tests on these materials are foreseen, except for the application in test facility.

CAN: The "old" lifeline tubing had problems with temperature and pressure exceeding the allowed limits. Dupont seems to have new material, which would meet the requirements. The lifeline consists of two nylon tubes and a sensor wire. The lifeline must be insulated. The price is approximately \$6.00 per meter.

Storage tank/heat exchanger

DK: A side-by-side test has been carried out with a mantle and an external heat exchanger. The tank with an external heat exchanger worked with a thermosiphon loop in the tank, from the heat exchanger. This heat exchanger provides 200 W/K capacity when using a 4 m² collector. Test results showed a considerably lower system output with the external heat exchanger as compared to the mantle heat exchanger. It seems clear that the efficiency of the heat exchanger influences the thermosiphon effect negatively. The alternative of introducing a pump to replace the thermosiphon loop is not considered to be cost effective.

CH: There is one new heat exchanger design for enhancing stratification of the tank. It is possible to incorporate the new design in the tank manufacturing process. Eventually a number of newly designed heat exchangers with stratification devices will be built and tested.

D: There is a tank on the market with a stratification device. This tank has a standard vertically-mounted, integrated electrical auxiliary heating element. During tests, the electrical element interacted with solar input. Therefore, the test results of the tank with its stratification device and the external heat exchanger are a little disturbed. Test procedures will be continued without the electrical element in operation. Backup heating will be supplied by an in-line auxiliary heater.

NL: A thorough study on helix heat exchangers has been carried out. Both a fundamental research model, as well as a more general approach, show no significant differences in the efficiencies of properly designed mantle and helix heat exchangers. If this is true, then final cost and durability will govern the choice among these types. A side by side test should provide additional proof.

USA: The United States is examining the use of an internal heat exchanger for variable flow systems and constant low flow with a stratification manifold.

Auxiliary

- DK: In Denmark research showed that the location of the electrical auxiliary heater in the top of the tank is critical. A vertical position is giving bad results. It is better to have the auxiliary element inserted horizontally at a some distance from the top. This experience is shared by Germany.
- CAN: According to Tony Caffel there are indications that side arm heat exchangers with internal auxiliary connected through a thermosiphon loop to the tank perform better than integrated auxiliary heaters. This might not be true if the auxiliary part of the tank is more or less separated from the solar tank.
- NL: The development of an integrated gas auxiliary heater is progressing according to plan. The first test unit has been built and tested. On the burner side, some more work has to be done in order to meet environmental and stiff efficiency demands for this product. The auxiliary tank is separated from the solar tank, although it is one unit.

Pump

- CAN: The first phase of the pump development from Negentropy has been finished. The Netherlands will obtain a prototype pump to do reliability tests. Conclusions are mentioned in the report. Time span for Phase II will range from 6-14 months (hopefully closer to 6 months).
- NL: The intermittent pump has been developed using a Grundfos UPS25/40 pump. The energy use will be reduced to approximately 13 W, which includes the electronics. The United States is interested in obtaining one pump to run durability tests. In addition, a Bosch pump is presently being tested for durability. Results are favorable so far and the price looks good. Durability tests will continue for a few more months.

Control unit

- NL: The control unit under development will produce a number of advantages. The work is not finished.
- CAN, CH, USA: Switzerland, Germany, and the United States are interested in variable flow strategies. The research on this subject will include both photovoltaic driven strategies and other experimental methodologies. Canada will supply these countries with the necessary algorithm.

Medium

- NL: Since glycol is not permitted in the Netherlands, the systems must have a drain-back capability. Thus, there is uncertainty about the pipe diameter (both for the absorber and the piping). The objective is to work with 6 mm ID pipe, but it might be necessary to change to 8 mm ID pipe. Test results will decide this.

CAN: The use a potassium carbonate (hydrated) brine was suggested. The United States found a paper on this issue. This approach may improve the effectiveness of the medium considerably. The viscosity and density is supposed to be comparable to that of water. Further information is not available at this time.

D: Germany reported that brines had been considered in the past by the air conditioning industry.

System

Canada offered to provide the ThermoDynamics system to any interested country for testing.

Many systems issues were addressed as part of the discussions on components in agenda items 2 through 8. One systems issue surfaced that is also germane to reporting: there were two different definitions of solar fraction being used. One was the load less auxiliary, the quantity divided by the load. The other was solar delivered divided by the quantity solar plus auxiliary. The different measures of performance may lead to different conclusions. If two tanks are used, as is commonplace in North America, the solar storage tank and the conventional DHW tank, the options become even more varied.

Format and reporting

Further discussion was held regarding mandating more explicit definitions of system and subsystem performance parameters so as to enable unambiguous communications when reporting results within the task. After much debate, a subgroup was assigned to develop such definitions in a parallel session of the SDHW Working Group meeting. The results of the subgroup's efforts are to be incorporated into the Task XIV Monitoring Guidelines.

Concept TXIV matched flow

An ideal matched flow concept, free of all national constraints, is to be collectively designed. A list of collector, piping, pump/control, and storage/heat exchanger considerations for this ideal concept, called the Matched Flow Dreaming List, was distributed. Participants were asked to submit their conclusions about the most desirable specifications for an ideal matched flow system after the meeting.

In addition to the ideal matched flow concept, a second level national ideal was to be specified by each participant, where only the most overriding national constraints were to be included. Finally, a third level concept, which included all appropriate national constraints and advantages, would be designed by each participant.

Copper Cricket cooperation

The United States and the Netherlands are interested in cooperating on an investigation of the Copper Cricket SDHW system. A donation of two systems will be sought. The following issues are of interest:

Stratification
Underpressure-caused leakage

Amount of thermal energy consumed for pumping
Heat exchange area influence on performance
Performance of different organic fluids
Stagnation and overheating

Integral collector storage SDHW systems

The United States, the Netherlands, and Germany will pursue an integral collector storage cooperation. The following concepts are of interest:

NL: An annular heat pipe integral collector storage system exists. Testing it is contemplated. A plastic integra collector storage SDHW system has been conceptualized.

USA: A cylindrical tank in an evacuated tube integral collector storage SDHW system is commercially available. Experimental evaluation is anticipated. Tanks with a trapezoidal reflector and tanks in a flat plate collector are other concepts of interest.

Inquiry

A questionnaire put together by Michael Mack was circulated. It asked for answers to questions about national SDHW activities.

LIQUID DESICCANT COOLING SYSTEM DEVELOPMENT

Research Team: Terry G. Lenz, Task Leader
Shailesh Potnis, Graduate Research Assistant

Objectives:

Primary objectives of this project include the development, testing, and performance evaluation for a liquid desiccant cooling system on Solar House II at Colorado State. Our existing experimental cooling system comprises solar collectors, two simple packed-bed contactors (a dehumidifier and a regenerator), heat exchangers, blowers, pumps, air pre-conditioning equipment, and data-acquisition hardware, as shown on the accompanying schematic diagram.

Work Plan:

1. Determine the characteristic mass transfer dimension for our Tripak random packing.
2. Obtain water diffusivity data for concentrated liquid desiccant solutions.
3. Carry out further mass transfer studies on the dehumidifier to complete the reciprocal coefficient analysis for random Tripak packing and structured Munters packing.
4. Conduct detailed mass transfer studies on the regenerator, analogous to those carried out on the dehumidifier, to assess the relative resistance to mass transfer for the gas and liquid films.
5. Provide bi-monthly progress reports and a final technical report covering our liquid desiccant system work.

Progress:

A short form was submitted to the department of Environmental Health Services in order to obtain permission to carry out diffusivity studies using tritiated water [TOH, β -emitter]. The form has been accepted and permission has been granted to conduct the experiments without any major changes in the proposed procedure or any special training. A copy of the shortform is attached.

A survey of standard diffusivity measurement methods was carried out and a suitable combination of these methods was developed to meet the requirements. The method proposed is similar to the twin bulb method to obtain the simplicity and high reliability of this method; however, the bulb volumes are significantly smaller. The smaller volumes (5 ml, each) help in reducing the duration of the experiment from several days to seven hours. However, as the volume of the bulb decreases, the amount of solution in each bulb decreases and this may lead to a violation of the steady state assumption, implicit in Equation 1 in the earlier report. This assumption implies the presence of a large amount of solution in the bulbs relative to the capillary. A similar assumption also applies to the development of the diaphragm cell method, and the volumes of the chambers usually used in this method are comparable to volumes of the bulbs proposed. Therefore, the design criteria developed for the diaphragm cell method were used for

the design of twin bulb apparatus after appropriate modifications. The chambers are analogous to the bulbs, and the diaphragm separating the two chambers is analogous to the capillary joining the two bulbs. The design criteria for the diaphragm cell method is:

$$V_{\text{diaphragm}} \ll V_{\text{chamber}} \quad - (1)$$

where V = volume.

Therefore, the criteria used for the design is:

$$V_{\text{capillary}} \ll V_{\text{bulb}} \quad - (2)$$

A capillary of 1.47 mm diameter and 30 mm length was chosen to meet this criteria ($V_{\text{capillary}} \approx 0.05$ ml). The apparatus is shown in Figure 1. The requirement of the valve in the capillary is eliminated by providing a teflon stopper in one of the bulbs. This modification reduces the number of joints in the capillary and thus reduces the end effects.

The procedure proposed to conduct these experiments will be similar to the twin bulb procedure discussed in the earlier report, with a minor modification. Instead of injecting TOH, a known amount of TOH will be used along with water to prepare the LiBr solution in one of the bulbs while the other bulb will be filled with LiBr solution in pure water. This modification will eliminate the possibility of disturbance due to injected volume and, thus, eliminate the need for large bulb volumes.

For a precise measurement of diffusivity of water in LiBr solution, it is essential to maintain a uniform temperature in both the bulbs and thus eliminate thermal diffusion. A constant temperature bath with a high accuracy is being purchased for this purpose.

Fig.1 Apparatus for measuring diffusion of water in LiBr solution

ENVIRONMENTAL HEALTH SERVICES MEMORANDUM

TO: *Les Tuley (Shaulish Potnis)* Radiological Health Sci.
MRB Bldg.
FROM: Radiation Control, C-206 Rockwell, by

Steven Lowman 2/25/92.

SUBJECT: Notice of Evaluation of a Short-Form Description of a proposed use of radioactive material.

Use of ^3H as TOH in diffusion experiment.

The attached description is accepted as consistent with the requirements of the CSU Radiation Control Manual for use of radionuclides.

Comments related to performance under this description:

*Waste liquid must not be disposed
to sewer.*

Expiration date *2/93*

A new description and new approval is required for work beyond the expiration date.

RADIATION PROJECT DESCRIPTION - SHORT FORM

The CSU Radiation Control Manual outlines the description needed for proposed uses of radiation. This form has been prepared as a convenience for those users who need to meet "short form" requirements.

Dr. Les Fraley
Assistant Professor

Dept. Radiological Health Sci.

Explained in the supplement

1. Who proposes this use?
(Project Supervisor)
2. What is Radiation Supervisor's
CSU affiliation?
3. What is the proposed use of radiation?
Describe steps of use in sufficient
detail to allow an evaluation of
adequacy of material and radiation
confinement.

If experimental animals are to be used, please attach a description of the kind and number of them, experimental facilities and procedures with them, expected excretion pattern of radioactive material and final disposition of the animals.

MRB building MR-115

MARCH 92 - March 93

Tritium, (^3H)

Liquid

TOH (Tritiated Water)

2 MBq (54.05 μCi) per use

20 MBq (540.5 μCi)

8 MR-115

Diagram attached.

Locked rooms and locked cabinets

Supplement attached

per day per month

per day per month

per quarter

4. Where is the work to be done?
5. Starting and completion dates.
6. Which radionuclides?
7. In what physical form?
8. In what chemical form?
9. Maximum activity of each radionuclide
in single order.
10. Maximum expected cumulative inventory
of each radionuclide.
11. Room(s) where your stock quantities will
be handled. Please attach a floor diagram
showing all areas where radiation will be
used or stored. Label on your diagram the
facilities necessary for the radiation
part of your work.
12. How will access to the experimental and
storage areas be restricted?
13. Rate of radioactive waste disposal?
(microcurie rate of each nuclide)
 - a. In liquid form to sewer?
 - b. As bagged solid animal waste to
sanitary land fill?
 - c. As non-animal waste for transfer to
RC Office for disposal?
 - d. Other (specify).
14. What means will you use to survey for
radiation and/or for radioactive
contamination?
15. List the names and ownership of intru-
ments that you will use to do this.

Wipe tests by Shulesh as trained by
Dr. Fraley

LSC (MR-115), Dr. Fraley,
Radiological Health Sci.

• IADIATION PROJECT DESCRIPTION - SHORT FORM
PAGE 2

New copies of this sheet should be filed as staff changes occur within a continuing project.

This page provides space for: 1. list of people associated with a project.
2. statement of delegated responsibilities within this project.

DEPARTMENT Agricultural and Chemical Engineering

Name of Project using Radiation Solar Cooling

Supervisor of this use of Radiation Dr. Les Fraley

Please list below employees and students who work on the project or who are exposed to radiation from materials used in the project.

For each person, show maximum activity of each nuclide that the person will handle.

NAME JOB TITLE

<u>Dr. Les Fraley</u>	<u>Assistant Professor</u>	
	<u>Radiological Health Sci.</u>	<u>Explained</u>
		<u>in the</u>
<u>Shailesh Patnis</u>	<u>Grad. Student</u>	<u>supplement.</u>
	<u>Agricultural &</u>	
	<u>Chemical Engineering</u>	

If not answered above:

a. Who maintains radioactive materials inventory records? Dr. Les Fraley

b. Who checks and keeps records on contamination and exposure levels?

Shailesh Patnis

Shailesh V. Patnis
Form completed by: Name (type or print)

02/24/92

Date

for RB.

Signature

Q. 3813

SUPPLEMENT

Q. 3813 -

TOH will be used as a tracer in ^{10ml} LiBr solution to measure the diffusivity using LSC. After the experiment the solution will be stored in bottles and will be kept in locked cabinets. Wipe test will be performed on each bottle before storing it in the cabinet. After all the experiments are over, the used solution (≈ 2 lit.) will be given to the ^{RC Office for eventual disposal at} ~~Department~~ of Hazardous Waste. There will be 60-100 experiments using 10 ml each.

Page 2.

The supervisor for this project will be Dr. Les Fraley. A total amount of 25 mCi of TOH will be purchased and stored as his inventory while, only 0.54 mCi will be made available to the graduate student, Shailesh, at a time. The funds required for this project will come through Prof. Terry G. Lenz's (Dept. Head, Agegie & Chem. Engrg.) project 'Solar Cooling'.

Fig. 25. MR-115 radioactive materials survey report form.

SURVEY REPORT. RAM LABORATORY. Date _____

Surveyor _____ Supervisor _____

Wipe #	Count Rate (c/s)	Exposure Rate Measurements	
		Location	(c/m) (mR/h)
1		A	
2			
3		B	
4			
5		C	
6			
7		D	
8			
9		Bkg	
10			
11			
12 (Blank)			

Survey and counting equipment used:

Type _____ Model number _____ Serial number _____
Type _____ Model number _____ Serial number _____

ANALYSIS OF ADVANCED SOLID DESICCANT SOLAR COOLING SYSTEMS

Research Team:

Charles C. Smith, Task Leader
George O.G. Löf, Senior Advisor
Douglas C. Hittle, Advisor
Ihsan A. Abbud, Graduate Research Assistant

Objectives:

Research on solar cooling with solid desiccant systems began with the ASK Energymaster unit in the summer of 1987. The first system employed a process known as the Pennington cycle. All of the conditioned air for cooling was supplied from the outside. It was dehumidified, and cooled by heat exchanger, then by evaporative cooling. This cycle exhibited the expected cooling capacity for the unit (3 tons), and a COP of 1.0. The following year an advanced cycle (SENC) was introduced which provides sensible cooling in the recirculated house air duct and yields a higher COP. The COP increased to approximately 1.5; however the capacity dropped substantially to the range of 1.0 to 1.5 tons.

The 1988 experiments were aimed primarily at increasing the capacity of the SENC cycle. The best available commercial cooling tower was not suited for this application. It provided too little residence time for the cooling water and wasted much of the dehumidifying effect provided by the ASK. The cooling tower was rebuilt with new packing, improved water distribution, and provisions for greater air and water flow adjustments. The duct cooling coil was also increased in size by fifty percent to better match the increased cooling tower capacity. Although these changes resulted in some improvement in the cooling capacity, the desired 3-ton target was not reached.

During 1989, important information was generated from an analysis based upon the tests of previous years. The analysis employed a TRNSYS computer model with values of specific engineering parameters based on the actual equipment used in the experiments. This work revealed that some earlier modeling used unrealistic performance values for components and thus explained partially the shortfall in experimental performance. Most important, the analysis revealed some improvement recommendations which involve adjustments in air flow, cooling water flow, and desiccant wheel speed. It was also shown that the cooling capacity could be significantly increased with modest increases in regeneration temperature. A major item identified in this study was a shortfall in the experimental cooling tower capacity.

In August of 1990 a meeting of Colorado State, ASK, and Texas A&M experts was held to review the status of the solid desiccant cooling project and offer recommendations for its future course. The findings of the Colorado State analysis were confirmed by this group. Evaluation of the results showed, moreover, that the desiccant wheel had not been dehumidifying up to specifications, and that there had been physical loss of the desiccant material itself. The desiccant wheel was resupplied with the proper quantity of lithium chloride.

Wheel speed and air flow adjustments were also performed. These improvements were tested for short periods and only with respect to ASK unit

performance (not the overall system performance), due to limited time and funding. These tests indicated that significant improvement in overall cycle performance is possible, both for the Pennington and SENC processes.

Work Plan:

The primary objective of the solid desiccant cooling project is to analyze and model the advanced, high efficiency cooling cycle based upon recent and increased knowledge of potential improvements. Specific tasks to be accomplished in this grant period include:

1. Summarize existing simulation and experimental results in a form and format to assist DOE program managers in the continued refinement of the solar desiccant cooling program.
2. Use TRNSYS to simulate the SENC solar cooling cycles using improved desiccant and heat wheel models (with the TRNSYS 13.1 and later versions).
3. Simulate and analyze the SENC cycle with separation of the process and building air streams through the cooling coil.

This modification has been reported as the CHILLC cycle, but with no performance information. By separating the process and building air streams at the cooling coil, two advantages are realized. A second law performance penalty is avoided by preventing the mixing of two streams of air at different psychometric conditions. Secondly, the process air flow rate can be optimized independently of the building air flow rate.

4. Simulate and analyze the SENC cycle with building return air used as supply air to the dehumidifier.

Another variation to the present SENC cycle which needs to be analyzed is one in which the building return air is used as supply air to the dehumidifier. One advantage of using the building return air is to again increase the air flow rate through the desiccant and heat exchanger elements of the system. A second advantage is that this air usually has lower humidity. Lower humidity conditions would not prevail at all times, and thus modeling of the overall performance is needed.

Progress:

Activities during January and February were devoted to development of a TRNSYS simulation deck for the Pennington (ventilation) solar desiccant cooling cycle. This simulation was developed in TRNSYS 13.1 for the first time and is organized into components and equations as shown in Figure 2.

The model is written to include constant temperature solar energy collection and also constant temperature supply from solar or conventional energy to the system regeneration. A nominal 10 KW (3 ton) cooling unit is assumed, with a building cooling load of three tons at the 97.5% design level. The variables to be considered are the regeneration temperature,

TRNSYS DECK FOR COOLING SIMULATION

Figure 2.

the regeneration flow rate (heat transfer liquid), and the collector area to supply a fifty percent seasonal solar fraction at each site.

Figure 3 is a preliminary presentation showing the influence of the collector area, regeneration temperature, and regeneration coil liquid flow rate upon seasonal solar fraction in Los Angeles. For example, the graph indicates that a 50 percent seasonal-cooling solar fraction can be achieved with a 20.4 square meter collector area and 80 C regeneration temperature. This is for a Pennington cycle with silica gel desiccant operated in the ventilation mode.

Current activity involves the development of advanced cycle models as well as the inclusion of electrical power consumption for fans, pumps, and desiccant wheel drives.

The Effect of Ac & Flowrate on SF
The Effect of Flowrate on Reg. Temp.

Figure 3.

END

**DATE
FILMED**

5 / 6 / 92