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

**PROJECT STATUS REPORT FOR THE MONTHS OF
JUNE AND JULY 1995**

Prepared for the

U.S. Department of Energy
Conservation and Renewable Energy
Under Grant DE-FG36-95GO10093

Submitted by

**SOLAR ENERGY APPLICATIONS LABORATORY
COLORADO STATE UNIVERSITY**

August 1995

MASTER

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UNIQUE SOLAR SYSTEM COMPONENTS

INTEGRATED TANK/HEAT EXCHANGER MODELING/EXPERIMENTS

The CSU wrap-around heat exchanger model will be incorporated into a new version of the TRNSYS Type 4 Thermal Storage Tank Model developed by B. J. Newton (1995) at the University of Wisconsin for TRNSYS 14. The computational method in the new model (now, Type 60) has been significantly improved over the TRNSYS 13 model previously used to create the wrap-around heat exchanger model. The new tank model also incorporates a model for simulating both supply and load side internal heat exchangers. The changes required to allow for the modeling of wrap-around heat exchanger geometry are relatively minor and have been made on a preliminary version of the Type 60 model. We are now waiting on a final release of the new model from the University of Wisconsin.

Final documentation of all of experimental results obtained to date is waiting on the completion of the new version of the wrap-around tank model.

Modifications to improve our heat exchanger test stand are complete. We now have a relatively compact assembly which contains a 7.5 kW hydronic heater, pump, and Micro Motion Coriolis flow meter. The hydronic heater elements are now controlled with a solid state relay and controller. Fluid temperatures in to and out of the hydronic heater are measured with 2252 Ω thermistor probes. A watt transducer has been modified to measure the average electrical power draw by the heater elements. Control of the hydronic heater is now much more robust.

Jeff Miller attended the 1995 American Solar Energy Society conference in Minneapolis, Minnesota, July 15-20, 1995.

References

Newton, B. J., Schmid, M., Mitchell, J. A., and Beckman, W. A., "Storage Tank Models," *Proceedings of the 1995 ASME Solar Energy Conference*, March 19-24, Maui, Hawaii, pp. 1111-1116, 1995.

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RATING AND CERTIFICATION OF DOMESTIC WATER HEATING SYSTEMS

June/July 1995

Current work on this project has been to install and instrument the Solahart thermosyphon solar domestic hot water system on the outdoor test bed at the Solar Energy Applications Laboratory to obtain additional data sets for model comparison. In addition, the rough draft of a paper accepted for the 1996 International Solar Energy Conference in San Antonio, Texas is near completion. This report summarizes the experimental and model results for the initial one-day outdoor tests.

SIMULATION OF OUTDOOR TESTS

Two one-day outdoor tests have been conducted to date. A 420 second draw at a flow rate of approximately 0.2 liters per second was made sometime after noon and a complete three volume draw off was made later in the afternoon for each test. Horizontal radiation, ambient temperature, and tank inlet and outlet temperatures were recorded and used to construct TRNSYS input decks to simulate the experiments. The simulations were run with the adjusted model parameters (described in the February and March 1995 progress report and in the paper to be submitted with the next progress report) and the unadjusted original parameters. The first day was clear and the second was partly cloudy as can be seen in Figures 1 and 2. Figures 3 and 4 show the experimental, unadjusted, and adjusted model results for the draw temperature profiles for both draws of the first test and Figures 5 and 6 show the same information for the second test. In all cases, the adjusted model greatly increases the accuracy of the temperature predictions and the integrated energy results. Table 1 summarizes the integrated energy results for the outdoor tests.

	Experiment	Original Model	Adjusted Model	% Error in Original Model	% Error in Adjusted Model
Test #1					
Short Draw Energy (kJ)	4551	7368	5371	+ 62	+ 18
Long Draw Energy (kJ)	26383	25042	26249	- 5	- 0.5
Test #2					
Short Draw Energy (kJ)	6534	8466	6140	+ 30	- 6
Long Draw Energy (kJ)	10774	8984	11030	- 17	+ 2

Table 1. Comparison of Integrated Energy Results for Outdoor Tests

Horizontal Radiation vs. Time

Test #1

Figure 1.
Horizontal Radiation
Profile for Test #1.

Horizontal Radiation vs. Time

Test #2

Figure 2.
Horizontal Radiation
Profile for Test #2.

Draw Temperature vs. Volume Fraction

Testbed Test #1 7/26/95 - Short Draw

Figure 3.
Draw Temperature vs
Time for Short Draw.
First Test.

Draw Temperature vs. Volume Fraction

Testbed Test #1 7/26/95 - Long Draw

Figure 4.
Draw Temperature vs
Time for Long Draw.
First Test.

Figure 5.
Draw Temperature vs
Time for Short Draw.
Second Test.

Figure 6.
Draw Temperature vs
Time for Long Draw.
Second Test.

ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (SDHW) SYSTEMS

This report is for June and July 1995. Experimental tests are being conducted on three side by side systems: ASN, NEG and Thermo Dynamics.

Experimental Work

The months of June and July were plagued with an uncommon number of experimental equipment failures. These, in part, were due to the systems sitting idle during the poor weather conditions in April and May.

The wind direction potentiometer failed in the first week of June. The faulty part was isolated and fixed.

Two of the turbine flow meters failed. One flow meter failure was due to electronic component failure (frequency to voltage conversions). This was fixed by an electronic technician on campus, but the cause of failure is unknown. If this occurs again (this is the second failure of these electronics) it will be sent in to the manufacturer for repair. The second flow meter had a mechanical failure (the turbine axis tilted). This was dismantled and repaired.

The vent valve on the NEG system failed during a test. It started leaking profusely from the press fit. It was replaced with an upgraded version.

The auxiliary heater controller on the Thermo Dynamics system burned out. It was replaced.

The NEG pump was not circulating fluid to the collectors. The problem was isolated (the check valve in the pump line failed closed) and fixed.

Many tests were attempted these past two months, but none were completed in full due to failures. One final problem remains to be fixed. The data acquisition hardware keeps shutting down erratically. It may occur after one, two, or three days, or even after just 2 hours. The problem is being worked on.

Optimization of Evacuated Tube Collectors

The computer modeling of the geometric variations of evacuated tube collectors continued with the study of a specular backplane reflector. A specular reflector will reflect photons at an angle equal to the angle at which they are incident (symmetric about the surface normal). The Monte-Carlo ray-trace computer program was used to calculate the IAM's for four NEG integral collector storage (ICS) tubes. Computer simulation runs were accomplished at three different tube center-to-center (pitch) spacings (15.8 cm, 48.0 cm, and 96.0 cm) and backplane dimensions (100%, 125%, and 150% of aperture dimensions). These IAM's were used in the TRNSYS program to calculate the annual performance of each collector geometry. Energy was drawn off the collectors each day at 3.1 gallons per minute for a total of 20 gallons at 8 a.m., noon, and 5 p.m. No system components (pumps, auxiliary storage, etc.) were included in the simulation in order to isolate the collector performance.

Graph 1 shows the annual energy of the four-tube module versus the pitch for a specular reflector, an isotropic diffuse reflector and a Lambertian diffuse reflector. The performance with the specular reflector is about the same as that with an isotropic diffuse reflector. Considering that an isotropic diffuse surface is a theoretical surface and not easily implemented in the real world, the results are encouraging. The specular reflector shows a performance increase of 48% over the Lambertian diffuse reflector at a pitch of 48 cm.

Increasing the dimensions of a specular reflector beyond the aperture dimensions produces very little increase in the annual energy collected (graph 2). Since the aperture plane extends to the right and left of the tubes by one half of the pitch, this is a significant reflector area increase for a large pitch (figure 1). On a clear day in June at a latitude of 40 degrees north, approximately 65% of the daily radiation occurs within three hours of solar noon; on a clear day in January, about 85% of the daily solar radiation occurs within three

(Fig. 1)

hours of solar noon. Since most of the energy available to solar collectors occurs at relatively small hour angles (less than 45°), extending the specular reflector beyond distance 'n' (figure 2) will provide a minimal amount of increased energy absorption. At a 45° angle, the distance n can be found from: $n = m + \frac{1}{2}d_{\text{tube}}$. The value of m (distance from the tube center to the backplane) in the computer simulations has been held constant at a value of 8.5 cm. Therefore, with a specular reflector equal in size to the aperture area, the edge effects at hour angles less than 45° are captured as long as the tube pitch is greater than 24 cm.

A similar analysis can be used in explaining why increased performance tapers off with increasing the pitch. Adjacent tubes shading the reflector would not be a concern more than 3 hours from solar noon. Therefore increasing the pitch beyond the amount

(Fig. 2)

shown in figure 2 would provide a minimal amount of increased energy absorption. For an NEG ICS tube with $m = 8.5$ cm., this pitch would be about 47 cm ($2m + \text{tube diameter}$). As shown in graph 3, the annual energy collected tapers off quickly for a pitch greater than 48 cm.

More computer simulations will be performed with different backplane reflector-to-tube-center spacings.

NEG 4 Tube Collector
Backplane Dimensions = 100%
Backplane Reflectance = 1.0

(graph 1)

NEG 4 Tube Collector

Specular Reflector
Backplane Reflectance = 1.0

(Graph 2)

NEG 4 Tube Collector

Specular Reflector
Backplane Reflectance = 1.0

(graph 3)

MANAGEMENT AND COORDINATION OF COLORADO STATE/DOE PROGRAM

Coordination of research activities continued on the three technical research tasks under the DOE grant, and accounts were maintained and updated. Financial and technical reports were submitted as required.