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**DEVELOPING, TESTING, EVALUATING AND OPTIMIZING
SOLAR HEATING SYSTEMS**

**PROJECT STATUS REPORT FOR
DECEMBER 1996 AND JANUARY 1997**

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Submitted by:

**Solar Energy Applications Laboratory
Colorado State University**

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UNIQUE SOLAR SYSTEM COMPONENTS

Integrated Tank/Heat Exchanger Modeling/Experiments

Work continues on the fortran code required for a two layer (boundary layer and core region) model of the wrap-around heat exchanger solar thermal storage tank. After a review of one-dimensional models of thermal storage tanks in the literature, a modified fixed volume model is being considered for the formulation of the one-dimensional model of the core region of the thermal storage tank.

In the traditional fixed volume TRNSYS model (Type 4) model an energy balance is written for individual sub-volumes of the tank. Upwind finite difference approximations are used to represent convection terms and central difference approximations for the diffusion terms. The resulting linearized first order ordinary differential equation is then integrated in time analytically in the subroutine DIFFEQ. Iteration is required to obtain the final solution for the collection of such equations which describe the tank.

In the most recent version of this fixed volume model, B. J. Newton (1995) found fault with the use of the analytical integration procedure in the DIFFEQ subroutine. Instead, he has implemented a Crank-Nicolson routine to carry out the integration of the set of equations in time. The formulation of the energy balance equations is not significantly changed.

One long term problem associated with these fixed volume models is that with a coarse grid, truncation error from the upwind differencing of the convection terms results can be significant. This truncation error appears as an additional source of diffusion (referred to as numerical mixing) in the solution.

There is an implicit assumption about the variation of the temperature within each control volume associated with the upwind difference representation of the convective terms and central difference representation of the diffusion terms (Patankar, 1980). That is that the temperature variation is piece-wise linear. Patankar shows from simple analytical solutions that the correct variation is an exponential decay which in only some cases (small grid size) can be modeled as linear. He instead, recommends an alternate exponential form of the differencing of the combined convection and diffusion terms. In the absence of source (sink) terms, exponential differencing will result in an exact solution even for very coarse grids.

A one-dimensional tank model employing Patankar's exponential differencing is being developed in the hope of reducing the numerical mixing problems encountered with the current fixed volume models thereby making the solutions less sensitive to the grid refinement (number of nodes). Patankar also has shown that variation of individual node temperatures in time is exponential (as is the case in the analytical solution method in the DIFFEQ subroutine) and has recommended an exponential form of the time differencing to replace the standard Crank-Nicolson formulation (Patankar, 1978).

References

- Newton, B. J., *Modeling of Solar Storage Tanks*, Masters Thesis, University of Wisconsin, Madison, WI, 1995.
- Patankar, S. V., and B. R. Baliga, "A New Finite-Difference Scheme for Parabolic Differential Equations," *Numerical Heat Transfer*, Vol. 1, pp. 27-37, 1978.
- Patankar, S. V., *Numerical Heat Transfer and Fluid Flow*, Hemisphere Publishing Corporation, Washington, 1980.

ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (SDHW) SYSTEMS

This report is for December 1996 and January 1997.

Experimental Work

The current emphasis of this work is the use of energy draw data from short-term tests for validating system performance. Long-term tests are to be used to substantiate the data and analysis from the short-term tests. The short-term test protocol to be followed is that of FSEC (Steven Long), and is available via anonymous ftp from [alpha.fsec.ucf.edu](ftp://alpha.fsec.ucf.edu).

The short-term test data have been collected, and the raw data (Volts and T/C readings) have been processed into engineering format (flow rates, temperatures, etc.). Last month, it was our plan to make available the processed data files on our WWW site (WWW.ColoState.EDU/Orgs/SEAL) as clickable links, together with the paper describing the data sets. We have delayed putting up these data because we have not had a complete calibration for the wind anemometer, needed because high winds resulted in the destruction of the wind vane and one of the cups on the anemometer, which had to be replaced. After replacement, a new calibration was necessary. We expect to obtain the data necessary for calibration next month.

During this time, the auxiliary tank for the Thermodynamics system developed a leak. The tank was replaced with that from the ASN system, which is no longer being tested. However, due to a different piping arrangement, a new heat loss test needed to be performed. Heat loss tests were performed using both the OG300 and ASHRAE test procedures, and different results were obtained. With valves closed, the OG300 method yielded UA values of 2.16 W/K and 1.94 W/K, while the ASHRAE method yielded values of 2.32 W/K and 2.35 W/K. We are currently looking into this discrepancy. This has delayed our long-term testing, which we plan to conduct according to DST protocol. The long-term test will commence next month.

Optimization of Evacuated Tube Collectors

This effort involves an array of evacuated tube collectors, which is being tested experimentally and simulated numerically. The simulations consist of the pre-calculation of IAM's, and subsequent simulation using TRNSYS. Phase I of this work is complete.

Specific tasks accomplished during these two months include:

- Our IAM work is now available at www.ColoState.EDU/Orgs/SEAL/research/IAM/iam.html. Both source code (Fortran 90), and executable codes for Intel-based and Sun systems are available. A user's manual and two input files are also available. A printout of this WWW page, entitled "IAM Program," is attached.
- A paper on this topic will be presented at the 1997 International Solar Energy Conference, Washington DC.
- An MS thesis on this topic by Joseph Ryan is complete, and is available .

IAM Program

The files contained on this page are copyrighted by Colorado State University. They can be distributed freely as long as they are distributed completely including any copyright message.

This program is used to compute Incidence Angle Modifiers (IAM's) for cylindrical solar collectors. The following six links are text files. To view the files, simply click the link. If you would like to save these files to your own computer, after clicking on the link, choose "save as" from your browser's menu.

1. [manual](#) - Program Manual (12k)
2. [iam.in.1](#) - sample input deck with 4 collector tubes (2k)
3. [iam.tab.1](#) - results from above input deck (1k)
4. [iam.in.2](#) - sample input deck with 8 collector tubes (2k)
5. [iam.tab.2](#) - results from above input deck (1k)
6. [iam.f90](#) - Program source code written in ANSI Fortran 90 (105k)

The next two links are the executable files. If you click on the link, your browser will download the file to your own computer. Read the manual to learn more about executing the program.

1. [iamsun.exe](#) - Executable for Sun Workstations (311k)
2. [iamdos.exe](#) - Executable for DOS (242k)

If you run into problems with this program, either downloading the files or executing the program, please e-mail me: jryan@k12.colostate.edu

Management and Coordination of Colorado State/DOE Program

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