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

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UNIQUE SOLAR SYSTEM COMPONENTS

INTEGRATED TANK/HEAT EXCHANGER MODELING/EXPERIMENTS

Computer codes have been developed to predict the velocity and temperature profiles in the natural convection boundary layer on the inside of the vertical walls of the wrap-around heat exchanger tank. A brief description of several of the methods considered is given. Heat and mass transfer results for these various methods are compared for one sample case with the results of an accurate finite difference solution obtained with Keller's box method (Keller, 1971) in Figures 1 through 4. These boundary layer solutions are required to predict the heat transfer at the wall and also the mass and energy transport within the in boundary layer

The results in Figures 1 through 4 are for the case when the wall temperature varies as

$$T_w(x) = \sin(x)$$

in uniform temperature ambient fluid. The fluid modeled is water with a Prandtl number of 3.77 (using the same values for the properties of water as used in previous calculations, Miller and Hittle, 1993 and 1995). Figure 1 shows the variation of the non dimensional temperature gradient at the wall. The results of each of the different methods shown in Figure 1 have been scaled to the nondimensionalization of the uniform wall temperature case for ease of comparison. Figure 2 shows the predicted wall heat flux. Figures 3 and 4 show the variation of the total mass and energy convected in the boundary layer.

The Similarity Solution

The derivation of each of the approximate methods described here and compared in the figures below is based on the concept of similarity. A brief review of the use of similarity variables is given here.

Pohlhausen (in Schmidt and Beckman, 1930) was the first to employed similarity analysis in the solution of the natural convection boundary layer. He considered the boundary layer which develops on a vertical, semi-infinite isothermal plate with a temperature T_w surrounded by a isothermal fluid of large extent with a temperature T_∞ . This is perhaps the simplest case which results in an exact solution for a natural convection boundary layer. Ostrach (1953) presents a comprehensive review of this solution. The analysis presented here is available in any convection text which deals with the natural convection boundary layer.

The essential concept behind similarity is that at a point sufficiently far from the leading edge (so that the boundary layer assumptions are satisfied) appropriate scaling functions will cause the velocity and temperature profiles at any streamwise location x to be identical to the profiles at any other streamwise location. The velocity and temperature profiles in the boundary layer retain their essential shape as they grow with the downstream coordinate x . Transformation (scaling) of the normal coordinate y with the streamwise coordinate x , the solution to the boundary layer equations will be independent of x . When similarity solutions exist, the system of partial differential equations are reduced to a mathematically simpler (thought not trivial) set of ordinary differential equations. The set of ordinary differential equations need only be solved once for flow and heat transfer results to be determined at any streamwise location. Similarity solutions are referred to as "exact solutions" because they represent the set of exact solutions to the boundary-layer equations for natural convection flow along a vertical flat plate. They are "exact" only to the extent that the boundary-layer approximations are accurate.

For the natural convection boundary layer which develops on a vertical, isothermal flat plate in an isothermal medium the appropriate similarity variable is

$$\eta(x, y) = \frac{y}{x} \left(\frac{Gr_x}{4} \right)^{1/4} \quad (1)$$

With a non dimensional stream function and reduced temperatures defined by

$$\psi(x, y) = 4\nu \left(\frac{Gr_x}{4} \right)^{1/4} f(\eta) \quad (2)$$

$$T(x, y) - T_\infty = \theta(\eta)(T_w - T_\infty) \quad (3)$$

where the Grashoff number is defined as

$$Gr_x = \frac{g\beta(T_w - T_\infty)x^3}{\nu^2} \quad (4)$$

the boundary layer equations that describe the natural convection boundary layer are transformed into a pair of coupled, nonlinear, ordinary differential equations.

$$f''' + 3ff'' - 2f'^2 + \theta = 0 \quad (5)$$

$$\theta''/Pr + 3f\theta' = 0 \quad (6)$$

with the boundary conditions,

$$f(0) = 0; \quad f'(0) = 0; \quad \theta(0) = 1 \quad \lim_{\eta \rightarrow \infty} f'(\eta) = 0; \quad \lim_{\eta \rightarrow \infty} \theta(\eta) = 0 \quad (7)$$

Prandtl number is the only parameter which appears in eqs. (5) and (6). The coordinates x and y appear only in the combination $\eta(x, y)$. With the solution eqs. (5) and (6) for the independent variables f and θ and their derivatives obtained by standard methods (Nachtsheim and Swigert, 1965 or Keller, 1971), heat and mass transfer results of interest can be determined at any streamwise location. Of primary concern is the local wall heat flux,

$$q''(x) = -k \frac{\partial T}{\partial y} \bigg|_{y=0} = \frac{k(T_w - T_\infty)}{x} \left(\frac{Gr_x}{4} \right)^{1/4} (-\theta'(0)) \quad (8)$$

which can also be expressed in terms of a local Nusselt number.

$$Nu_x = \frac{h_x x}{k} = \frac{q''(x)}{(T_w - T_\infty)} \frac{x}{k} = \frac{-\theta'(0)}{\sqrt{2}} Gr_x^{1/4} = \frac{-\theta'(0)}{\sqrt{2} Pr^{1/4}} Ra_x^{1/4} \quad (9)$$

For water with a Prandtl number of 3.77, $\theta'(0) = -0.876$ and,

$$Nu_x = 0.62 Gr_x^{1/4} = 0.44 Ra_x^{1/4} \quad \text{where} \quad Ra_x = Gr_x Pr \quad (10)$$

Formulation of a two layer model of the thermal storage tank that accounts for the convective motions in side the tank will require a reasonable approximation of the total convected mass (mass flow rate) in the boundary layer,

$$\dot{m}(x) = \int_0^\delta \rho u dy = 4\mu \left(\frac{Gr_x}{4} \right)^{1/4} \int_0^{\eta_\infty} f' d\eta \quad (11)$$

and the total convected energy in the boundary layer,

$$E(x) = \int_0^\delta \rho u c_p (T - T_\infty) dy = \mu c_p 4 \left(\frac{Gr_x}{4} \right)^{1/4} N x^n \int_0^{\eta_\infty} f' \theta d\eta \quad (12)$$

Approximate Methods for the Nonsimilar Natural Convection Boundary Layer

"Exact" similarity solutions also exist when the wall temperature varies with some power of x (the power law form will be explored a little further below in the context of Webb's method) or with the exponential of x (Yang, 1960). In practice, however, the variations in the thermal boundary conditions encountered will not match one of these similarity forms. The problem is then, to obtain solutions of the boundary layer equations for cases when the thermal boundary conditions vary with x in a "nonsimilar" manner. Several promising approximate methods to solve the nonsimilar natural convection boundary layer problem are outlined below.

Local Similarity

In general, the non-dimensional stream function and reduced temperature will be functions of both x and η and the solution of the boundary layer equations at any streamwise position will depend on the solutions upstream and perhaps downstream of that point. Additional terms which account for the variation of the functions $f(x, \eta)$ and $\theta(x, \eta)$ should appear in the boundary layer equations. Transformation of the boundary layer equations in terms of similarity variables should still, reduce the overall streamwise dependency of the solutions. In many cases, we could expect that the size of the nonsimilar terms to be small and could reasonably neglect these terms. The equations would then reduce to the form in eqs. (5) and (6) above. The heat and mass transfer results at any specific streamwise location are computed by calculating the local Grashoff number. This approximate approach is termed "local similarity". The non dimensional wall temperature gradient calculated using this form of local similarity approximation remains constant as shown plotted against an accurate finite-difference method solution in Figure 1 below. Figure 2 shows the discrepancy in the calculated local heat flux. Although this method under estimates the local heat flux, it over estimates the mass and therefore energy entrained into the boundary layer. It should be noted that the approach applied (although a little naively) in the formulation of our original wrap-around heat exchanger tank model (Miller and Hittle, 1993 and 1995) was essentially a local similarity approximation.

Kao's Transformation

In order to incorporate the effect of the variation of the thermal boundary conditions on the solution and further reduce streamwise dependency of the boundary layer equations, Kao (1974, 1976, and 1977) employs the following transformation

$$\xi = \int_0^x F(x) dx \quad (13)$$

where, for specified wall temperature, $F(x)$ is simply

$$F(x) = (T_w(x) - T_\infty) \quad (14)$$

Then, with the "pseudo" similarity variable

$$\eta(x, y) = C_1 F^{1/2} y \xi^{-1/4} \quad (15)$$

and the non dimensional stream function and reduced temperature given by

$$\psi(x, y) = 4C_1 \nu \xi^{3/4} F^{-1/2} f(\xi, \eta) \quad (16)$$

$$T(x, y) - T_\infty(x) = F(x) \cdot \theta(\xi, \eta) \quad (17)$$

the transformed boundary layer equations become

$$f''' + (3 - 2\tilde{\beta})ff'' - 2f'f' + \theta = 4\xi \left(f' \frac{\partial f'}{\partial \xi} - f'' \frac{\partial f}{\partial \xi} \right) \quad (18)$$

$$\frac{\theta''}{Pr} + (3 - 2\tilde{\beta})f\theta' - 4\tilde{\beta}f'\theta - 4 \frac{\xi}{F^2} \frac{dT_\infty}{dx} f' = 4\xi \left(f' \frac{\partial \theta}{\partial \xi} - \theta' \frac{\partial f}{\partial \xi} \right) \quad (19)$$

where

$$\tilde{\beta} = \frac{\xi}{F^2} \frac{dF}{dx} \quad (20)$$

with the boundary conditions

$$f(\xi, 0) = 0; \quad f'(\xi, 0) = 0; \quad \theta(\xi, 0) = 1; \quad \lim_{\eta \rightarrow \infty} f'(\xi, \eta) = 0; \quad \lim_{\eta \rightarrow \infty} \theta(\xi, \eta) = 0 \quad (21)$$

Each of the parameters $F(x)$, $\xi(x)$, and $\tilde{\beta}(x)$ can be calculated from the specified boundary conditions.

Kao's Local Similarity Method

A "local similarity" solution can be obtained using Kao's variables (eqs. 19 and 20) by, once again, neglecting the terms on the right-hand-sides. Figures 1 and 2 shows that better agreement is obtained using Kao's local similarity method than with a local application of uniform wall temperature similarity solution.

Sparrow's Local Nonsimilarity

The agreement can be improved with the application of Sparrow's "local nonsimilar method" (Minjowycz and Sparrow, 1974) to eqs (19) and (20). Without going into extensive detail here, Sparrow's method proceeds as follows. The right-hand-side terms are retained in eqs. (19) and (20). The partial derivatives required to calculate these terms are obtained by solving an auxiliary set of equations generated by taking the derivative of eqs (19) and (20) with respect to ξ and neglecting the higher order partial derivatives in the new equations. Presumably, successively better approximations can be obtained by continued application of this procedure.

Results for the second and third levels of truncation (the first level is Kao's local similarity solution above) are shown in Figures 1 and 2 below. Indeed, agreement with the finite-difference method solution is improved with each level of truncation. However, the computational effort increases with each level and experience shows that convergence using this method becomes more difficult at larger values of x for the sinusoidal case shown.

Kao's Strained Coordinate Method

Kao (1974) also developed an asymptotic expansion solution using the transformed eqs. (19) and (20). The equations are first transformed from (ξ, η) coordinates to $(\tilde{\beta}, \eta)$.

$$f''' + (3 - 2\tilde{\beta})ff'' - 2f'f' + \theta = \epsilon \left(f' \frac{\partial f'}{\partial \tilde{\beta}} - f'' \frac{\partial f}{\partial \tilde{\beta}} \right) \quad (22)$$

$$\frac{\theta''}{Pr} + (3 - 2\tilde{\beta})f\theta' - 4\tilde{\beta}f'\theta = \epsilon \left(f' \frac{\partial \theta}{\partial \tilde{\beta}} - \theta' \frac{\partial f}{\partial \tilde{\beta}} \right) \quad (23)$$

with the boundary conditions

$$f(\tilde{\beta}, 0) = 0; \quad f'(\tilde{\beta}, 0) = 0; \quad \theta(\tilde{\beta}, 0) = 1; \quad \lim_{\eta \rightarrow \infty} f'(\tilde{\beta}, \eta) = 0; \quad \lim_{\eta \rightarrow \infty} \theta(\tilde{\beta}, \eta) = 0 \quad (24)$$

Kao then seeks solutions of eqs. (22) and (23) by substituting perturbation expansions for the functions f , θ , and $\tilde{\beta}$ in terms of the presumably small quantity $\epsilon(\tilde{\beta})$ where

$$\epsilon(\tilde{\beta}) = 4\xi \frac{d\tilde{\beta}}{d\xi} \quad (25)$$

and power series expansions of the form,

$$\tilde{\beta} = \beta + \epsilon(\tilde{\beta})\Delta_0(\beta) + \epsilon(\tilde{\beta})^2\Delta_1(\tilde{\beta}) + \dots \quad (26)$$

$$f = f_0(\beta, \eta) + \epsilon(\tilde{\beta})f_1(\beta, \eta) + \epsilon(\tilde{\beta})^2f_2(\beta, \eta) + \dots \quad (27)$$

$$\theta = \theta_0(\beta, \eta) + \epsilon(\tilde{\beta})\theta_1(\beta, \eta) + \epsilon(\tilde{\beta})^2\theta_2(\beta, \eta) + \dots \quad (28)$$

are used. β is a new strained coordinate. The equations of order unity and ϵ are then solved. The solution procedure is to find the pair of values β (the "strained coordinate") and Δ_0 for which $\theta'_1(\beta, 0) = 0$. This requirement means that only the solutions to the zeroth order equations are required to determine heat transfer results (local wall heat flux for example). The results of Kao's "strained coordinate" method show very good agreement with the finite difference solution in Figures 1 and 2.

Webb's Modified Local Similarity

Webb (1990) has developed an approach he calls "modified local similarity." A family of exact similarity solutions of the boundary layer equations is when the wall temperature varies according to the form

$$T_w(x) - T_\infty(x) = d(x) = Nx^n \quad (29)$$

The transformed boundary layer equations for this form are

$$f''' + (n+3)ff'' - 2(n+1)f'^2 + \theta = 0 \quad (30)$$

$$\theta''/\text{Pr} + (n+3)f\theta' - 4nf'\theta = 0 \quad (31)$$

with the boundary conditions from eq. (7) above. In fact, the solution for the case of isothermal wall temperature is a member of this family of solutions ($n=0$).

For a power-law variation of the temperature difference, the ratio of the local heat flux $q''_w(x)$ to the average heat flux $Q(x)$ at any streamwise location is a function of the power-law exponent.

$$Q(x) = \left(\frac{4}{5n+3} \right) q''_w x \quad (32)$$

This ratio is 4/3 for the uniform wall temperature case above. Solving for the power law exponent gives

$$n = \frac{1}{5} \left(4 \frac{q''_w(x) x}{Q(x)} - 3 \right) \quad (33)$$

Webb's method picks a solution from the family of power law similarity solutions which provides the "best" approximation to the boundary layer profiles at any streamwise position. The procedure is as follows. With the temperature specified at the wall, a value for the exponent, n , is assumed. With the solution of eqs (30) and (31), wall heat flux is

$$q''_w(x) = k \frac{Nx^n}{x} \left(\frac{\text{Gr}_x}{4} \right)^{1/4} (-\theta'(0)) \quad (34)$$

and the total heat flux is

$$Q(x) = \int_0^x q''_w(x) dx \quad (35)$$

A new value for n can then be calculated (eq. 33). The best value for n is determined iteratively.

Results using Webb's method are shown for the sample case. While not as accurate as those obtained with Kao's strained coordinate method, the results are reasonable and a little easier to obtain.

Discussion

Each of these methods is "local" in the sense that the approximate solution of the boundary layer equations at each streamwise position is independent of the solution at any other. The solutions depend on one or more parameters, but not on the upstream solutions. The advantage of using a local method is that the natural convection boundary layer solutions can be calculated in advance and tabulated as a function of these parameters for use in a TRNSYS tank model with the hope of reducing the computational effort required.

The calculation of the natural convection heat transfer coefficient (for laminar flow) in the formulation of our original wrap-around heat exchanger tank model (Miller and Hittle, 1993 and 1995) was calculated from the empirical correlation

$$Nu_L = 0.59 Ra_L^{1/4} \quad \text{where} \quad Ra_L = \frac{g\beta\Delta TL^3}{\alpha\nu} \quad (36)$$

where the local Raleigh number is a local temperature difference. This is essentially an implementation of the concept local similarity. My original application was, however, flawed. Equation (36) is a correlation for the mean Nusselt number. A correlation for the local Nusselt number should have been used. For the isothermal wall similar solution, the mean Nusselt number is related to the local Nusselt number by

$$\overline{Nu}_L = \frac{\bar{h}L}{k} = \frac{4}{3} Nu_x = 0.59 Ra_L^{1/4} \quad \text{where} \quad \bar{h} = \int_0^x h \, dx \quad (37)$$

The correspondence between the coefficients of the Raleigh numbers in eqs. (36) and (37) is accidental (though not unwelcome). Equation (37) suggests that the natural convection coefficients were over estimated by 33% perhaps explaining a large part of the discrepancies noted between modeling and experiment. Figure 2 below, however, indicates that the wall heat flux is underestimated by a local similar model.

The original model does not, of course, attempt (except through the mixing routine incorporated to eliminate unstable thermal stratification in the calculated tank temperature profile) to model the effect of the convective motions in the tank on the formation of the temperature profiles in the storage. It appears that with the exception of the isothermal wall local similarity model, all of the methods compared here provide reasonable good predications of the heat and mass transfer in the natural convection boundary layer for the case considered.

The ability of each of these methods to account for the affect of thermal stratification on the growth of the boundary layer is now being assessed.

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Figure 1. Comparison of the predicted wall temperature gradient with finite-difference method (FDM) solution. (LS - local similarity, LNS - local nonsimilar)

Figure 2. Comparison of the predicted wall heat flux with finite-difference method (FDM) solution. (LS - local similarity, LNS - local nonsimilar)

Figure 3. Comparison of the predicted total convected mass with finite-difference method (FDM) solution. (LS - local similarity, LNS - local nonsimilar)

Figure 4. Comparison of the predicted total convected energy with finite-difference method (FDM) solution. (LS - local similarity, LNS - local nonsimilar)

ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (SDHW) SYSTEMS

This report is for August and September, 1996.

Experimental Work

The current emphasis of this work is the use of energy draw data from short-term tests for validating system performance. The 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). A summary of the test protocol follows.

Isothermal initial conditions are to be obtained for two classes of conditions: a "hot" and a "cold" start, and data are to be taken for each of these initial conditions during sunny, partly sunny and cloudy days. Thus constitutes six tests, each of approximately two to three hours duration. At the end of the tests, full energy purges are to be performed, by opening the system to mains water, and purging until the difference between the inlet and outlet temperatures is small. The purges take from an hour to an hour and a half to perform, during which time the collectors are covered with a reflective cover. During the tests, the systems are run according to the normal operation of their controllers, with no draws and with no auxiliary heat added.

At the end of July 1996, it was apparent to us that some system changes were necessary to obtain the desired data.

- For the NEG system the pump is run until the system is isothermal to within 1 C. A pump had to be added to the Thermodynamics system, to circulate water between the primary and auxiliary tanks. This is necessary in order to obtain an isothermal "hot" start, as the auxiliary heater in the Thermodynamics auxiliary tank is used to heat the water in the primary tank.
- Testing commenced in September. Data were taken for the days of September 3, 10, 12 and 17. Initial analysis and observations indicate that:
 - During cloudy days, there is insufficient solar irradiation to elevate the temperature of the systems by 10 C. We have been able to achieve about 7 C elevation.
 - During cloudy days, for a "hot" start, the systems actually lose energy to the ambient.
 - It is very difficult to achieve less than about 1.2 C temperature drop across the systems. Even with the collectors covered, there is still heat gain from the pump and from the outdoor piping. This is especially a problem for the NEG system. A goal of 0.2 C is probably not practical.
 - During "hot" starts on sunny days, we have experienced shut-off of the Thermodynamics system due to exceeding an over-temperature limit. We have subsequently overridden this control feature.
 - For the Thermodynamics system, during start-up, it is virtually impossible to achieve a temperature difference of less than 1 to 2 C across the collectors. This is due to the fact that the fluid is glycol (lower thermal capacitance) and the flow rate is low for this system.
 - Finally, our collectors are fixed at a tilt of 45 degrees. It is only for a certain portion of the year that the noon sun is within 4 degrees of normal.

Thus, this indicates that the data collection procedure needs further refinement. We plan to work with FSEC on this during the next month. A copy of the test protocol we suggest is attached, for review.

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. In the last progress report, the progress to date was given encompassing data collection using an eight-tube system with various backplanes.

Specific tasks accomplished during these two months include:

- Additional outdoors tests were conducted on a four-tube array, with different backplanes. Here, every other tube was removed from the eight-tube array to obtain data at a larger tube to tube spacing. The same set of backplanes were used during these tests as during the tests for the eight-tube array: (1) black, (2) stainless steel (specular reflectance of about 0.6), and white paint (diffuse reflectance of about 0.7).
- Joe Ryan has a fully functional IAM code. A complete set of IAM's, for 45 incident angles, can be run in about 5 minutes on a Pentium system. It is our plan to distribute this package via anonymous ftp as both source code and executable code. First, we have to prepare a user's manual. These will be products of Joe Ryan's MS work.
- IAM and TRNSYS runs of the eight-tube system have been completed. Figure 1, attached, shows the daily energy collected (outdoors), and the TRNSYS simulations. Agreement is excellent. Runs for the four-tube system are in process.

Proposed Short Term Test Protocol

1. Cold Start.

- a. Turn on pump and purge collector, solar storage tank, and auxiliary tank until draw temperature and mains temperature are within 1 C, except for the thermodynamics system collector loop. The temperature difference for this will be reasonably small.
- b. Commence data acquisition at 10 AM solar time. Instantaneous data, sampled at 15 sec intervals, will be logged.
- c. Circulating pumps will be energized by the differential controllers.
 1. To establish a definite initial state during quiescent conditions, data will be logged for 10 minutes before the systems are turned on.
- d. Collected data until at least a 10 C temperature rise in the average temperature of the water tank(s) is achieved.
- e. Cover collectors, and draw all energy out of system through the auxiliary tank until draw temperature and mains temperature are within 1 degree C. Draw will be between 2 and 3 GPM.

Note: The energy will be purged from the Thermodynamics system first. During this time the NEG system will be allowed to operate normally. (the NEG system will be covered and purged after the thermodynamics system has been purged.)
- f. Compute integrated energy for draw.
- g. One data set will be collected during a "sunny" day, one during a "cloudy" day, and one during a "partly cloudy" day.

2. Warm Start.

- a. Turn on the heating element in the auxiliary tank. Pump through collector, solar storage tank, and auxiliary tank until all tank and collector temperatures are within 1 C, except for the thermodynamics system collector loop. The temperature difference for this will be reasonably small.
- b. Shut off heating elements. Commence data acquisition at 10 AM solar time. Instantaneous data, sampled at a 15 sec intervals, will be logged.
- c. Circulating pumps will be energized by the differential controllers.
 1. To establish a definite initial state during quiescent conditions, data will be logged for 10 minutes before the systems are turned on.
- d. Collect data until a temperature rise of at least a 10 C in the average temperature of the water tank(s) is achieved.

- e. Cover collectors, and draw all energy out of system through the auxiliary tank until draw temperature and mains temperature are within one degree C. Draw will be between 2 and 3 GPM.

Note: The energy will be purged from the Thermodynamics system first.

During this time the NEG system will be allowed to operate normally. (the NEG system will be covered and purged after the Thermodynamics system has been purged.)

- f. Compute integrated energy for draw.

- g. One data set will be collected during a "sunny" day, one during a "cloudy" day, and one during a partly cloudy day.

Proposed Long Term Test Protocol

1. Cold start: The systems will be purged with mains water until the inlet and outlet temperatures are within 1 degrees C.
2. Data Acquisition will be started at dawn on the first day.
 - a. Data will be taken at 15 second intervals, and then averaged over 5 minute intervals.
3. The systems will be turned on ten minutes after data collection has begun.
4. The pumps will be controlled by the controllers.
5. Draws will be performed according to OG300 standards:
 - a. Draw flow of approximately 3 GPM. (This will be adjusted to satisfy the daily energy draw requirement of 43,300 KJ)
 - b. Draws at 9:30, 10:30, 11:30, 12:30, 13:30 and 14:30 solar time.
 - c. Draw duration: Each draw will be performed for 4 minutes.
6. Data will be collected for five to seven days.
7. Cover collectors, and draw all energy out of system through the auxiliary tank until draw temperature and mains temperature are within 1 degree C. Draw will be between 2 and 3 GPM.

Note: The energy will be purged from the NEG system first.
During this time the Thermodynamics system will be allowed to operate normally. (the Thermodynamics system will be covered and purged after the NEG system has been purged.)
- f. Compute integrated energy for draw.

FIGURE 1

NEG Collector

Experimental vs. Analytical

Management and Coordination of Colorado State/DOE Program

Director Dr. Douglas Hittle attended a meeting with representatives from the University of Wisconsin and the University of Minnesota to discuss future solar water heating technologies. Dr. Hittle attended planning workshops and the Solar Building Products Division meeting at the SEIA.

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.