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SRCC™ DOCUMENT TM-1-2016-03

Solar Thermal Component Test and Analysis Protocol

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Contents

1.0 Introduction

These test protocols are intended to address the specific requirements for the testing of solar thermal system components. The results of these tests are intended to be used as input into the TRNSYS simulation program.

The intent of these protocols is to address system performance derived from these component tests. Consequently, these tests should be conducted at the conclusion of the specified durability tests. Chapter 4 of ICC 901/SRCC 100 addresses these issues for flat plate thermal collectors. The ICC 900/SRCC 300 standard currently does not clarify what durability requirements are to be met for system components other than the collector. Therefore, these components (e.g. heat exchangers) used in the system shall also be subjected to any of the relevant durability tests (e.g. pressurization of the collector loop of the heat exchanger) before the device is tested for performance. Additional durability tests may be required as specified to determine operation under extreme conditions such as freezing or overheating.

These test methods have been developed as an alternative to the more extensive ISO 9459 test methods. The intent is to speed up and simplify the collection and analysis of data. Note that some of the methods have been adapted from the ISO tests.

This set of protocols is intended to be an outline of the type of tests required for particular classes of generic system components. Most of the components to be tested may not need to undergo many of the tests specified in this document. The decision upon which tests to be conducted will be based upon a variety of factors including:

1. The generic component being considered
2. Availability of TRNSYS models
3. Uncertainty in the modeling of these systems in the current TRNSYS program
4. Previous experience in the performance of a particular class of system component
5. The fundamental relationships regarding optics and thermodynamics that govern a collector's performance.

The user of the test data should be consulted prior to testing to ensure that the proposed test plan meets their requirements.

2.0 Generic Component Classes

The following table summarizes some of the generic systems that have been considered in the development of the following protocols. Note that some systems may actually incorporate more than one of these components. In these cases, some additional testing may be required. However, if a system falls into multiple classes, but the second class is a part of the other's "black box" model, then only the first system class needs to be considered. The exception would be when the second class is used to extrapolate results for other system configurations. As new generic component classes are encountered, these protocols will be expanded to accommodate them.

A: System with an integral auxiliary heater or separate auxiliary heater. This test protocol assumes that the auxiliary is electric. If this is not the case, an additional recovery efficiency test will be needed. A solar system with an integral heater within the primary heat exchange zone shall be required to undergo additional tests due to the effect on stratification caused by the heater. Please contract SRCC prior to testing.

DC: System making use of a differential controller

HP: Heat pipe collector with integral storage

HX: System utilizing a heat exchanger (EHX: External, IHX: Internal, MHX: Integral Mantle, WHX: Integral Wrap-around)

ICS: Integral Collector Storage collector

NCL: System utilizing a Natural Convection Loop that is *not* within the collector loop

PV: PV Panel (not used for a pump)

PVP: PV Driven Pump

PU: Pump (Only DC is currently considered)

SP: Self pumped (phase change) system

T: System utilizing a Timer controller

TO: System with tubular optics

TS: Thermosiphon Collector utilizing a natural convection loop

TSHX: Thermosiphon Collector utilizing a natural convection loop and heat exchanger

Table 1. Summary of Component Classes

Component Type	Abbreviation	Description	Applicable Paragraphs
Separable Thermosiphon	TS	A multi component collector/storage unit that has piping with flow induced by fluid density differences in the collector and tank system.	None if the collector can be tested separately from the tank and there are no HX units.
Separable Thermosiphon with a heat exchanger	TSHX	A multi component collector/storage/heat exchanger unit that has piping with flow induced by fluid density differences in the collector and tank system.	9.1, 9.2, 9.3[1], 9.4, 10.1, 10.2, 10.3, and (10.4.4 or 10.4.5 or 10.4.6) The collector and storage tank must be tested as a unit.
Heat Pipe Collector/Storage	HP	Heat pipe collector with integral storage (currently modeled like ICS).	6.4, 7.5.1, 7.5.2, 8.1, 8.2[1], 8.3,
Non-separable Self-pumped System	SP	A unitary collector/storage unit that has flow induced by fluid phase changes	6.4, 7.4.1 or 7.4.2, 7.5.1, 7.5.2, 8.1, 9.1, 9.2, 9.3[1], 9.4. Please contact SRCC for additional requirements.
Photovoltaic Powered System	PV	Typically a combination of one or more PV modules, DC-AC inverters or DC-DC converters and other controls that are used to provide electrical input to one or more electrical heating elements.	11.1, 11.4, 11.5
Photovoltaic Powered Pumping	PVP	Typically a combination of a PV Panel, DC pump and other controls that is used to provide pumping for the system.	11.1, 11.2, 11.3
External Heat Exchanger	EHX	A heat exchanger that is not contained within a tank or collector component. Different types include shell and tube, flat plate with counter/cross/parallel flows	10.1, 10.2, 10.3, 10.4.1 or NCL: 10.4.2 or 10.4.3

Component Type	Abbreviation	Description	Applicable Paragraphs
Internal Heat Exchanger	IHX	A heat exchanger that is contained within a tank or collector component. Different types include mantle (MHX), immersed , and wrap around (WHX).	10.1, 10.2, 10.3, 10.4.4 or 10.4.5 or 10.4.6 (Note: if the vessel containing the heat exchanger also serves as thermal storage, 9.1, 9.3[1], and 9.4 are also required.)
Natural Convection Loop	NCL	A multi component system that has piping with flow induced by fluid density differences between system components such as a HX or tank.	See AUX and EHX
Solar Tank or Auxiliary/ Backup Tank	TANK	The solar storage tank or the tank and heating component used to provide backup heating.	9.1, 9.2, 9.3[1], 9.4

[1] The capacitance test may not be required for most tanks. See details in the applicable section and/or contact SRCC.

3.0 Nomenclature

Note all units used should be consistent.

Term	Definition
C_{heated}	Thermal capacitance of the electrically heated fluid volume
C_{solar}	Thermal capacitance of the solar heated fluid volume
C_{total}	Thermal capacitance of the entire tank fluid volume
C_p	Heat capacity
DE	Internal energy change
F	Friction factor
$FLOW_{TK}$	Tank flow rate
G	Total irradiance
G_{dh}	Horizontal diffuse irradiance
G_{sc}	Solar constant
H_{pump}	Pump head
I	Current

K_T	Average clearness index for specified test
M_{drawn}	Mass withdrawn
M_{pump}	Pump mass flow rate
M_{tank}	Tank fluid mass
Q_{aux}	Auxiliary heating element energy use rate
Q_{coll}	Collected energy
Q_{del}	Instantaneous purge energy
$Q_{initial}$	Initial charge energy of a tank when subjected to an instantaneous purge between two set temperatures.
Q_{net}	The energy delivered without auxiliary heating
Rho	Density
T_{amb}	Ambient temperature
$T_{amb\ ave}$	Average ambient temperature
$T_{amb\ final}$	Final ambient temperature at the end of a test
$T_{amb\ orig}$	Original ambient temperature at the start of a test
T_{ave}	Average temperature
T_{del}	Temperature of the water delivered at the outlet
T_{high}	Temperature of the water in a test article at the beginning of a high-temperature test (typically 55 - 60°C (131 - 140°F))
T_{in}	Temperature of the fluid entering the test article
$T_{in\ final}$	Temperature of the fluid entering the test article at the end of the test
$T_{initial}$	Temperature of the water in the test article at the beginning of a test (heat loss or warm-up)
T_{low}	Temperature of the water in a test article at the beginning of a low-temperature test (approximately equal to T_{amb})
T_{max}	Recommended maximum temperature of tank
T_{purge}	Purge temperature (T_{low} or T_{high})
T_{pv}	Photovoltaic panel temperature
T_{set}	The setpoint of the activated auxiliary heating element

T_{sink}	Heat sink average temperature (estimate from $\frac{T_{in} + T_{out}}{2}$)
T_{source}	Heat source temperature
$T_{tank\ ave}$	Average tank fluid temperature
$T_{tank\ ave\ final}$	Final average tank fluid temperature after the decay, irradiation or charge (usually immediately prior to the purge period).
$T_{tank\ ave\ orig}$	Original average tank fluid temperature before the decay or irradiation, (usually immediately after the initial charge period).
$T_{tank\ ave\ purge}$	Final average tank fluid temperature after the purge period. This value is usually estimated by averaging the tank inlet temperature and $T_{del.}$
$Time_{draw}$	Draw duration
$Time_{decay}$	Decay test duration
$UA_{hx\ loss}$	UA loss from the heat exchanger to environment
$UA_{hx\ trans}$	UA transfer from the hot side to the cold side of the heat exchanger
$UA_{isolated\ loss\ aux}$	Isolated total UA loss of auxiliary heated portion of the storage tank
$UA_{isolated\ loss\ solar}$	Isolated total UA loss of solar heated portion of the storage tank
$UA_{isolated\ loss\ total}$	Isolated total UA loss of the storage tank from a decay test
$UA_{installed\ loss\ total}$	Installed total UA loss of the storage tank from a decay test
UA_{other}	Installed total UA loss of the storage tank piping or fittings
UA_{pipe}	Installed total UA loss of the NCL loop piping
V	Voltage
V_{rate}	Volumetric flow rate

Greek:

θ	Incidence angle relative to the collector aperture normal

4.0 Referenced Documents

ICC 901/SRCC 100-2015, Solar Thermal Collector Standard

ICC 900/SRCC 300-2015, Solar Thermal System Standard

Qin Lyn, Stephen Harrison and Mikael Lagerquist, "Analysis and Modeling of Compact Heat Exchangers for Natural Convection Loop Applications,"Eurosun 2000, Third ISES-European Solar Congress, Copenhagen, Denmark, 2000.

TRNSYS: "A Transient System Simulation Program," Solar Energy Laboratory, University of Wisconsin – Madison, 1303 Engineering Research Building, 1500 Engineering Drive, Madison, WI 53706 WI, March 2000. http://sel.me.wisc.edu/trnsys/default.htm

UL 1703, Standard for Flat-Plate Photovoltaic Modules and Panels

UL 1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

5.0 Testing Policy

In order to expedite the testing and certification of Solar Hot Water Systems (SHW) and collectors, the current policy is to test the most common size to be sold and possibly one extreme (with respect to the collector area/storage tank volume ratio). If the results from the first two model re-normalization exercises are not reasonably consistent, the other extreme will be tested. The decision about which tests to run and some of the specifics of the operating parameters shall be as necessary to meet the requirements of modeling the solar thermal system. Please consult with SRCC prior to starting testing.

Different configurations that will require at least one test (not necessarily both of the tests) include: different collector absorber coating, the use of a supply side or load side heat exchanger, integral heater in the solar tank as well as any significant model changes. Similar systems incorporating more than one generic component may not require a full array of additional tests. Data for each system component will be required for all configurations unless existing analytical techniques can be used to extrapolate it from previous data or if one of the components can be modeled as part of another component (e.g. a heat exchanger internal to an ICS unit).

6.0 General Testing Procedures

All system or component test objects shall be mounted in a manner that is similar to the intended usage. This requirement would include the use of such devices as reflectors and roof support structures. The intent is that all hydraulic, thermal, electrical and optical characteristics are reproduced during the test. Structural issues may be evaluated secondarily.

Delivery energy instrumentation shall be positioned so that the mixing valve, if tested, has no effect on the test results. On systems utilizing a NCL loop, the use of strap-on loop temperature sensors would be useful for obtaining information about NCL flow rates and comparing to those predicted by the TRNSYS models. For these types of systems, the instrumentation should not impede the fluid flow as this may adversely impact the performance of the system. Systems that have some type of self-draining mechanism shall be plumbed in such a manner so that a physical head of 4.88 m (16.0') is achieved. Any other required plumbing (heat traps, safety valves, drain lines, etc.) shall also be installed. A bypass loop, plumbed in parallel to the test object should be utilized to precondition the test loop before making purges to ensure inlet temperature stability.

On systems where an internal tank probe(s) can be inserted, this would be useful information for determining the satisfaction of the test criteria and for comparison with the TRNSYS models. One suggested method for determining average tank temperature is a line averaging RTD. When this method is used to measure average tank temperature, it is important to note that the cross sectional area of the tank perpendicular to the line of the RTD needs to be constant. If this is not possible, it may be possible to "correct" the measurement by physically weighting the RTD probe. For the standard application of internal tank probes, where used to measure required temperatures, probes should be placed no more than 0.3 m apart vertically and should be aligned vertically.

The applicability of extrapolating these test results to fluids other than water is limited. When testing with a fluid other than water, it is recommended that fluid composition tests be performed to ensure that the specified fluid composition exists. At a minimum, a hygrometer test or its equivalent should be performed and checked with the fluid specification before proceeding with the experiment.

Any system with a HX loop and a closed storage/HX unit (usually with an IHX or MHX) containing more than 2.5% (by volume) of the storage tank fluid shall be preheated to the same temperature as the rest of the system for all warm-up and tank tests prior to system operation. In most cases, desirable preheating of the closed storage unit will occur during the heating of the adjacent fluid. For atmospheric systems, the rate of the fill rate may be limited by the system's components. Note that these loops are not to be directly purged at the end of the test. However, the energy within them should be purged in the normal operating fashion. This may require extended draw periods.

Systems utilizing varying flow shall be run with the flow conditions expected during normal operational mode (collection, discharge, etc.).

No performance test shall be performed in excess of manufacturers recommended operating conditions. This may necessitate the adjustment of certain test operating conditions to conform to the intent of the test.

6.1 Recommended Instrumentation Accuracy/Resolution

Table 1 indicates the recommended assurances for the instrumentation required in the following tests. The radiation measurements shall be performed with devices that meet the standards of the World Meteorological Organization for a first class pyranometer or pyrheliometer. The data resolution shall be no lower than the stated accuracy.

Value to be Measured	Accuracy SI Units (±)	Accuracy IP Units (±)
Temperature	0.1˚C (precisión 0.1˚C)	0.2 ˚F (precisión 0.2 ˚F)
Temperature Difference	0.1 K (precisión 0.1 K)	0.2 R (precisión 0.2 R)
Mass	1%	1%
Fossil Fuel Usage	1%	1%
Electric Energy Usage	Max (1%, 15Wh)	Max (1%, 511 Btu)
Air Flow	1%	1%
Liquid Flow	1% measured mass value	1% measured mass value

Table 2.1 Instrumentation Accuracies

The test lab should ensure that data is checked for any offsets immediately prior to and at the conclusion of the test. Offsets should be applied to the processed data and noted in the test report.

6.2 Minimum Data Time Step

Unless otherwise indicated, all data shall be sampled with a maximum of a fifteen-second-time step. This data shall be averaged and reported at a maximum rate of 5 minutes for long-term tests (duration is longer than 1 day) or 0.5 minutes for short-term tests. Due the interaction with TRNSYS, which uses a fixed time step, it is required that all data for all collected channels shall be reported in fixed time steps. Note that any test using an energy purge should be measured with the highest practical data resolution.

6.3 Instrument Calibration

All instrumentation used in the experimental setup shall be calibrated to an accepted standard on a regular basis.

6.4 Required Experimental Data

6.4.1 Required Numerical Data

The minimum real time data to be collected for the tests shall consist of the following in SI/TRNSYS units. All data channels shall be reported on a regular time interval with non-null data, even if not used.

The test lab shall review for and address any missing or bad data. This data reduction should occur prior to submission for modeling.

Gaps or corrections for critical data shall not last any longer than 10 minutes during non-purge periods. During purge periods, no critical data should be missing or bad. The missing or adjusted data should be filled in using proxy measurements or interpolation to existing data and highlighted in the data set and noted in the test report.

A log indicating such things as the timing of the draw, purge, and irradiation start and stop times shall be included. Other data including site elevation, longitude, latitude, and test sample orientation shall also be supplied. Any data that does not meet these minimum requirements shall be rejected.

1. Data collection time (both local and solar) and date, and day of year (*dd-mm-yyyy*)
2. Inlet temperature(s) (ºC)
3. Outlet temperature(s) (ºC)
4. Ambient temperature (e.g. “Outside”, if applicable) (ºC)
5. Environmental temperature (e.g. “Inside”, if applicable) (ºC)
6. Flow Rate(s) (kg/hr)
7. Fluid heat capacities(s) (Kj/kg- ºC)
8. Wind velocity (m/s)
9. Auxiliary energy usage (if applicable) kJ
10. Radiation measurements (see below) (if applicable) (kJ/m^2)
    a. Total surface
    b. Total horizontal
    c. Horizontal diffuse
    d. Horizontal infrared (unglazed collectors only)

The radiation measurements shall include at least “a” through “c” above. Measurement “d” will depend upon the component type being tested.

Spreadsheets available from SRCC detail the format of the data that is required for each test type. The test labs should populate these as part of the testing process and use the checks on the QC and summary worksheets to ensure that testing requirements are met and the spreadsheet is filled out correctly. The raw data without any adjustments should also be provided.

6.4.2 Required Physical Data

Measure all easily accessible significant characteristics of the component or system, including:

a. Diameters and/or lengths and/ or widths (internal and external).

b. Lengths (internal and external) and spacing of tubes and/or fins.

c. Heights (internal and external), denote any minimum and maximum water levels.

d. Thickness (insulation, tank shell, tank vessel, fins, etc.).

e. Volumes (at T_{amb}) of the tank and any integral heat exchanger(s).

f. Provide a diagram indicating geometry including vessel, shell, and any protrusions such as HX's and plumbing connections.

g. Indicate materials used for vessel, insulation, shell, tank liner, heat exchangers.

h. Indicate piping lengths and orientations.

i. Indicate slope of components.

Measurements shall be reported in consistent sets of units, unless convention overrides this.

6.4.3 Additional Required Documentation

Provide documentation:

a. Equipment model number(s)

b. Description of the test method(s) and any deviations from the standard method. A test plan should be drafted by the test lab and approved prior to test initiation. This test plan should be included as part of the report.

c. Photographs of any applicable equipment.

6.5 Data Processing Methods

The goal of these tests methods is to provide data for TRNSYS modeling of systems and or system components. The method of modeling depends upon the test and available TRNSYS models. SRCC will provide direction for new and innovative system tests that are not explicitly covered in this test method.

Test labs are expected to perform the testing work and general data analysis using the SRCC supplied spreadsheets. SRCC will perform the analysis related to fitting TRNSYS to the test data.

The calculation of temperature dependent densities and heat capacities shall be done using real-time data by the test lab. Data reduction shall include the filtering out of any bad data. The Q_{del} value is to be used when matching net delivered energy with TRNSYS. Normally it is not necessary to adjust this value as the TRNSYS model accounts for tank energy changes (due to different starting and ending temperatures) and losses from the unit during the purge period.

It may be necessary to adjust some of the provided data so that it is consistent with the testing being done prior to submitting to SRCC. For example, to account for the covering of the collector during the purge period, it is necessary to zero the visual radiation and adjust the sky infrared radiation to an equivalent sky radiation if the pyranometer and pyrheliometer are not covered by the collector cover. Any adjustments should be noted in the test report and the provided data files.

The experimental and analytical work consists of several steps:

1. The test lab should determine physical parameter from the tests (e.g. length)

2. The test lab should run intermediate component tests (e.g. heat exchanger tests).

3. If applicable, the test lab should collect extended test data from a warm up tests that utilize data collected in steps 1 and 2.

4. The test lab will generate the analysis included as part of the SRCC supplied spreadsheets.

5. SRCC will determine intermediate or component values from component tests except those found in the spreadsheets indicated in step 4 (e.g. heat exchanger UA).

6. Where applicable, SRCC will determine system component values from component tests except those found in the spreadsheets indicated in step 4 (e.g. collector loss).

7. SRCC creates the audit TRNSYS models from the fits in steps 5 and 6.

8. SRCC creates a rating model from the fits determined in steps 5-7.

6.6 TRNSYS Processing for Component Model Calibration

Upon receipt of the processed data, a series of TRNSYS models are created. The modeling is usually performed by the certification agency. One model is created for each test. This model is called the “audit” model. Each of the audit models is then fit to the test data as indicated below:

a. Tank heat loss is generally determined as follows:

   1. When both capacitance and heat loss tests are performed:

      The results (in the spreadsheet available from SRCC) from the heat loss test and capacitance tests are iterated upon until a final value of tank loss UA value is determined.

      i. For standalone tanks, this value may be used as the starting point for the model calibration; however, the data from the tank tests is typically used directly to fit the TRNSYS loss value to the experimental results.

ii. For systems utilizing integral tanks (ICS, NSTS), the loss value is input to the model directly. No other explicit fit is done at this point.

2. Only the heat loss test is performed:

The results (in the spreadsheet available from SRCC) from the heat loss test are used to fit the TRNSYS model.

i. For standalone tanks, the data from the tank tests is used directly to fit the TRNSYS loss value to the experimental results.

ii. For systems utilizing integral tanks (ICS, NSTS), the loss value is input to the model directly. No other explicit fit is done at this point.

b. Parameters for heat exchangers integral to a tank are generally determined as follows:

i. For standalone tanks, a TRNSYS model is set up for each test. This model, along with the savings parameter from the test, is used to fit the entire set of data to determine the tank HX coefficients (NU coefficient and exponent, UA loss multiplier, or conduction resistance). The fit is done by minimizing the chi^2 value for all data sets.

ii. For collectors utilizing integral tanks (ICS, NSTS), the heat exchanger parameter(s) are input to the model directly. No other explicit fit is done at this point. The fit is done by minimizing the chi^2 value for all data sets.

c. The tank parameters from the tank tests (if applicable), the heat exchanger parameters from the heat exchanger tests (if applicable), the pump and PV panel parameters (if applicable), and the data from the flat plate thermal performance test (if applicable) will be used to create an audit TRNSYS model of the complete component. Minor variations of this model will be created for each of the data points to be evaluated. One model is created for each test run.

d. The data from each of the individual data points in the warm-up tests will be used to calibrate the TRNSYS model using the FR_{TA} and FR_{UL} isothermal initial conditions. A fitting routine will be used to fit the observed net, solar or auxiliary energy deliveries (to the observed data points (one per test). The fit is done by minimizing the chi^2 value for all data sets.

For ICS collectors, the FRUL adjustment is actually a UAloss adjustment since there is no FRUL data point. (Note that the ICS night time loss test shall be fit as part of the data set). The net result of this process are two points (FR_{TA} and FR_{UL}) that are used in the rating model.

e. If the tank is initially stratified due to the presence of a backup heater, a separate set of tests and fits may be required. This is typically done when a heater is located within the storage tank of a thermosiphon collector or within the heat exchanger zone of a storage tank.

7.0 Standard Experimental Procedures

7.1 Tank charge

Charge Method:

a. Charge may occur at any rate up to manufacturer's recommended maximum flow rate.

b. Heat and fully mix tank to $T_{initial}$ by filling with conditioned fluid until $\left|T_{in} - T_{del}\right| = 0.2°K\,(0.4°R)$ or $\frac{\partial\left|T_{in} - T_{del}\right|}{\partial t} = 0.05\,°K\,(0.09\,°R)$ for the minimum of a 10-minute period or the dwell (fill) time. The dwell time is the time required for the fluid leaving a tank to attain 63.2% of its steady state value following a step change in inlet fluid temperature.

7.2 Tank purge

Test Method:

a. Use the bypass loop to pre-condition the inlet water to the specified temperature before introducing water to the test article. Unless otherwise specified, the purge temperature is the same temperature as the charge temperature in order to minimize tank DE.

b. Purge the energy in the test article by circulating water through it.

c. Draw should occur at 0.125- 0.189 l/s (2-3 GPM) until $\left|T_{in} - T_{del}\right| = 0.2°K\,(0.4°R)$ or $\frac{\partial\left|T_{in} - T_{del}\right|}{\partial t} = 0.05\,°K\,(0.09\,°R)$ for a 10-minute period.

d. Conduct real time measurement of M_{drawn}, T_{in} T_{del} and T_{amb}

Analysis Method:

The analysis of all tank energy purges shall utilize the following equation:

$$Q_{del} = \int Rho\,(t) * C_p(t) * V_{rate} * \left[T_{del}(t) - T_{in}(t)\right] dt$$

If the capacitance test and the heat loss test are not run at the same initial temperature, adjust the delivered energy as follows:

$$T_{used} = \left.\frac{T_{tank\ ave\ orig} + T_{in}}{2}\right|_{purge}$$, average tank temperature during the heat loss test purge.

$$T_{test} = \left.\frac{T_{tank\ ave\ orig} + T_{in}}{2}\right|_{capacitance}$$, average tank temperature during the capacitance test.

$$Q_{initial} = Q_{del} * \frac{Rho(T_{used}) * Cp(T_{used})}{Rho(T_{Test}) * Cp(T_{Test})} * \frac{(T_{tank\ ave\ orig} - T_{in\ final})_{Used}}{(T_{tank\ ave\ orig} - T_{in\ final})_{Test}}$$

Where Q_{del} is the instantaneous purge energy and 'test' refers to the capacitance test conditions and 'used' refers to the heat loss purge conditions. $Q_{initial} = Q_{del}$ unless adjustment is required.

7.3 Installed Capacitance Test

The purpose of this test is to measure the tank capacitance value to be used in the loss test. This test is typically only required if it is determined that the tank could stratify significantly on charge due to parts of the tank not getting fully charged.

This test is to be performed indoors, preferably in an environment with nearly constant temperature. The unit is to be installed in a manner consistent with the intended system design. Piping connections are to be made, but isolated with valves. This test is typically performed before the loss tests so that a baseline tank capacitance can be determined. This test should also be used in conjunction with the solar testing to determine initial charge energy for a high temperature warm-up test. In these cases, the test does not necessarily have to be performed immediately before the system test if the tank and surroundings are maintained at similar temperatures before commencing this test and the subsequent warm-up tests.

a. Charge tank to T_{high} (see 7.1).

b. Measure ambient temperature during the entire test period.

c. Purge the energy in the tank (see 7.2) with $T_{in} = T_{amb}$

The resulting capacitance energy calculation from this test is used as the basis for the initial tank energy value in tests 7.4 and 7.5 when the construction characteristics of the tank make the analytical determination of this value difficult. The values for T_{high} and T_{low} should be set as part of the test or the extrapolation in Section 7.2 so that they match the corresponding test conditions for the heat loss test.

7.4 Heat Loss Test Methods

7.4.1 Heat Loss Test [Standard Decay Method]

Test Method:

This method can be used when:

- the tank can be placed in a nearly constant temperature room
- the tank capacitance can be readily determined
- the tank can be fully mixed.

The unit is to be installed in a manner consistent with the intended system design. This test is to be performed indoors, preferably in an environment with nearly constant temperature. Any source of heating, including resistance heaters and/or solar radiation, are to be shut off or blocked. All pumps, etc. should be shut off for the duration of the test. If the room temperature variation is greater than 10% or if significant stratification is anticipated, the use of internal tank temperature probe(s) is recommended, in which case the alternative test method should be used.

a. Charge the tank (see 7.1) to T_{high}.

b. Piping connections are to be made, but isolated with valves.

c. Wait until:

$$\frac{T_{\text{tank ave orig}} - T_{\text{amb ave}}}{3} \leq (T_{\text{tank ave final}} - T_{\text{amb ave}}) \leq \frac{2 * (T_{\text{tank ave orig}} - T_{\text{amb ave}})}{3}.$$

This will be estimated before the test is run using the known tank volume and estimated environmental temperatures. Measure the environment temperature during the entire test period.

d. Open the valves closed in step b.

e. Purge the remaining energy in the tank (see 7.2) with $T_{in} = T_{amb}$.

Analysis Method:

The following calculations shall be used, which assume ideal exponential temperature decay.

a. Determine tank thermal capacitance from either the capacitance test or a theoretical calculation.

1. Experimental Method (preferred, see 7.3)

$$M_{tank} * C_P = \frac{Q_{initial}}{T_{\text{tank ave orig}} - T_{\text{tank ave final}}}$$

2. Theoretical Method

This calculation should include full mass and C_P of all significant tank components

$$M_{tank} * C_P = M_{\text{tank shell}} * C_{\text{p-tank shell}} + M_{water} * Cp_{water} + M_{\text{tank components}} * Cp_{\text{tank components}}$$

b. Determine the steady state ideal heat loss (UA).

1. $T_{tank\ ave\ final} = T_{tank\ ave\ purge} + \dfrac{Qdel}{M_{tank} * C_p}$

2. $UA = \dfrac{M_{tank} * C_p}{Time_{decay}} * \ln\left[\dfrac{(T_{tank\ ave\ orig} - T_{amb\ ave})}{(T_{tank\ ave\ final} - T_{amb\ ave})}\right]$

Data from this test can be used to determine the $UA_{installed\ loss\ total}$. $UA_{isolated\ loss\ total}$ value is to be used in the TRNSYS tank model if both the capacitance and heat loss tests are used. Note the availability of the experimentally determined $Q_{initial}$ value in section 7.3. Determination of the UA and MCp values will require iteration of these values from these two tests (7.3 and 7.4.1) if both the capacitance and heat loss tests are conducted.

If only the heat loss test is run, the actual data from the test will be used in the TRNSYS model. In these cases, an estimate of MCp shall be input into the spreadsheet which includes the MCp of the water and an estimate of the MCp of the tank shell and/or other tank components that are heated up and/or discharged significantly during normal operation.

7.4.2 Heat Loss Test [Real Time Measurement Method]

Test Method:

This method should be applied when the tank is instrumented with internal tank temperature probes (e.g. a “tree”). The unit is to be installed in a manner consistent with the intended installation. This test is to be performed indoors. Any source of heating, including resistance heaters and or solar radiation, are to be shut off or blocked. All pumps, etc. should be shut off for the duration of the test.

a. Charge the tank (see 7.1) to T_{high}.

b. Piping connections are to be made, but isolated with valves.

c. Run the test until the following are satisfied, measuring the tank temperatures and environmental temperature during the entire test:

    a. The tank temperature drops at least 3°C.
    b. The differential between the average tank temperature and the average environmental temperature changes by at least 3°C.

d. Open the valves closed in step b.

e. Purge the remaining energy in the tank (see 7.2) with $T_{in} = T_{amb}$.

Analysis Method:

A real time numerical loss calculation is to be used to calculate the losses. The real time method requires the use of internal tank temperature measurements and is the preferred calculation method when this instrumentation can be installed. Tank Tave is calculated as the straight average of the equally placed temperature sensors on the tank tree.

a. $Q_{loss} = Q_{initial} - Q_{del}$ (the delivered energy from the purge)

b. Numerically solve for UA, $Q_{loss} = \sum UA * (T_{ank\ ave} - T_{amb}) * \Delta t$

Data from this test can be used to determine the $UA_{installed\ loss\ total}$. $UA_{isolated\ loss\ total}$ value is to be used in the TRNSYS tank model.

7.5 Solar Collector Warm-Up and Decay Tests

These are the primary set of tests used to calibrate the TRNSYS models to the experimental results. Due to the variation in the factors that influence the operation of the solar component of the different generic collectors, there is one primary set of tests. Several additional sets of tests (included in Appendix A) may also be specified as needed.

These tests have been designed for outdoor conditions. A solar simulator can be used with some adjustments; however, the use of a simulator requires that considerations for infrared radiation, diffuse radiation, ambient airflow, sky temperature, and the view of the collector be made when taking and/or analyzing the data.

An implicit consideration in these protocols when testing thermal collectors is that the collector is sized on the order of 60-80.3 l/m^2 (1.5-2 gal/ft^2) storage per collector area, which is typical of residential SDHW systems used in the United States. These tests are intended for collectors with at least 5 gallons (18.7 l) of capacity. If a particular collector/ design falls outside of this range, the test exposure times and temperature rises (see 7.5.1 and 7.5.2) shall be adjusted with respect to this ratio.

These tests are to be performed on the actual pre-heat collector installed in a conventional manner (with added instrumentation and bypass loops for preconditioning). If the system is a one-tank system with integral heating (except for PV water heating collectors), then this system shall be tested with and without the heater in operation. In the test with the heater, set $T_{set} = 50^{\circ}C$ ($122^{\circ}F$) and energize the heater for the first hour of each test if a stratified start is desired.

For active solar systems, an additional constraint is that the system pump shall be activated during purges to extract any uncaptured energy within the hydronic system (this should occur normally in most cases). For PV pump driven systems, the PV panel shall not be covered during the purge period, so that all of the collected energy can be purged.

Because of the variability of these tests, it may be necessary, when testing a thermal collector or system, to extract summary information from a previous test in order to set the operating conditions of a succeeding test. This is necessary so that the minimum temperature and/or radiation requirements are met. If the criteria are not met, it will be necessary to perform additional test(s) in order to satisfy the diversity of data. In general, the clear, low temperature tests are designed to give the “high” performance when the test is run at “cool” temperatures, and the cloudy, high temperature tests and nighttime decay tests are designed to give the “low” performance when the test is run at “high” temperatures. On the low temperature tests, the initial temp is preferably near the ambient air temperature. The high temperature test uses elevated starting temps. In addition to meeting the specified solar radiation, each individual warm-up test also shall have a minimal 5 K (9 R) tank temperature rise, to minimize the effect of errors in the experimental data. Decay tests should have a similar drop in temperature.

In tests utilizing an end of period purge, a cover shall be placed on the thermal collector component at the beginning of the purge process. The cover shall consist of 0.04 m (1.6 inches) insulation board, with foil-covered surfaces. The cover shall extend at least 0.08 m (3.1 inches) beyond the gross horizontal collector aperture area and cover any vertically exposed optical components. The exposed side of the cover shall be backed with any appropriate material required for structural rigidity and exposure to the weather (e.g. plywood and plastic).

Before commencing the warm up or decay tests on a thermal collector or system, it is necessary to pre-heat the entire collector to a uniform temperature. In collectors with integral collector and storage components (ICS), this is accomplished by fully mixing the collector heat transfer fluid. In systems utilizing a heat exchanger between the collector and storage components, it may be necessary to take additional steps to ensure that the collector is pre-heated to the tank temperature. For active systems, the pumps should be activated manually in order to fully mix the heat transfer fluid(s). The following are a few recommendations:

a. Desired tank temperature is close to the ambient temperature:

   1. Thermosiphon (NSTS): Uncover collector during mixing period (about 10 minutes prior to exposure start)

   2. Others: Cover collector

b. Desired tank temperature is lower than the ambient temperature:

   1. All: Cover collector

c. Desired tank temperature is higher than the ambient temperature:

   1. NSTS: Uncover collector during mixing period (about 10 minutes prior to exposure start)

   2. Others: Partially uncover the collector during mixing to allow some heating, do not allow stagnation.

All test articles shall be positioned and fixed with the collecting surface facing the equator. The recommended tilt for the collector in warm-up mode is that the collector should be normal to the sun at solar noon +/- 4° on the day of the test, unless this contradicts the manufacturers recommended tilt. For systems such as TS or SP, the manufacturer may recommend a minimum tilt to ensure adequate flow, in these cases, use the recommended tilt that will come closest to meeting the above requirement. For active systems, the operation of the controllers and pumps should be automatic once the manual mixing has been completed.

These procedures assume that T_{low} is relatively constant during the test period(s) and close to ambient temperature.

Wind at a speed between 1 and 3 m/s shall be required for the testing of units with integral storage tanks and/or unglazed collectors that have not been tested with a measured wind blowing across them.

For simulator testing, there are two different profiles for each of the "cloudy" days. The clear day has only one profile. The clear day is a constant 800 W/M^2 for 4 hours. The first cloudy day is a constant 400 W/m^2 for 6 hours. The second cloudy day is also 4 hours long consisting of rotating 30-minute periods of 200 W/m^2 and 600 W/m^2. Note there are no specific profiles for outdoor testing.

The warm-up tests on thermal collectors and systems are expected to yield a minimum of 4 data points (2 clear, low temperature differential and 2 cloudy, high temperature differential, where the differential is measured from the tank average temperature to the ambient average temperature). The warm-up tests on PV water heating collectors are expected to yield a minimum of 4 data points (2 clear days and 2 cloudy days). A data point (test) is considered to meet the criteria if the radiation condition is met and the minimal 5 K (9 R) tank temperature rise is achieved. The goal of the tests is to gather approximately 13,000 kJ/m^2 (1145 Btu/ft^2) of radiation for all tests (cloudy test length shall be adjusted to not exceed this value) to equalize relative experimental errors and to equally weight the various conditions. T_{in} should be selected so that T_{high} does not exceed T_{max}. Make all of the measurements listed in 6.4.1 during all the tests. The clearness index, K_T, is used to classify clear vs cloudy test conditions for exterior warm-up tests:

$$K_T = \frac{Horizontal\ Irradiance}{Extraterestrial\ Horizontal\ Irraciance}$$

where the extra-terrestrial horizontal irradiance is given by:

$$G_o = (G_{SC} * [1+ 0.033 \cos(D)] \cos \theta$$

where:

$D = 2\pi n / 365$ radians

n = day of the year, ranging from 1 on January 1 to 365 on December 31

Report the results of this test using the spreadsheet available from SRCC.

Appendix B contains some other tests developed for non-standard collector.

7.5.1 Warm Up Test Clear, Low Temperature Differential, Isothermal Start

This test is to be performed on a minimum of two clear ($0.65<K_T$) days. For simulator testing, only one test needs to be performed.

a. Charge the collector (see 7.1) until $T_{initial}$ = $T_{low.}$ T_{low} needs to be low enough [typically 20°C (68°F)].so that the T_{high} requirement (see 7.5.2) can be met.

b. Expose the collector for 3-4 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with T_{in} = T_{low}.

d. Check radiation requirements (see 7.5) to see if further data is required.

7.5.2 Warm Up Test: Cloudy, High Temperature Differential, Isothermal Start

This test is to be performed on a minimum of two cloudy (K_T<0.65) days.

a. Charge the collector (see 7.1) until $T_{initial}$= $T_{high,}$ where T_{high}=T_{low}+30° C (approximately).

b. Expose the collector for 5-6 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with T_{in} = T_{high}.

d. Check the radiation requirements (see 7.5) to see if further data is required.

8.0 PV Water Heater Collectors

9.0 Storage Tank Tests

In general, these tests are to be performed for any storage tank that can be physically separated from the solar component. Any integral heat exchanger shall be filled with the specified operating fluid and external connections shall be sealed and insulated. If required, preheating of the specific operating fluid shall also be done. Conventional, commercially available water heaters are modeled in TRNSYS without additional testing for a specific system certification. All others shall undergo the tests specified here.

Wind at a speed between 1 and 3 m/s shall be blown across the face of any tank unit that is to be used outdoors and is not to be tested in outdoor warm-up tests.

9.1 Storage Tank Qualification Tests

Collect physical data (see 6.4.2).

9.2 Storage Tank Pressure Integrity Tests

These tests are only required if the tank has not undergone similar testing by an approved certification agency.

The minimum test pressure shall be 1100 kPa Gauge (160 PSIG) for street pressurized portions of the storage tank.

For non-street pressurized portions of the unit rated above 550 kPa gauge (80 PSIG), the minimum test pressure is the smaller of one and one half times the manufacturer's rated pressure or 1100 kPa gauge (160 PSIG).

For non-street pressurized portions of the unit rated below 550 kPa gauge (80 PSIG), a pressure of one and one half times the manufacturer's rated pressure with a minimum of 170 kPa Gauge (25 PSIG) is required.

For unpressurized portions of the unit, the minimum pressure will be set by the certification body using the manufacturer's design pressure as a guideline.

The result of this test is "pass" if no observable pressure change has occurred.

Note that any internal heat exchangers shall be tested in accordance with Section 10.2 below.

For tanks with no built-in heat exchanger, only one of the tests described in Sections 9.2.1 and 9.2.2 is required.

9.2.1 Storage Tank Supply Side of Tank

a. A pressure gauge is attached to the exit port of the supply side (heat exchanger or tank) and the outlet is sealed.
b. The supply side is filled with unheated water.
c. Hydraulic pressure is applied to the supply side inlet port until the gauge indicates that the test pressure has been reached.
d. The inlet pressure port is then closed and the pressure is monitored for 15 minutes.
e. The final pressure is recorded.

9.2.2 Storage Tank Load Side of Tank

a. A pressure gauge is attached to the exit port of the load side (heat exchanger or tank), and the outlet is sealed.
b. The load side is filled with unheated water.
c. Hydraulic pressure is applied to the inlet port until the gauge indicates the test pressure has been reached.
d. The inlet pressure port is then closed and the pressure is monitored for 15 minutes.
e. The final pressure is recorded.

Note: Internal coil heat exchangers often compress when pressure is applied on the outside of the coil. This can lead to a relaxing of the applied pressure outside of the coil. Care should be taken to avoid recording a false failure due to compression (creep) of the coil heat exchanger.

9.3 Storage Tank Capacitance Test

Conduct a capacitance test (see 7.3). Report the results of this test using the spreadsheet available from SRCC.

9.4 Storage Tank Heat Loss Test

There are two recommended methods for determining tank losses: the decay test and the constant temperature loss test. The decay test (7.4.1 or 7.4.2) is recommended for most applications. However, when there is a significant degree of stratification during the test that cannot be measured by an internal probe, the constant temperature loss test (optional method, see Appendix B) may be used. Note that this test will tend to increase the loss value slightly due to the movement of the fluid in the tank.

Report the results of this test using the spreadsheet available from SRCC.

a. Conduct a heat loss test (see 7.4).

b. Constant Temperature Loss Test [Optional Method] see Appendix B.

10.0 Heat Exchanger Tests

These tests are to be performed with the heat transfer fluid(s) to be used in the installed system. If multiple fluids are to be used, tests using each fluid are required. The preferred testing conditions are indoors, although outdoor tests may be performed if the collector is covered during the test. For separable thermosiphon systems, these tests will be required. Heat exchangers shall be tested with the fluid levels and flows encountered during normal operation.

10.1 Heat Exchanger Qualification Tests

Collect physical data (see 6.4.2).

10.2 Heat Exchanger Pressure Integrity Tests

The test pressure shall be 1100 kPa Gauge (160 PSIG) for street pressurized portions of the heat exchanger.

For non-street pressurized portions of the unit rated above 550 kPa gauge (80 PSIG), the test pressure is the smaller of one and one half times the manufacturer's rated pressure or 1100 kPa gauge (160 PSIG).

For non-street pressurized portions of the unit rated below 550 kPa gauge (80 PSIG), a pressure of one and one half times the manufacturer's rated pressure with a minimum of 170 kPa Gauge (25 PSIG) is required.

For unpressurized portions of the unit, the pressure will be set by the certification body using the manufacturer's design pressure as a guideline.

The result of this test is "pass" if no observable pressure change has occurred.

10.2.1 Supply side of Heat Exchanger Pressure Integrity Test (As applicable)

a. A pressure gauge is attached to the exit port of the heat exchanger's supply side and the outlet is sealed.

b. The supply side is filled with unheated water.

c. Hydraulic pressure is applied to the inlet port until the gauge indicates that the test pressure has been reached.

d. The inlet pressure port is then closed and the pressure is monitored for 15 minutes.

e. The final pressure is recorded.

10.2.2 Load side of Heat Exchanger Pressure Integrity Test (As applicable)

a. A pressure gauge is attached to the exit port of the heat exchanger's load side and the outlet is sealed.

b. The load side is filled with unheated water.

c. Hydraulic pressure is applied to the inlet port until the gauge indicates that the test pressure has been reached.

d. The inlet pressure port is then closed and the pressure is monitored for 15 minutes.

e. The final pressure is recorded.

10.3 Heat Exchanger Pressure Drop Test

These tests shall be conducted at 37.78°C (100°F) +/- 5 K (9 R). The flow rates used for testing the heat exchanger should satisfy the following criteria: They should adequately represent the anticipated laminar, transition, and turbulent flow regimes experienced during operation. Note that some units, such as thermosiphon units, may have flow rates only in the laminar range and thus should be tested accordingly. For NCL testing, the unit should be oriented horizontally.

The temperatures and heat transfer fluids used in the heat exchanger should represent the certified system. A minimum of three valid data points shall be collected for each specified temperature/flow/fluid combination.

a. Supply Side of Heat Exchanger (As applicable)

   1. Heat fluid to specified operating temperature at the specified flow rate.

   2. Allow the pressure transducers to stabilize and measure the pressure drop.

   3. Repeat steps 1 and 2 for each specified flow rate.

b. Load Side of Heat Exchanger (As applicable)

   1. Heat fluid to specified operating temperature at the specified flow rate.

2. Allow the pressure transducers to stabilize and measure the pressure drop.

3. Repeat steps 1 and 2 for each specified flow rate.

A second order pressure drop curve shall be generated for both the supply side and load side coils.

For NCL modeling, thermosiphon flow rates shall be calculated from an energy balance on the heat exchanger, using measured temperatures and collector flow rates. A second order fit of pressure drop (Pa) vs. flow (kg/hr) will be generated for the NCL side of the HX.

10.4 Heat Exchanger Performance Tests

The flow rates used for testing heat exchangers shall adequately represent the anticipated laminar, transition, and turbulent flow regimes experienced during system operation. Note that some units, such as thermosiphon units, may have flow rates only in the laminar range and thus should be tested accordingly. Only for load side heat exchangers, where the load is the domestic hot water draw, the following flow rates shall be used: 0.032, 0.095, 0.19 l/s (0.5, 1.5, 3.0 GPM).

Report the results of this test using the spreadsheet available from SRCC.

For heat exchangers tested under low flow operating conditions (NCL), special care shall be taken for the accuracy of flow and temperature information. The use of a thermopile is required for measuring the temperature difference between inlet and outlet ports. The preferred method is to operate the heat exchanger with the NCL loop in operation. In these cases, the flow rate will have to be backed out of the energy balance of the “tank” and “collector” loops. No flow meter shall be used in the NCL test loop in these cases. When the energy balance technique cannot be used to measure the flow, use a forced flow and a low flow meter.

10.4.1 External Doubly Pumped Heat Exchangers

Test Method:

a. Stabilize flow rates to within +/- 0.006 l/s (0.1 GPM) and temperatures to +/- 0.1 K (0.2 R) of that specified in the table below.

b. Commence data collection at 15-second intervals. The rate of data collection and/or stabilization time shall be increased for any flows at or below 0.0315 l/s (0.5 GPM).

c. Run the test for a minimum of 10 minutes.

d. Adjust the temperatures and/or flow rates and proceed to step “a” above until the proper number of valid data points has been collected, as indicated below.

e. Provide summary results:

Sample External Heat Exchanger Effectiveness Test Results

"Hot Side" Heat exchanger flow rate (kg/sec): ______________________
"Hot Side" Heat exchanger fluid: ________________________
"Cold Side" Heat exchanger flow rate (kg/sec): ______________________
"Cold Side" Heat exchanger fluid: ________________________

$T_{Cold\ in}$ (°C) → $T_{Hot\ in} - T_{Cold\ in}$ (K)	10	60 (conduct the test at this temperature only on supply side heat exchangers)
5	Enter effectiveness here	Enter effectiveness here
20	Enter effectiveness here	Enter effectiveness here

For each test point, provide the following raw data in a Microsoft Excel spreadsheet:

- Heat exchanger inlet ($T_{HX\ inlet}$) on both the hot and cold sides
- Heat exchanger outlet ($T_{HX\ outlet}$) on both the hot and cold sides
- Heat exchanger flow rate ($FLOW_{HX}$) on both the hot and cold sides
- Environment temperature near the heat exchanger
- Energy transferred to the cold fluid
- Duration of the test point (minutes: seconds)
- Calculate the heat exchanger effectiveness:

$$\varepsilon = \frac{Q}{Q_{max}} = \frac{\dot{m}\, C_p (T_{out} - T_{in})_{cold\ side}}{C_{min}(T_{hot_{in}} - T_{cold_{in}})}$$

Analysis:

a. The goal is to obtain steady state data for each operating condition.

b. The data from each of the data point sets in the test will be used in the TRNSYS model using the calculated ε or equivalent UA values in the selected heat exchanger model.

c. For external HX models that only have a single input for ε or UA, a straight average of all the calculated ε or UA values from the table above will be used for modeling the HX in TRNSYS. This single value will be used for all applications of this HX with similar design parameter including flow, temperatures, and fluids.

10.4.2 External NCL Heat Exchangers - Empirical Parameter Method

Test Method:

a. Connect heat exchanger, tank and piping together, allowing for the external control of tank and collector temperatures.

b. Start data collection in 15-second intervals. The data will include the two inlet and outlet temperatures, ambient temperature, the collector-side flow rate, and the flow rate through the tank (not between the tank and the heat exchanger). Additional temperature measurements may be needed because of the non-linear nature of the heat transfer in long heat exchangers. If necessary, this can be accomplished by using three surface probes (assumed to be on the outer surface) and two internal probes at the NCL inlet and outlet ports.

c. Maintain the tank at a constant temperature near the ambient temperature by using a measured flow of tempered water.

d. Stabilize collector flow to within +/- 0.006 l/s (0.1 GPM) and temperature to +/- 0.1 K (0.2 R) of that specified.

e. Measure all heat exchanger temperatures, heat exchanger hot side flow rate, and energy required to maintain the tank at a constant temperature.

f. Every 15 minutes, raise the heat exchanger inlet temperature by 15 K (8.333 R) until it reaches 95°C (203°F).

g. Stop flow to the tank.

h. Maintain heat exchanger inlet temperature at 95°C (203°F).

i. Measure all heat exchanger temperatures and collector-side flow rate.

j. Stop the test when the tank is within 1 K (1.8 R) of the temperature of the fluid entering the collector side of the heat exchanger. This may take up to 1 day.

Analysis Method:

a. The use of linear regression software is a necessary component of data analysis.

b. Use the data from both portions of the test along with material properties to generate a fit in the following form: $UA = P1 Gr^{P2} Re^{P3} Pr^{P4}$

Where P1 through P4 are coefficients from the fit and the Gr, Re, and Pr are calculated dimensionless values. UA is calculated using standard heat transfer forms for the geometry of the heat exchanger and its plumbing connections. The thermosiphon flow rate is calculated from an energy balance on the system. (This may require that other losses be quantified first).

10.4.3 External NCL Heat Exchangers- Modified Effectiveness Method

Test Method:

a. Connect the heat exchanger, tank and piping together, allowing for external control of tank and heat exchanger hot side temperature. The collector loop must be supplied with a controllable hot water loop.

b. Measure the heat loss coefficient of the heat exchanger.

c. Start data collection at 60-second intervals. The data must include the two heat exchanger inlet and outlet temperatures, ambient temperature, and the collector loop flow rate.

d. Stabilize collector flow to within +/- 0.006 l/s (0.1 GPM) and temperatures to +/- 0.1 K (0.2 R) of that specified in the table below.

e. Measure all heat exchanger temperatures, heat exchanger hot side flow rate, and ambient temperature.

f. Run the test for the minimum time indicated below.

f. Set the collector and tank loop temperatures for each of the following sample cases. Additional cases may be required for different fluids, flow rates, etc. Collect data for the indicated periods.

Sample Case	**Collector**	**Tank**	**Length (hr)**
1	80	15	2
2	65	40	2

Analysis Method:

a. Thermosiphon flow rates shall be calculated from an energy balance on the heat exchanger, using measured temperatures and collector flow rates. Allowances shall be made for thermal losses from the HX. Plot thermosiphon flow versus time for the various tests.

b. Calculate the driving pressure using average tank and HX (NCL loop) temperatures, along with the density of the fluids as a function of temperature. Fit the flow to:

Equation 1: $M = C_1 * \Delta P^{C2}$

Plot Flow vs ΔP for the test period.

c. Generate fits of heat exchanger performance in terms of modified effectiveness vs. flow rate and modified capacity ratio. Calculations will be based upon Equations 2 and 4 of the Lin/Harrison analysis.

Equation 2: $$\varepsilon_{mod} = \frac{(M_{tank} * CP_{tank}) * (T_{tankout} - T_{tankin})}{(M_{coll} * CP_{coll}) * (T_{collin} - T_{tankout})}$$

Equation 4: $$Crmod = \frac{M_{tank} * CP_{tank}}{M_{coll} * CP_{coll}}$$

Using these values, calculate a fit for $Cr\,\mathrm{mod}$ as in Equation 5:

Equation 5: $$\varepsilon_{mod} = C_1 * Cr\ \mathrm{mod}^2 + C_2 * Cr\ \mathrm{mod}$$

Plot ε_{mod} as a function of $Cr\,\mathrm{mod}$ for the test period.

10.4.4 Integral Tank Supply Side Heat Exchanger (Wrap around or Immersed)

Two approaches can be utilized to measure tank temperature:

1. The preferred approach is to utilize a tank temperature “tree” that contains equal vertically spaced temperature sensors. The average tank temperature is based upon an average of the individual sensors. If this approach is utilized, the tank purge is not required.

2. The optional approach is to utilize the tank inlet and outlet ports with temperature sensors to estimate average tank temperature. The average tank temperature is based upon an average of these two sensors when tank flow is occurring. If this approach is utilized, a tank purge is required to quantify actual tank temperatures. This approach should be utilized when a “tree” cannot fit into the tank or if the test lab cannot perform the preferred method.

Test Method

a. Charge the tank to the specified temperature (select from the table below), typically above ambient. (See 7.1)

b. Tank flow should be shut off during the HX charging period unless the tank flow would normally occur during most of the time the HX is operating.

c. Stabilize heat exchanger flow to within +/- 0.006 l/s (0.1 GPM) and temperature (T_{in}) to +/- 0.1 K (0.2 R).

d. Commence data collection at 15-second intervals. The rate of data collection and/or stabilization time shall be increased for any flows at or below 0.0315 l/s (0.5 GPM).

e. Run the test with stable inlet flow rate and temperature until at least 2000 kJ of energy has been transferred through the HX. Ideally, the amount of energy transferred is the same for each test point.

If using a tank purge:

Run the test so that there is a significant change in tank temperature (at least 5 K (9 R)) to limit experimental error. Purge tank at the specified test temperature ensuring that the change in tank internal energy (DE), from the start of that heat exchanger test to the end of that purge, is minimized.

If a tank temperature "tree" is used, measure internal tank temperatures using the "tree" to confirm that added energy (from both the heat exchanger and any auxiliary input) is consistent with the internal energy change in the tank.

f. Repeat steps a-e for various flow rates (laminar, transition, and turbulent) heat exchanger inlet/tank temperature differences, and tank temperatures as shown in the table below.

g. Provide the results of the tests in the spreadsheet available from SRCC.

If there is any backup energy input to the tank below the top edge of the heat exchanger, repeat tests a-g with these two steps inserted between 4.b and 4.c:

4.b.i Activate power or fuel to the backup heater.

4.b.ii Wait for the heater to cycle on and then off. Then turn off the power or fuel to the backup heater.

Sample Integral Supply Side Heat Exchanger Test Summary

Heat exchanger flow rate (kg/sec):		Heat exchanger fluid:
Tank flow rate (kg/sec)		Tank fluid:
T_{tank} (C) → $T_{HX\ inlet} - T_{tank}$ (K)	10	60
5		
20		

The following data shall be provided in the spreadsheet available from SRCC. Environment temperature near tank (T_{env})

- Supply Side Heat exchanger inlet ($T_{HX\ inlet}$)
- Supply Side Heat exchanger outlet ($T_{HX\ outlet}$)
- Supply Side Heat exchanger flow rate ($FLOW_{HX}$)
- Tank average temperature ($T_{tank\ ave}$)
- Tank inlet temperature ($T_{in)}$
- Tank discharge temperature ($T_{del)}$
- Tank flow rate ($FLOW_{TK}$)
- Auxiliary input energy

Analysis Method:

a. The spreadsheet available from SRCC will analyze the data to determine the following energy flows:

   1. Heat exchanger input energy
   2. Tank differential energy (DE).
   3. Estimated tank losses
   4. Purge energy (if a "tree" is not utilized)
   5. Auxiliary input energy

b. The data from each of the data point sets in the test will be used to calibrate the TRNSYS rating model using the UA value and exponent in the tank coil heat exchanger model. The highest accuracy data set should be utilized for this process. A fitting routine will be used to fit the observed energy input to the observed data points (one per data point). See section 6.6 for additional details.

10.4.5 Integral Tank Load Side Heat Exchanger (Immersed Coil)

Two approaches can be utilized to measure tank temperature:

1. The preferred approach is to utilize a tank temperature "tree" that contains equal vertically spaced temperature sensors. The average tank temperature is based upon an average of the individual sensors. If this approach is utilized, the tank purge is not required.

2. The optional approach is to utilize the tank inlet and outlet ports with temperature sensors to estimate average tank temperature. The average tank temperature is based upon an average of these two sensors when tank flow is occurring. If this approach is utilized, a tank purge is required to quantify actual tank temperatures. This approach should be utilized when a "tree" cannot fit into the tank or if the test lab cannot perform the preferred method.

Test Method:

a. Charge the tank to the specified temperature.

b. Tank flow should be shut off during the HX charging period unless the tank flow would normally occur during most of the time the HX is operating (For example, in a drain back tank with a load side heat exchanger, the collector loop will be flowing during the day. If most of the load is drawn during the day, there will be flow on both sides of the heat exchanger.).

c. Stabilize heat exchanger flow to within +/- 0.006 l/s (0.1 GPM) and temperature (T_{in}) to +/- 0.1 K (0.2 R).

d. Commence data collection at 15-second intervals. The rate of data collection and/or stabilization time shall be increased for any flows at or below 0.0315 l/s (0.5 GPM).

e. Run the test with stable inlet flow rate and temperature until at least 2000 kJ of energy has been transferred through the HX. Ideally, the amount of energy transferred is the same for each test point.

If using a tank purge:

Run the test so that there is a significant change in tank temperature (at least 10 K (18 R)) to limit experimental error.

Re-charge (purge back to the starting temperature) the tank at the specified test temperature ensuring that the change in tank internal energy (DE) from the start of that heat exchanger test to the end of that purge is minimized.

If a tank temperature "tree" is used, measure internal tank temperatures using a "tree" to confirm that the energy removed by the load-side heat exchanger is consistent with the internal energy change in the tank.

f. Repeat steps a-e for the desired flow rates (laminar, transition, and turbulent, or those specified for domestic water flow), heat exchanger inlet temperatures, and tank temperatures shown in the table below. For load side heat exchangers, where the load is the domestic hot water draw, the following flow rates shall be used: 0.032, 0.095, 0.19 l/s (0.5, 1.5, 3.0 GPM).

g. Provide the results of the tests in the spreadsheet available from SRCC.

Sample Integral Load Side Heat Exchanger Test Summary

Heat exchanger flow rate (kg/sec):		Heat exchanger fluid:
Tank flow rate (kg/sec)		Tank fluid:
T_{tank} (C) → $T_{HX\ inlet}$ (C)	10	60
5		
15	---	
30	---	

The following data shall be provided in the spreadsheet available from SRCC.

- Environment temperature near tank (T_{env})
- Load Side Heat exchanger inlet ($T_{HX\ inlet}$)
- Load Side Heat exchanger outlet ($T_{HX\ outlet}$)
- Load Side Heat exchanger flow rate ($FLOW_{HX}$) Tank average temperature ($T_{tank\ ave}$)
- Tank inlet temperature ($T_{in)}$
- Tank discharge temperature ($T_{del)}$
- Tank flow rate ($FLOW_{TK}$)

Analysis Method:

a. Data analysis should determine the following energy flows utilizing the templates available from SRCC:

1. Heat exchanger energy transfer
2. Tank differential energy (DE).
3. Estimated tank losses
4. Re-charge energy (if a "tree" is not utilized)
5. Auxiliary input energy

b. The data from each of the data point sets in the test will be used to calibrate the TRNSYS model using the UA value and exponent in the tank coil heat exchanger model. The highest accuracy data set should be utilized for this process. A fitting routine will be used to fit the observed energy deliveries to the observed data points (one per data point). See section 6.6 for additional details.

10.4.6 Integral Thermosiphon Tank Supply Side Heat Exchanger (Mantle and Immersed Coil)

Two approaches can be utilized to measure tank temperature:

1. The preferred approach is to utilize a tank temperature "tree" that contains equal vertically spaced temperature sensors. The average tank temperature is based upon an average of the individual sensors. If this approach is utilized, the tank purge is not required.

2. The optional approach is to utilize the tank inlet and outlet ports with temperature sensors to estimate average tank temperature. The average tank temperature is based upon an average of these two sensors when tank flow is occurring. If this approach is utilized, a tank purge is required to quantify actual tank temperatures. This approach should be utilized when a "tree" cannot fit into the tank or if the test lab cannot perform the preferred method.

Test Method:

a. Charge the tank to the specified temperature, typically above ambient.

b. Tank flow should be shut off during the HX charging period unless the tank flow would normally occur during most of the time the HX is operating.

c. Stabilize heat exchanger flow to within +/- 0.003 l/s (0.05 GPM) and temperature (T_{max}) to +/- 0.1 K (0.2 R).

d. Commence data collection at 10-second intervals.

e. Run the test for approximately 10-60 minutes, so that there is a significant change in tank temperature. Ideally, the time period shall be set so that the amount of input energy is the same for each test and enough energy (2000 kJ minimum) is input to avoid experimental error.

f. Purge tank at the specified temperature or measure internal tank temperatures using a "tree" to determine added energy.

g. Repeat steps "a-f" for the flows and temperatures in the table below:

Test #	Flow l/s (GPM)	Tank Temperature C (F)	HX Inlet Temperature C (F)
1.	0.006 (0.1)	20 (68)	30 (86)
2.	0.03 (0.5)	20 (68)	30 (86)
3.	0.006 (0.1)	20 (68)	60 (140)
4.	0.03 (0.5)	20 (68)	60 (140)

5.	0.006 (0.1)	40 (104)	60 (140)
6.	0.03 (0.5)	40 (104)	60 (140)
7.	0.006 (0.1)	50 (122)	60 (140)
8.	0.03 (0.5)	50 (122)	60 (140)

h. Provide the results of the tests in the spreadsheet available from SRCC.

Sample Mantle Supply Side Heat Exchanger Test Summary

Heat exchanger flow rate (kg/sec):		Heat exchanger fluid:	
Tank flow rate (kg/sec)		Tank fluid:	
T_{tank} (C) → $T_{HX\ inlet}$ (C)	20	40	50
30		---	----
60			

The following data shall be provided in the spreadsheet available from SRCC:

- Environment temperature near tank (T_{env})
- Supply Side Heat exchanger inlet ($T_{HX\ inlet}$)
- Supply Side Heat exchanger outlet ($T_{HX\ outlet}$)
- Supply Side Heat exchanger flow rate ($FLOW_{HX}$)
- Tank average temperature ($T_{tank\ ave}$)
- Tank inlet temperature (T_{in})
- Tank discharge temperature (T_{del})
- Tank flow rate ($FLOW_{TK}$)

Analysis Method:

a. Data analysis should determine the following energy flows utilizing the SRCC spreadsheet:

    1. Coil charge energy
    2. Tank DE
    3. Estimated tank losses
    4. Purge energy (if a “tree” is not utilized)
    5. Auxiliary input energy

b. The data from each of the data point sets in the test will be used to calibrate the TRNSYS rating model using the UA gain value of the thermosiphon model. The highest accuracy data set should be utilized for this process. A fitting routine will be used to fit the observed energy input to the observed data points (one per data point).

c. For mantle heat exchangers, the physical dimensions of the heat exchanger are entered into the model. For the immersed coil heat exchangers, the model is configured as an open loop system.

d. The model is configured so that the collector input is equated to the "solar" input for the model, and $T_{ambient}$ of the collector is set to the HX inlet temperature. $T_{environment}$ of the tank is set to the tested ambient temperature. See section 6.6 for additional details.

11.0 Solar Photovoltaic (PV) Component Tests

PV panels may be used to provide electrical energy for either system pumping or for system heating. Section 11.1 outlines requirements for all PV panels. Additional performance data requirements for DC pumping applications are outlined in section 11.2. Section 11.3 outlines requirements for DC pumps powered by PV panels, and section 11.4 outlines requirements for Inverters. Section 11.5 specifies the tests required for PV water heaters where the storage fluid is heated by PV generated electricity.

11.1 Photovoltaic Panel

All PV Panels shall be listed to the following standards:

a. IEC 61215 or IEC 61646 (depending upon panel type)
b. UL 1703

These reports shall be provided to SRCC with the application for certification.

11.2 Photovoltaic Panel Performance Map (I and V Vs G curves and T_{pv})

Test Method:

The current analysis method does not integrate the panel temperature into the empirical curve fit. Therefore, it is required that the panel temperatures be maintained within the range of 35-45°C (95-113°F).

a. Expose the panel to varying amounts of solar radiation between 100-1000 W/m^2 (32-317 $Btu/h\text{-}ft^2$) by varying the azimuth and tilt of the collector or the irradiance level if tested indoors. Obtain data at irradiance levels no greater than 150 W/m^2 apart.

b. For each irradiance level, ramp the panel through a series of voltages from open circuit to short circuit using a controllable load.

c. Measure the observed current, voltage, irradiance, panel temperature, and ambient temperature for each set of data.

Analysis Method:

For each set of irradiance data, generate empirical curve fits relating current to voltage for each radiation data set. Note that the panel temperature relationship is not currently fit.

11.3 DC Pump Performance Map (P_{pump} Vs H_{pump})

Test Method:

All pumps shall be tested with the specified fluids at a temperature of 38˚C (100˚F).

a. Subject the pump to a series of system pressure drops by adjusting the throttle on the system loop containing the pump.

b. For each throttle adjustment, subject the pump to varying voltages by using a variable power supply.

c. Measure the observed flow rate, pressure increase across the pump, pump voltage and current draw.

Analysis Method:

See Appendix A for additional information on this method.

a. Generate empirical curve fits relating pump head to flow and voltage.

b. Generate empirical curve fits relating pump head to flow and current.

c. Determine the system pressure drop curve based on the certification program assumptions for plumbing.

d. Generate an empirical curve fit relating pump flow to irradiance for the specified PV module and DC pump combination for the system using the fits in a-c and the results of 11.1.

e. In order to model PV pumping, the fits of flow vs. irradiance and power vs. flow are used in the TRNSYS model, along with the starting radiation and average and maximum pump flow rate to model PV driven pumping.

11.4 Inverter Efficiency

All inverters shall be listed to UL 1741

Efficiency relative to maximum power output shall be measured at the following points. This data shall be provided to SRCC:

a. 25% of maximum output
b. 50% of maximum output
c. 75% of maximum output
d. 100% of maximum output

11.5 PV Water Heater

A PV water heating collector is defined as the PV module(s), the inverter/converter, and the heating element(s). The collector shall be tested as a complete unit. If the collector will always be connected to a specified tank, that tank shall also be included in the test. If the PV collector can be installed on any tank, the test shall include a tank of the size specified by the PV collector manufacturer.

Measure all of the physical parameters:

- PV module size
- Wire sizes and lengths
- Electric element resistance

Document the model and serial number of all components.

Conduct the warm-up test specified in Section 7.5.1,

When testing the PV water heating collector:

- The tank used in the test must be characterized in accordance with Section 7.4,
- The power wiring between the PV array and the heating element must be 7.6 +/- 0.76 meters.
- The current through and the voltage at the output of the PV array and across the heating element shall be measured at the rate specified in Section 6.2.

Requirements:

- All wiring and disconnects shall comply with NFPA 70 and the local requirements of the Authority Having Jurisdiction at the installation site.
- Flash test data for every PV module submitted with the collector for testing shall be provided to SRCC.
- The tested output of every PV module submitted with the collector for testing shall be within +/- 5% of the nominal output claimed for the collector.

Appendix A

Analysis Method for Evaluating PV Powered DC Pumps in Solar Thermal Systems

To model the performance of solar thermal system using photovoltaic PV driven pumps it is necessary to characterize the operation of the fluid circulation system. Outlined below is a method to mathematically combine measured and modelled performance of individual components in a PV forced-circulation system to predict the collector loop flow rate as a function of solar irradiance. The fits are set up to discard any data that is not interpolated, so the data sets shall have ranges exceeding the desired system operation. This method assumes the pump and PV module are directly connected. If any controls are integrated into either component, the pair shall be tested together under varying levels of irradiance and under varying pump heads.

A.1 Analysis Method for Evaluating the System

The performance of a system comprised of multiple components can be predicted if the performance of the individual components is known and there is no active control done by any component. A PV forced-circulation system has three main components. These components are the pump, the system piping, and the PV panel. The variables associated with each component are:

Pump – current (I), voltage (V), flow (F), and head (H)

System piping – flow (F) and head (H)

PV Panel – current (I), voltage (V), irradiance (G), PV panel temperature (Tpv)

The performance of each component can be empirically described as functions of these variables. The form of the equations representing the functions varies with the specific components. Some can be represented by simple quadratics while others are more complex. The attached figures illustrate one specific example.

Pump performance can be measured directly under various conditions in a test stand (see E.2). All four pump variables can be measured simultaneously. Surface fitting the data yields two functions:

{1} H as a function of F and V:

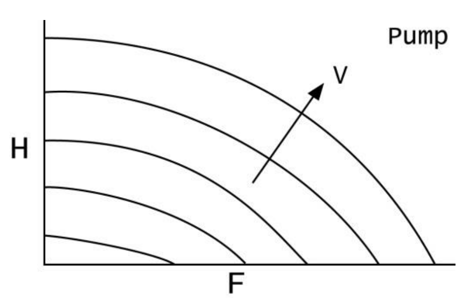

Figure E1

{2} H as a function of F and I:

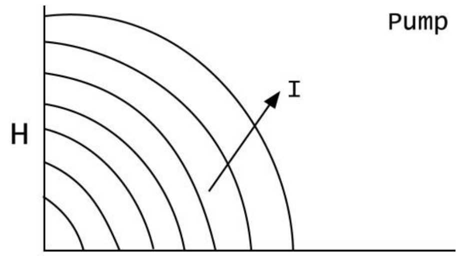

Figure E1

The system piping performance can be predicted using a pipe distribution analysis program [1]. However, most commercial programs are not well suited for laminar flow applications, because of the relative differences in fitting losses and the correlations used to predict them. Curve fitting the data yields one function:

{3} H as a function of F:

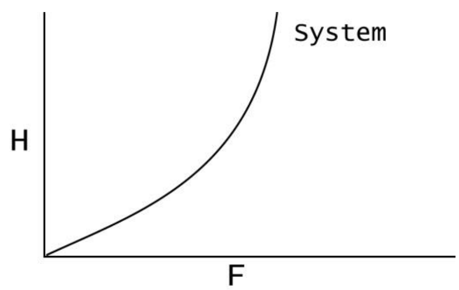

Figure E2

The PV panel parameters can be measured at various reference conditions (see E.3). A modelling program can predict parameters under other conditions. [2] This yields one function:

{4} I as a function of V, G, and Tpv:

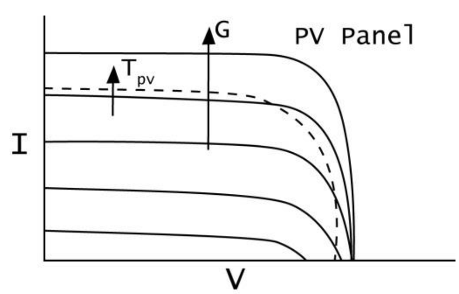

Figure E3

Note that Tpv is currently not being evaluated.

With each component's curve fit known, the functions can be combined to eliminate unnecessary variables. The steps used in the analysis are outlined below.

Pump function {1} combined with system function {3} eliminates H as a variable leaving:

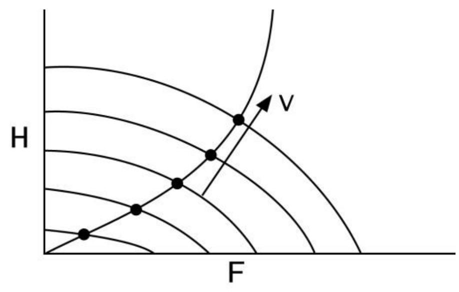

Figure E4a

{5} F as a function of V:

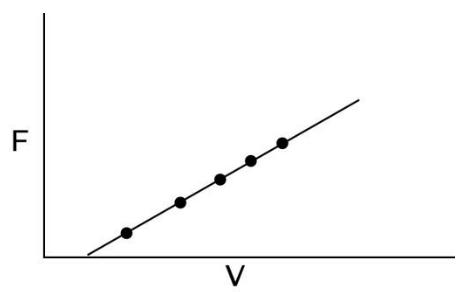

Figure E5b

Pump function {2} combined with system function {3} eliminates H as a variable leaving:

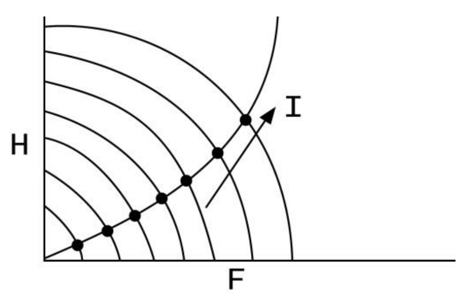

Figure E5a

{6} F as a function of I:

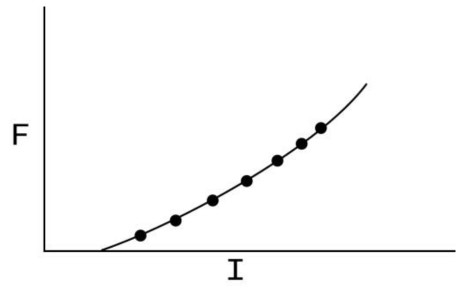

Figure E6b

Pump/system function {5} combined with pump/system function {6} eliminates F as a variable leaving:

{7} I as a function of V:

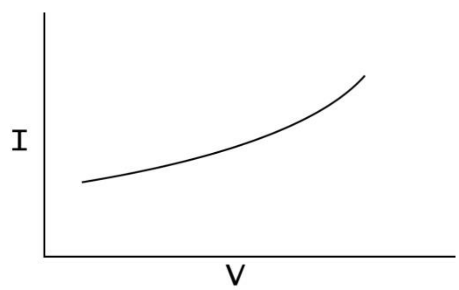

Figure E6

PV function {4} combined with pump/system function {7} eliminates I as a variable leaving:

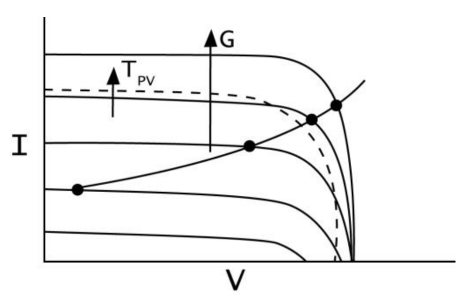

Figure E7a

{8} V as a function of G and T_{pv} (fig 8b)

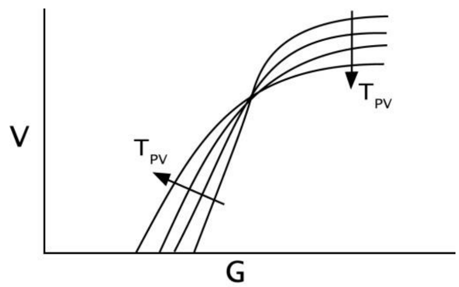

Figure E8b

Pump/system function {5} combined with PV/pump/system function {8} changes the dependent variable from voltage to flow leaving:

{9} F as a function of G and T_{pv}

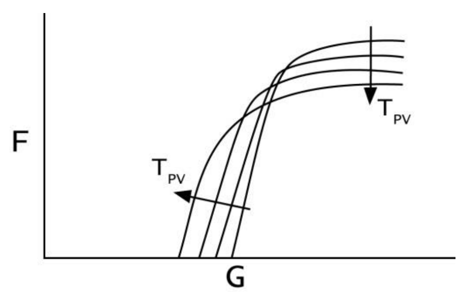

Figure E8

An empirical formula exists [3] which relates T_{pv} to both T_{amb} and G. This formula together with above function {9} describes the flow through the collector loop as a function of solar irradiance and ambient air temperature, although this has not been implemented.

Combining {1} and {2} yields dynamic pump power:

{10} P as a function of F

An empirical formula exists which relates P as a function of F. This formula describes the power used by the pump.

Integrating this curve fit into a computer simulation model requires the determination of several values from the fit:

The start-up radiation is usually read from the F vs. G graph. Average flow (for stratification) is usually taken from the F vs. G graph. A total of six parameters for the flow and power are input into the computer simulation model from fits {9} and {10}. In some cases, the minimum pump current or voltage must be manually adjusted for a specific system. The likely cause is that there are multiple solutions to the empirical fits, one of which is not desired.

References:

[1] Cybernet, Waterbury, CT: Haestad Methods, Inc. 1992

[2] Buresch, Matthew, Photovoltaic Energy Systems, New York:
McGraw-Hill, Inc. 1993, p. 87

[3] Ibid., p.76

Appendix B

Additional Tests

B.1 Constant Temperature Loss Test

Test Method

This test is typically used when the assumptions for the exponential decay cannot be maintained and the impact of the increased heat transfer is not significant on collector performance. This test is to be performed indoors, preferably in an environment with nearly constant temperature. This test functions by fully mixing the tank whenever the element comes on. An insulated external loop with a pump is used to fully mix the tank. The flow rate of this loop should be at least 15 l/m (4 GPM). The use of a thermostat with a 3 K (5 R) deadband or less is recommended.

a. Charge tank (see 7.1)

b. Allow element to cycle for a minimum of 5 Cycles.

c. Measure Q_{aux} and the ambient temperatures during the test period.

d. Test is finished at the end of the fifth cycle.

Analysis

Calculate the following to determine the loss.

a. $Q_{loss} = Q_{aux}$

b. Numerically solve for UA, $Q_{loss} = \sum UA * (T_{ank\ ave} - T_{amb}) * \Delta t$

The Q_{aux} can be equated to the internal energy input for the last four cycles. This assumes a constant difference between the average tank temperature and the ambient temperature, and a fully mixed tank. Adjustments may need to be made to the input energy to account for the pumping energy, the additional piping losses, and the change in the film coefficient during pump operation.

B.2 Isolated Heat Loss Test [Standard Decay Method]

This method is used when the losses due to the fluid connections is desired.

Test Method

This test is similar to Test 7.4, with one exception:

a. Instead of just closing the valves during the duration of the test, the actual piping should be isolated using quick disconnects or similar.

Analysis

Analysis is the same as Test 7.4. The result is $UA_{isolated\ loss\ total}$.

B.3 Isolated Delayed Purge (Vertical Conductivity)

Test Method

This test is to be performed indoors, preferably in an environment with nearly constant temperature. This test functions by fully mixing the tank whenever the element comes on. An insulated external loop with a pump is used to fully mix the tank. The flow rate of this loop should be at least 15 l/m (4 GPM). The use of a thermostat with a 3 K (5 R) deadband or less is recommended.

a. Charge tank (see 7.1)

b. Draw 1/2 of tank volume @ 5 l/min. (1.3 GPM) or less to avoid destratifying the tank, measuring ambient temperature during the entire test period.

c. Disconnect piping connections

d. Wait until:

$$T_{tank\ ave\ final} \leq T_{tank\ ave\ orig} - 5\text{ K (9 R) and } T_{tank\ ave\ final} \geq T_{amb\ ave} + 5\text{ K (9 R)}$$

These will be estimated before the test is run using the known tank volume and estimated environmental temperatures. Measure Q_{aux} and the ambient temperatures during the test period.

e. Reconnect piping connections.

f. Purge the remaining energy in the tank at $T_{initial}$.

Analysis

The data from this test will be used to adjust the vertical conductivity of the TRNSYS tank modeling based on energy matching of the data.

B.4 Isolated Auxiliary Capacitance

Test Method

This test is used to determine the heater height and T set when these values are not known. This test is to be performed indoors, preferably in an environment with nearly constant temperature.

a. Charge tank (see 7.1)

b. Disconnect piping connections

c. Activate power and let tank heat up to T_{set} [set to T_{max} +/- 5° K (9° R)]. Measure Q_{aux} during the warm-up and the ambient temperatures during the test period.

d. Reconnect piping connections

e. Disconnect the element and purge the energy in the tank.

Analysis

a. The heater set point is determined from the initial asymptote of the draw after stabilization and before the "hot fluid plug" has been purged.

b. The effective height of a horizontal heater is determined by estimating:

$$Q_{aux} = C_{heated} * (T_{set} - {}_{Tank\_}T_{ave\_orig})$$

c. T_{set} is determined from step a and T_{start} is the mixed tank temperature. A TRNSYS model is then used to iterate on Q_{aux}, adjusting the height of the heater until the height / volume are physically reasonable and the differential temperature rms of the purge is acceptable.

d. $C_{solar} = C_{total} - C_{heated}$. The solar volume can be derived from this step. The solar volume is the volume of water in a solar storage tank which is not heated by the auxiliary element.

B.5 Isolated UA Fraction

Test Method

This test is used to determine the thermostat deadband and the UA of the solar heated portion of the tank. This test is to be performed indoors, preferably in an environment with nearly constant temperature. Note that this test can be combined test B.1.

a. Charge tank (see 7.1)

b. Disconnect piping connections

c. Allow element to cycle for a minimum of 5 Cycles.

d. Measure the temperature range of the heated portion using an internal tank probe. Measure Q_{aux} and the ambient temperatures during the test period.

e. Test is finished at the end of the fifth cycle.

Analysis

a. Determine the average high and low temperatures from the internal tank temperature data. These are used to determine the water basis thermostat deadband for use with TRNSYS.

b. The deadband information is then used as the basis for comparison to the TRNSYS model. The model would incorporate the measured deadband, setpoints, heater location, nodes as determined from the other tests. The Q_{aux} from the test will be matched to the TRNSYS model to determine $UA_{isolated\ loss\ aux}$.

c. $UA_{isolated\ loss\ solar} = UA_{isolated\ loss\ total}(\text{test B.2}) - UA_{isolated\ loss\ aux}(TestTBD)$. Note that this equation is only valid for a fully mixed tank. If decay loss test 7.1 is used, it is recommended that the simulation be used (with stratification) to back out these values using the same formula. A simplified approach (when internal tank measurements are available) for either test is to determine the solar fraction of the losses from the dimensions of the tank.

d. Iterate on tests the Isolated Loss Aux test and B.5 until all of the parameters are physically reasonable and match the test data.

B.6 Installed Draw Stratification Test

This method is used to determine the draw mixing parameter, which is typically the size or number of the entry nodes.

Test Method

This test is similar to Test 7.3.

Analysis

a. The data from this test will be used to adjust the tank entry node dimension (usually the bottom node) parameter of the tank modeling. The graph of the draw temperature versus time will be used to extrapolate the estimated heated volume of the tank. This will indicate the relative size of the entry node during a heavy draw for the TRNSYS model. For an ICS type of collector, this value will be determined from a physical parameter (e.g. number of tanks in series). This value may be affected by the present limitations of the computer model.

B.7 Mantle Heat Exchangers

This method is used to determine the heat exchanger performance parameters. Note that if this is type of a thermosiphon collector, this is separate test is not usually required.

Test Method

a. Charge the internal tank to T_{max} temp.

b. Stabilize flow in the mantle HX to within +/- 0.006 l/s (0.1 GPM) and temperature to +/- 0.1 K (0.2 R).

c. Commence data collection on 15 second intervals. The rate of data collection and/or stabilization time should be increased for any flows at or below 0.0315 l/s (0.5 GPM). The data includes the inlet and outlet temperatures, ambient temperature, and the flow rates. Additional temperature measurements may be required for long heat exchangers or heat exchangers used in NCL because of the non-linear nature of the heat transfer. If necessary, this can be accomplished by using three surface probes (if accessible) and two internal probes on the NCL inlet and outlet ports. What tank temperatures should be specified? Or should tank be isothermal?

d. Adjust the temperatures and/or flow rate and proceed to step 1 until the proper number of valid data points has been collected. Adjust tank temperatures and or flow within the tank or tank stratification? *Use Graham Morrison's methods for this section.*

Analysis

a. The data from each of the data point sets in the test will be used to calibrate the TRNSYS model using the UA value and exponent in the tank coil heat exchanger model. A fitting routine will be used to fit the observed energy deliveries to the observed data points (one per data point).

b. The UA adjustment(s) shall be used for modeling the HX in TRNSYS.

B.8 Warm Up Tests: Low Radiation, Partially Diffuse, Isothermal Start

Test Method

This method is used to determine collector operation at conditions between the standard cloudy and clear conditions. Some collector may operate differently than the standard fit due to the quality of radiation received.

Each of these two tests are to be performed on a minimum of 2 cloudy days ($0.2<K_T<0.65$) with ($0.6<G_d/G<0.9$. This is expected to yield a minimum of 2 data points

a. Charge the collector (see 7.1) until $T_{initial} = T_{low.}$ T_{low} needs to be low enough [typically 20^{o}C (68^{o}F)].so that the T_{high} requirement (see 7.5.2) can be met.

b. Expose the collector for 4-5 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with $T_{in} = T_{high}$.

d. Check the radiation requirements (see 7.5) to see if further data is required.

Analysis

a. The data from this test and from 7.5.1 are combined to form set of 4 data points.

b. Analysis is the same as for the other warm-up tests (7.5).

B.9 Warm Up Tests: Low Radiation, Partially Diffuse, Stratified Start

Test Method

This method is used to determine collector operation at conditions between the standard cloudy and clear conditions. Some collectors may operate differently than the standard fit due to the quality of radiation received.

Each of these two tests is to be performed on a minimum of 2 clear ($0.65<K_T$) days. This is expected to yield a minimum of 2 data points

a. Charge the collector (see 7.1) until $T_{initial} = T_{low.}$ T_{low} needs to be low enough [typically 20^{o}C (68^{o}F)].so that the T_{high} requirement (see 7.5.2) can be met.

b. Energize electric heater for the first hour of the test.

b. Expose the collector for 3-4 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with $T_{in} = T_{high}$.

d. Check the radiation requirements (see 7.5) to see if further data is required.

Analysis

a. The data from this test and from 7.5.2 are combined to form set of 4 data points.

b. Analysis is the same as for the other warm up tests (7.5).

B.10 Warm Up Tests: Low Radiation, Totally Diffuse, Isothermal Start

Test Method

This method is used to determine collector operation for collectors sensitive to the sun angle (tubular optics). Some collectors may operate differently than the standard fit due to the quality of radiation received.

These tests are to be performed on a minimum of 2 cloudy ($0.2<K_T<0.65$) days with ($0.9<G_d/G$). This is expected to yield a minimum of 2 data points

a. Charge the collector (see 7.1) until $T_{initial} = T_{low.}$ T_{low} needs to be low enough [typically 20^{o}C (68^{o}F)].so that the T_{high} requirement (see 7.5.2) can be met.

b. Expose the collector for 4-5 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with $T_{in} = T_{high}$.

d. Check the radiation requirements (see 7.5) to see if further data is required.

Analysis

a. The data from this test and from 7.5.2 are combined to form set of 4 data points.

b. Analysis is the same as for the other warm up tests (7.5).

B.11 Warm Up Test: High Radiation, Transverse IAM Specification, Isothermal Start

Test Method

This method is used to determine collector operation for collectors sensitive to the sun angle (tubular optics). Some collectors may operate differently than the standard fit due to the quality of radiation received.

These tests are to be performed on a minimum of 2 clear ($.65<K_T$) days. The determination of data points will be based upon the angles with high uncertainty. For angles < 30°, the incidence angles should be within 2% of the nominal incidence angle. These tests assume that the large IAM discrepancies are in the transverse angles. If longitudinal discrepancies are also in question, another test procedure will be required. The irradiation schedule will need to be created to satisfy the following requirements:

a. Minimum Two hour testing period (e.g. minimum angle resolution is 30°).

b. Staggering the testing periods so that different angle ranges are measured in the morning and afternoon.

c. Accounting for the time of year and latitude of the testing site so that the appropriate angles will measured at the appropriate test times.

d. Staggering the testing times on multiple days so that effective resolution from multiple tests can be increased.

e. The weighting of the data as it applies to “d.”

f. The values for solar noon have already been tested in the primary warm-up test.

This is process is expected to yield a minimum of 2 data points

a. Charge the collector (see 7.1) until $T_{initial} = T_{low.}$ T_{low} needs to be low enough [typically 20°C (68°F)].so that the T_{high} requirement (see 7.5.2) can be met.

b. Irradiate for the daily specified solar times, at least 2 hours.

c. At the conclusion of the irradiation period, cover the collector and purge (see 7.2) the gathered energy from the tank with $T_{in} = T_{high}$.

d. Check the radiation requirements (see 7.5) to see if further data is required.

Analysis

a. The data from this test and from 7.5.2 are combined to form set of 4 data points.

b. Analysis is the same as for the other warm up tests (7.5).