



The SPP 25 Handbook

1. Introduction to Evacuated Tubes

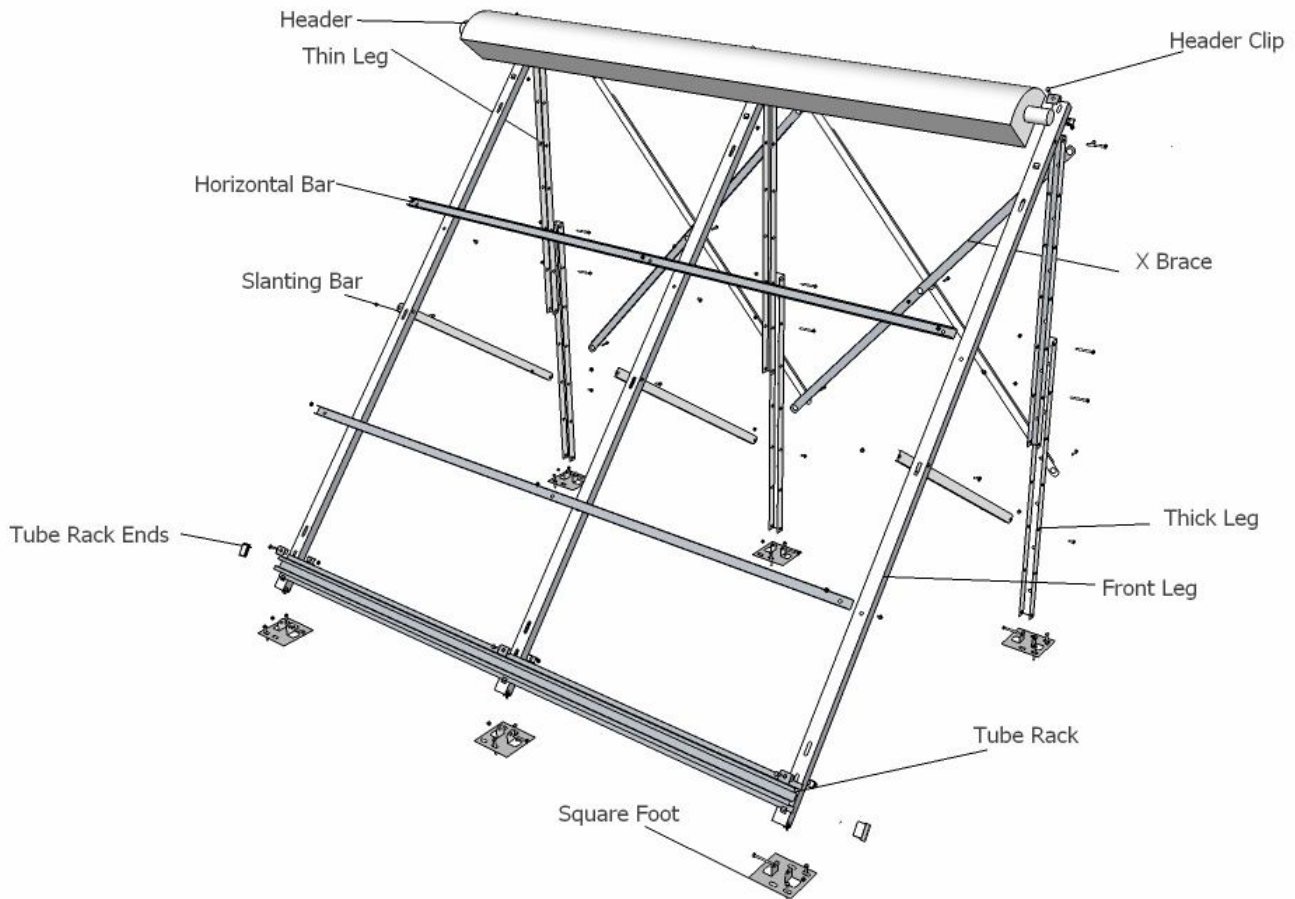
The SPP 25 uses evacuated tube technology to provide hot water for domestic and commercial use. The evacuated tube is made with a double walled borosilicate glass tube with a vacuum between the two sides. Borosilicate glass is used for its high durability while the vacuum allows for the light to go through the tube unimpeded and this increases the output of the tube.

When the light goes through the second layer of glass it hits an absorber containing three layers in order, aluminum sputtering, steel and copper. The absorber has an absorbance rate of 92 %.

The heat from the light is then transferred to heat fins inside the tube which concentrate all the heat onto a copper pipe in the middle of the tube. The copper pipe contains a liquid that boils at 85 F due to the vacuum inside the pipe. When the heat is transferred to the pipe, the liquid boils into a gas and then moves up to the cylindrical head which is in contact with the manifold. Once the heat is transferred from the head to the manifold, the gas condenses and the liquid returns to the bottom of the pipe.

2. Dimensions

SPP High Angle Frame



a. Gross Dimensions

Header Box Width	2057	mm
Header Box Length	166	mm
Header Gross Area	0.341	sq meter
Tube Length	1821	mm
Tube Width	2007	mm
Tube Array Area	3.655	sq meter
Gross Area	4	sq meter

b. Aperture Dimensions

Tube Length	1720	mm
Individual Tube Width	58	mm
Number of Tubes	25	
Area of 25 Tubes	2.494	sq meter
Tube Array Width with Spacing	1992	mm
Aperture Area	3.28	sq meter

c. Frame

Width	2250 mm
Length of the Front Leg	2000 mm
Range of Motion	0 to 61.6 degrees

Angle	Height (mm)	Front to Back Leg
28.8°	908	1652
34.1°	1058	1561
39.9°	1208	1446
46.1°	1358	1307
53.1°	1508	1132
61.6°	1658	897

3. Materials

a. Absorber

Materials (plate/fin and tube):	metal fin, copper risers
Plate or fin thickness	.004 inches
Riser tube to header connection method	condensers pushed in sockets in manifold
Flow pattern	Straight through
Spacing between riser tubes (distance between center to center)	80 mm
Glazing to absorber air space	3 mm
Header OD:	22 mm
Header ID:	20 mm

b. Glazing

Glazing Thickness	1.5 mm (outer tubes)
Glazing Thickness	1.5 mm (inner tubes)
Seal type	Silicone Rubber

c. Insulation

Insulation	Rock Wool
Insulation Thickness	6.5 in x 5.5 in

d. Frame

Material	304 Stainless Steel
Thickness	1.1 mm

Weights	
Header	41.75 lbs
Frame	34.5 lbs
Tube with Cap	5.625 lbs
Tube Rack	5.5 lbs

	Flush Mount	Mid Angle	High Angle
Front Legs	3	3	3
Thin Leg	0	3	3
Thick Leg	0	0	3
Horizontal Brace	0	2	2
X Braces	0	4	4
Slanting Brace	0	3	3
Feet	0	6	6
Tube Rack	1	1	1
Header	1	1	1
Clips	6	6	6

4. Thermal Shock Tests

a. Water Spray Test

Solar Irradiance:	950 W/m ² for at least 1 hour previous to each test
Water flow rate:	.03 to .05 L/s/m ² of collector aperture area
Test duration:	15 minutes each test

Test 1	
Flow Rate:	.0331 L/s/m ²
Water temperature:	7 °C
Air temperature:	12 °C

Test 2	
Flow Rate:	.038 L/s/m ²
Water temperature:	6 °C
Air temperature:	16 °C

Test 3	
Flow Rate:	.035 L/s/m ²
Water temperature:	7 °C
Air temperature:	20 °C

Result: No visible signs of leakage

b. Cold Fill Test

Solar Irradiance:	950 W/m ² for at least 1 hour previous to each test
Water flow rate:	.03 to .05 L/s/m ² of collector aperture area
Test duration:	> 5 minutes

Fill rate:	.03 L/s/m ²
Fluid temperature:	10 °C
Air temperature:	22 °C

Result: No visible signs of damage

c. Final Inspection Results

Collector Component	Evaluation
a) Collector box / fasteners	no problem
b) Mountings / structure	no problem
c) Seals / gaskets	no problem
d) Cover / reflector	no problem
e) Absorber coating	no problem
Absorber tubes & headers	no problem
Absorber mountings	no problem
f) Insulation	no problem

5. Thermal Efficiency

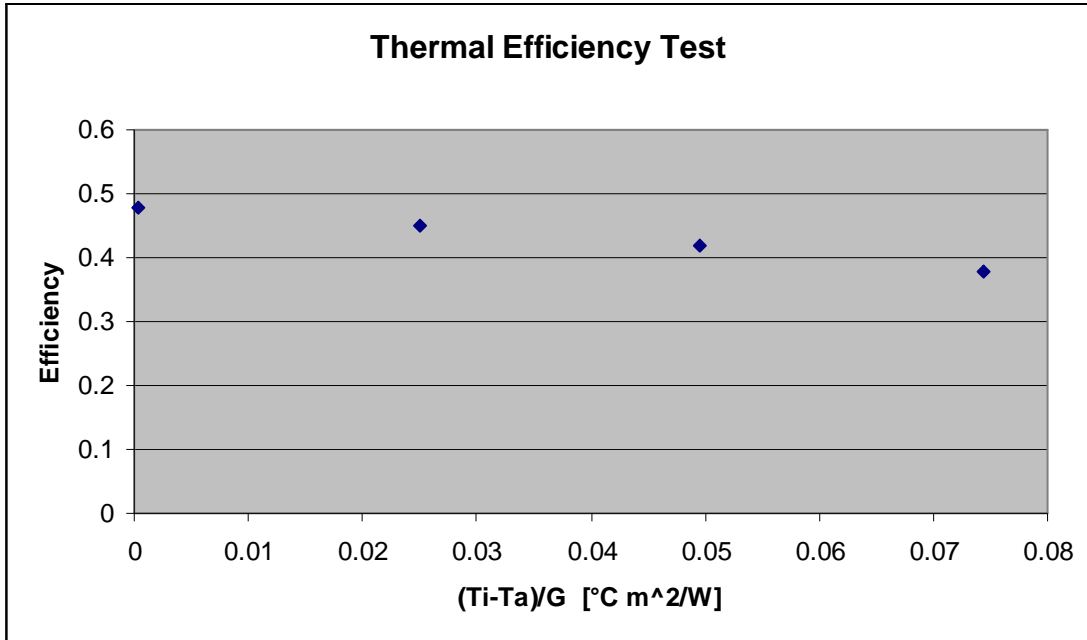
The efficiency of the collector can be based on the gross area of the collector or the aperture area of the collector. In both cases the general form of the efficiency equation can be written as $\eta = \eta_0 + k_1 * (Ti - Ta) / G + k_2 * (Ti - Ta)^2 / G$, where η_0 , k_1 and k_2 are constants and η is the efficiency of the collector. T_i is defined as the temperature of the fluid entering the header, T_a is the outside temperature and G is the insolation (power of the sun for every square foot or meter). The general form of the equation shows that insolation levels play a large role in determining the efficiency of the system, but the equation also shows an interesting relationship between the temperatures. What the equation tells us is that one does not need to be concerned solely with the desired temperature of the system. Instead one needs to be concerned about the difference between the desired temperature and the outside temperature.

Test Fluid	Water
Mass Flow Rate	.071 kg/s
Wind Speed (average)	3.3 m/s
Mean Ambient Temp	24.9 °C
Irradiance Intensity	808 W/m ²

Thermal Efficiency Test Data										
Len. <i>Min</i>	G (W/m ²)	Ta °C	Ti °C	ΔT °C	Ws m/s	(dm/dt)*Cp W/°C	dm/dt kg/s	Ti-Ta °C	(Ti-Ta) °C*m ² /W	η
5	805	24.8	25.1	4.55	3.3	296	0.0708	0.3	0.0003	0.476
5	806	24.8	25.1	4.57	3.3	295.3	0.0707	0.2	0.0003	0.477
5	809	24.8	25.1	4.6	3.3	295	0.0706	0.3	0.0004	0.477
5	810	24.8	25	4.63	3.3	293.9	0.0703	0.2	0.0002	0.477
5	809	24.9	45.1	4.35	3.3	295.7	0.0708	20.2	0.025	0.452
5	808	24.9	45.1	4.34	3.3	296.2	0.0709	20.3	0.0251	0.452
5	811	24.9	45.2	4.34	3.3	296.3	0.0709	20.3	0.0251	0.45
5	811	24.9	45.2	4.33	3.3	296.3	0.0709	20.4	0.0251	0.45
4	809	24.9	65	4.01	3.3	295.6	0.0707	40.1	0.0496	0.417
4	808	24.9	65	4.02	3.3	295.1	0.0706	40.1	0.0496	0.417
4	807	24.9	65	4.01	3.3	295.8	0.0708	40.1	0.0497	0.418
4	810	24.9	64.9	4.01	3.3	295.8	0.0708	40.1	0.0495	0.417
5	807	24.9	85.1	3.64	3.3	295	0.0706	60.2	0.0745	0.378
5	809	24.9	85.1	3.64	3.3	295.1	0.0706	60.2	0.0744	0.378
5	809	24.9	85.1	3.65	3.3	294.7	0.0705	60.2	0.0744	0.378
5	809	24.9	85.1	3.65	3.3	295	0.0706	60.2	0.0744	0.379

$$\text{Efficiency} = A + B * (Ti - Ta) / G + C * (Ti - Ta)^2 / G$$

Based On	A	B	C	
Gross Area	0.4772	-0.9374	-0.0066	SI units
Gross Area	0.4772	-0.1652	-0.0006	IP units
Aperture Area	0.586	-1.151	-0.0081	SI units
Aperture Area	0.586	-0.2028	-0.00074	IP units



6. Incident Angle Modifier

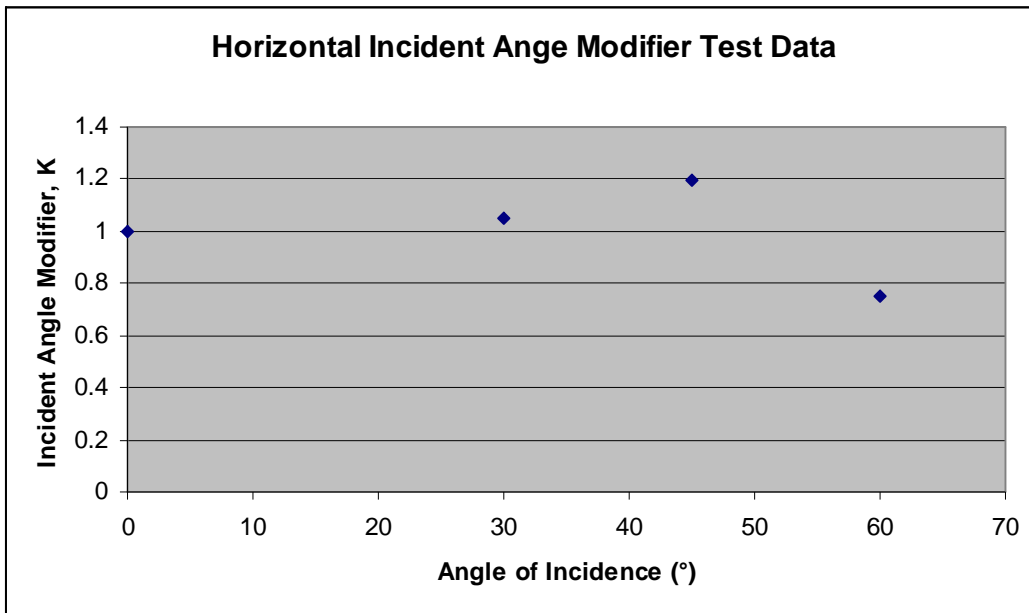
The Incident Angle Modifier (IAM) is a factor that helps determine the output of the system and is defined as $K = \eta(\theta) / \eta(0)$. When one looks at the IAM curve for evacuated tubes, they will notice that the IAM is 1 when light is perpendicular to the collector and can rise above 1 before reaching zero when the angle of incidence reaches 90 degrees. The reason for the unusual value is that the efficiency is defined as the output divided by the gross area or aperture area. As a result the IAM does not care how much area is receiving light but only the output when the angle of incidence is at zero and the output at the angle that it is being evaluated at. The evacuated tubes' cylindrical shape passively tracks the sun throughout the day which allows for a larger area to be exposed to sunlight as opposed to a flat plate collector. The passive tracking and reflectors result in an exposed area greater than the gross or aperture area. Since the difference between the inlet and ambient temperatures are the same along with the insolation levels, the larger exposed area allows for higher output values. As a result the collector achieves an "efficiency" greater than the theoretical max efficiency. The relationship between the

incident angle and the light modifier can be summed up as $K = 1 + b * \left(\frac{1}{\cos(\theta)} - 1 \right) + c * \left(\frac{1}{\cos(\theta)} - 1 \right)^2$.

a. Horizontal Incident Angle Modifier

$K = \eta(\theta) / \eta(0)$	
Test Fluid	Water
Mass Flow Rate	.071 kg/s
Wind Speed (nominal)	3.3 m/s
Mean Ambient Temp	25.1 °C

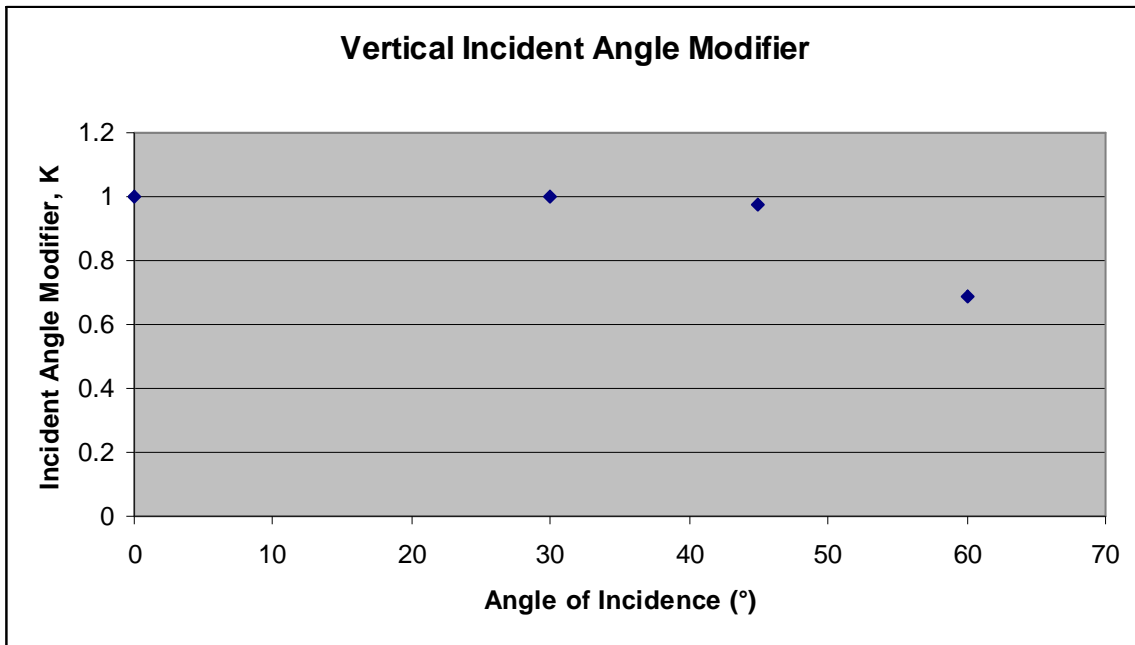
Incidence Angle	Len. Min	G (W/m ²)	Ta °C	Ti °C	ΔT °C	(dm/dt)*Cp W/°C	dm/dt kg/s	Ti-Ta °C	(Ti-Ta) °C*m ² /W	η	K
0	5	798	24.8	25	4.58	293.8	0.07	0.2	0.0003	0.48	1.003
0	5	800	24.8	25	4.58	293.6	0.07	0.2	0.00028	0.478	1
0	5	802	24.8	25	4.58	293.8	0.07	0.2	0.00027	0.477	0.998
0	5	801	24.7	25.1	4.58	293.8	0.07	0.3	0.00042	0.478	1
30	5	688	25.1	24.7	4.13	294.9	0.071	-0.3	-0.00049	0.504	1.049
30	5	688	25.1	24.7	4.13	295.1	0.071	-0.5	-0.0007	0.503	1.048
30	5	690	25.1	24.6	4.12	296.2	0.071	-0.5	-0.00067	0.503	1.047
30	5	690	25	24.6	4.13	296.1	0.071	-0.4	-0.00058	0.503	1.049
45	5	545	25.3	24.8	3.74	294	0.07	-0.4	-0.00077	0.574	1.195
45	5	544	25.2	24.8	3.74	293.8	0.07	-0.4	-0.00074	0.574	1.196
45	5	543	25.2	24.8	3.74	293.8	0.07	-0.3	-0.00063	0.575	1.198
45	5	544	25.2	24.9	3.74	293.8	0.07	-0.3	-0.00063	0.574	1.197
60	5	365	25.4	24.9	1.57	295	0.071	-0.5	-0.00126	0.362	0.749
60	5	363	25.4	24.9	1.56	295.6	0.071	-0.4	-0.00121	0.361	0.748
60	5	363	25.4	25	1.56	295.8	0.071	-0.4	-0.00099	0.36	0.747
60	5	362	25.4	25	1.57	295.1	0.071	-0.4	-0.00105	0.364	0.756



b. Vertical Incident Angle Modifier

$K = \eta(\theta)/\eta(0)$	
Test Fluid	Water
Mass Flow Rate	.071 kg/s
Wind Speed (nominal)	3.3 m/s
Mean Ambient Temp	25.1 °C
Irradiance Intensity	624 W/m ²

Incidence Angle	Len. Min	G (W/m^2)	Ta $^{\circ}C$	Ti $^{\circ}C$	ΔT $^{\circ}C$	(dm/dt)*Cp $W/^{\circ}C$	dm/dt kg/s	Ti-Ta $^{\circ}C$	(Ti-Ta) $^{\circ}C*m^2/W$	η	K
0	5	798	24.8	25	4.58	293.8	0.07	0.2	0.0003	0.48	1.001
0	5	800	24.8	25	4.58	293.6	0.07	0.2	0.00028	0.478	1.002
0	5	802	24.8	25	4.58	293.8	0.07	0.2	0.00027	0.477	0.999
0	5	801	24.7	25.1	4.58	293.8	0.07	0.3	0.00042	0.478	0.999
30	5	688	25.1	24.7	4.13	294.9	0.071	-0.3	-0.00049	0.504	1.001
30	5	688	25.1	24.7	4.13	295.1	0.071	-0.5	-0.0007	0.503	0.997
30	5	690	25.1	24.6	4.12	296.2	0.071	-0.5	-0.00067	0.503	1
30	5	690	25	24.6	4.13	296.1	0.071	-0.4	-0.00058	0.503	0.998
45	5	545	25.3	24.8	3.74	294	0.07	-0.4	-0.00077	0.574	0.977
45	5	544	25.2	24.8	3.74	293.8	0.07	-0.4	-0.00074	0.574	0.98
45	5	543	25.2	24.8	3.74	293.8	0.07	-0.3	-0.00063	0.575	0.976
45	5	544	25.2	24.9	3.74	293.8	0.07	-0.3	-0.00063	0.574	0.975
60	5	365	25.4	24.9	1.57	295	0.071	-0.5	-0.00126	0.362	0.688
60	5	363	25.4	24.9	1.56	295.6	0.071	-0.4	-0.00121	0.361	0.691
60	5	363	25.4	25	1.56	295.8	0.071	-0.4	-0.00099	0.36	0.685
60	5	362	25.4	25	1.57	295.1	0.071	-0.4	-0.00105	0.364	0.692

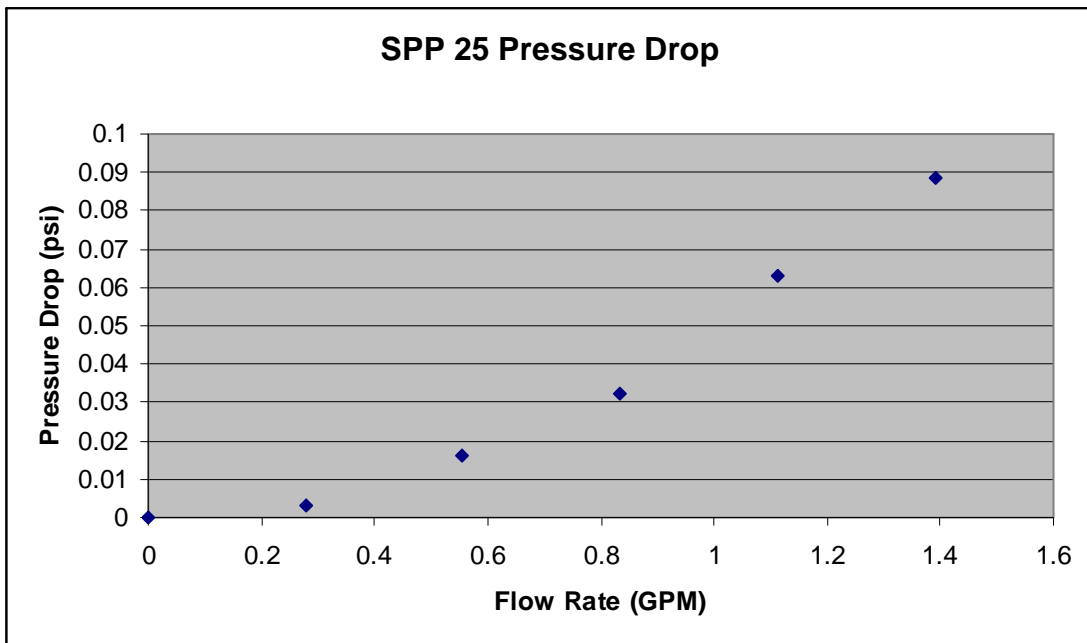


7. Pressure Drop vs. Flow Rate

Standard: ISO 9806-1

Flow Rate (kg/s per m ²)	flow (kg/s)	flow (GPM)	T_in(F)	T_amb(F)	P drop (Pa)	P drop (psi)
0	0	0	75.9	77.2	0	0
0.004	0.0176	0.27808	76.3	77.4	23	0.0033
0.007	0.0352	0.55616	75.9	77.7	112	0.0162
0.011	0.0528	0.83424	75.9	78.1	223	0.0323
0.015	0.0704	1.11232	76.3	78.6	433	0.0628
0.018	0.088	1.3904	76.1	78.6	612	0.0888

HTF Water
D0 0.998 kg/L



8. Examples

a. Heating a tank of water at noon

Insolation = 500 W/m^2

Inlet Temperature = $38 \text{ }^\circ\text{C}$ ($100 \text{ }^\circ\text{F}$)

Ambient Temperature = $18 \text{ }^\circ\text{C}$ ($64 \text{ }^\circ\text{F}$)

50 gallons

$$\eta = .4772 - \frac{.9374 * (38^\circ\text{C} - 18^\circ\text{C})}{500\text{W} / \text{m}^2} - .0066 * \frac{(38^\circ\text{C} - 18^\circ\text{C})^2}{500\text{W} / \text{m}^2}$$

$$K = 1$$

$$\text{Energy} = \eta * \text{Insolation} * \text{Area} * 1\text{hour}$$

$$\text{Energy} = 3.13 * 10^6 \text{ Joules} * \frac{1\text{BTU}}{1055\text{Joules}} = 2965\text{BTU}$$

$$\Delta\text{Temperature} = \text{Energy} / (8.33 * \text{gallons})$$

$$\Delta\text{Temperature} = 7.1^\circ\text{F}$$

b. Heating moving water at noon

Insolation = 500 W/m^2

Inlet Temperature = $38 \text{ }^\circ\text{C}$ ($100 \text{ }^\circ\text{F}$)

Ambient Temperature = $18 \text{ }^\circ\text{C}$ ($64 \text{ }^\circ\text{F}$)

3 GPM

$$\eta = .4772 - \frac{.9374 * (38^\circ\text{C} - 18^\circ\text{C})}{500\text{W} / \text{m}^2} - .0066 * \frac{(38^\circ\text{C} - 18^\circ\text{C})^2}{500\text{W} / \text{m}^2}$$

$$K = 1$$

$$\text{Power} = \eta * \text{Insolation} * \text{Area}$$

$$\text{Power} = 869 \frac{\text{Joules}}{\text{s}} * \frac{1\text{BTU}}{1055\text{Joules}} * \frac{3600\text{s}}{1\text{hr}} = 2965\text{BTU} / \text{hr}$$

$$\Delta\text{Temperature} = \text{Power} / (500 * \text{GPM})$$

$$\Delta\text{Temperature} = 2^\circ\text{F}$$