There are two type of Solar heating panels

<u>1) Flat plate solar heater collectors</u>: consist of

*__The outer shell__: made of galvanized steel or treated aluminum sheets, so that it can withstand impacts Weather

*__Transparent side (glass):__ It is a cover of reinforced glass that allows sunlight to pass through to the panel

The heat absorber inside the collector allows 90% of the solar radiation falling on a surface to pass through The collector is to be absorbed into the absorbent plate, and it also protects the internal parts of the collector from rain And other weather factors, and it is polished from the inside to reduce the percentage of reflected rays

*__Absorbent plate__: It is a metal plate made of black iron, aluminum, or copper, coated with a layer of Dark-colored Coating Surface (characterized by a high rate of absorption of solar radiation and a radiation rate Low Radiation Thermal

*__Rising pipes:__ made of copper, aluminum, or galvanized steel and fixed to the roof

The absorber, as shown in Figure (8), to transfer the heat absorbed by the absorbent plate to the water contained within it

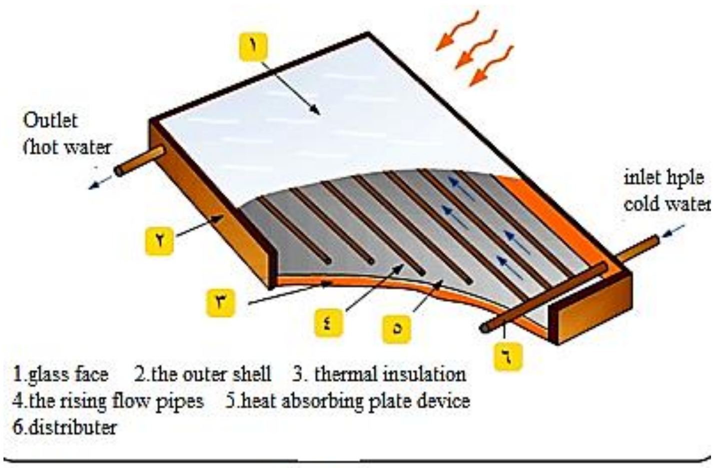
*__Distributor__: It is made of the same material as the riser pipes, and usually receives less hot water coming from Hot water tank, and distributes it to the rising pipes to heat it

*__Thermal insulation__: Rock wool or polyurethane foam is used as an insulating material that prevents heat loss Heat by conduction to the surrounding atmosphere

<u>2) Evacuated tube solar collectors</u>: In the past few years, technology has emerged

Evacuated tubes, which are mainly based on Evacuated Tubes (which It absorbs solar energy with high efficiency and converts it into thermal energy, to heat water, and this type of

Collectors will be studied later through an educational unit specific to this type of solar collector



Flat collector parts

*الغلاف الخارجي: يصـــــــنع من صفائح الفولاذ المجلفن أو الألمنيوم المعالج، بحيث يتحمل تأثيرات العوامل الجوية.

* الوجه الشـفاف (الزجاج): وهو غطاء من الزجاج المقوى، يسـمح بمرور أشعة الشـــمس إلى اللوح الماص للحرارة داخل اللاقط، إذ يسمح بمرور (٩٠%) من الإشعاع الشمسي الساقط على سطح اللاقط لكي يتم امتصــاصه في اللوح الماص، كما أنه يحفظ أجزاء اللاقط الداخلية من الأمطار والعوامل الجوية الأخرى، وهو مصقول من الداخل لتقليل نسبة الأشعة المنعكسة .

*اللوح الماص: وهو صفيحة معدنية من الصــاج الأسود أو الألمنيوم أو النحاس مطلية بطبقة داكنة اللونCoating Surface تمتاز بمعدل امتصاص عال للإشعاع الشمسي وبمعدل إشعاع حراري منخفض Radiation Thermal

*الأنابيب الصــــــاعدة: تصـــــنع من النحاس أو الألمنيوم أو الفولاذ المجلفن وتثبت على الســـــطح الماص، كما هو مبين في الشــــــكل () لتوصيل الحرارة التي يمتصــها اللوح الماص إلى الماء الموجود بداخلها

*الموزع: يصنع من نفس مادة الأنابيب الصــاعدة، ويستقبل بالعادة الماء الأقل سخونة القادم من خزان الماء الساخن، ويقوم بتوزيعه على الأنابيب الصاعدة لتسخينه .

*العازل الحراري: يسـتخدم الصــوف الصـــخري أو رغوة من متعدد اليوريثان كمادة عازلة تمنع فقدان الحرارة بالتوصيل للجو المحيط

2) **اللواقط الشــــمســـــية ذات الأنابيب المفرغة**: في الســنوات القليلة الماضية ظهر تقنية الأنابيب المفرغة، والتي تعتمدً أســاسـا على الأنابيب المفرغة Tubes Evacuated التي تمتص الطاقة الشمسية بكفاءة عالية وتحولها إلى طاقة حرارية، لتسخين المياه،

Types of Water Heaters: Solar Water Heaters

Two types of solar water heating systems are available:
Systems differ also with respect to **the way the heat transfer fluid is transported**:

- **Natural (or passive) circulation systems [no pump is employed to circulate the fluid].**
- **Forced circulation (or active) systems [a pump or fan is employed to circulate the fluid].** A wide range of collectors have been used for solar water heating systems, such as flat plate,

addition to these types of collectors, bigger systems can use more advanced types, such as the parabolic trough. The amount of hot water produced by a solar water heater depends on **the type and size of the system**, **the amount of sunshine available at the site, and the seasonal hot water demand pattern**

● **Passive Systems**: Two types of systems belong to this category: thermosiphon and the integrated collector storage systems.

Thermosiphon Systems: Thermosiphon systems, shown schematically in Figure (1), heat potable water or transfer fluid and use natural convection to transport it from the collector to storage. The **thermosphoning effect** occurs because the density of water drops with the increase of the temperature. Therefore, by the action of solar radiation absorbed, the water in the collector is heated and thus expands, becoming less dense, and rises through the collector into the top of the storage tank.

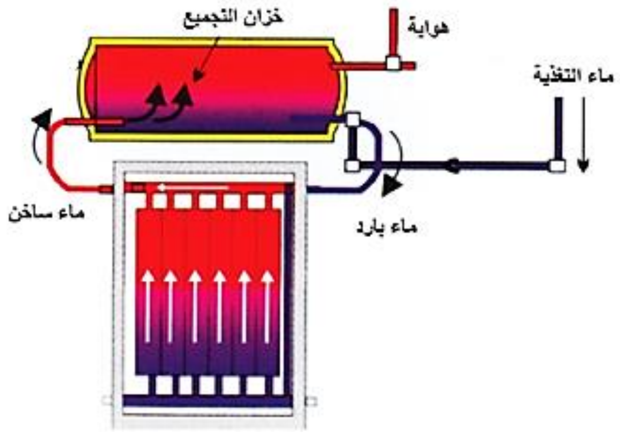


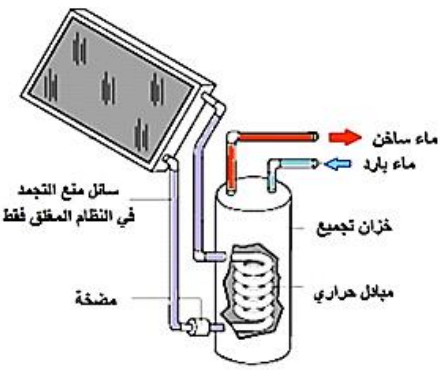
Fig (1): Schematic diagram of a thermosiphon solar water heater (Passive system)

There it is replaced by the cooler water that has sunk to the bottom of the tank, from which it flows down the collector. Circulation is continuous as long as the sun is shining. Since the driving force is only a small density difference, larger than normal pipe sizes must be used to minimize pipe friction Connecting lines must also be well insulated to prevent heat loss and sloped to prevent formation of air pockets, which would stop circulation

The advantages of thermosiphon systems are that they do not rely on pumps and controllers, are more reliable, and have a longer life than forced circulation systems. Moreover, they do not require an electrical supply to operate and they naturally modulate the circulation flow rate in phase with the radiation levels.

The main disadvantage of thermosiphon systems is that they are comparatively tall units, which makes them not very attractive aesthetical

- **Active Systems**: In active systems, water or a heat transfer fluid is pumped through the collectors. These are usually more expensive and a little less efficient than passive systems. Additionally, active systems are more difficult to modify in houses, especially where there is no basement, because space is required for the additional equipment, such as the hot water cylinder. Five types of systems belong in this category: direct circulation systems, indirect water heating systems, air systems, heat pump systems, and pool heating systems.



Fig(2) Active system

Operational Characteristics of a Flat Plate Collector

A solar heating panel is said to be operational when useful heat is being extracted. The steady-state energy balance equation is

$$F_{abs} - J_{loss} = J_C \quad \text{.............10}$$

where J_C is the heat flux collected, that is, the amount of useful heat per unit time per unit plate area actually extracted from the panel. If the transfer fluid enters at some temperature $T_{f,i}$ and leaves at a temperature $T_{f,e}$, the collected flux is

$$J_C = \dot{\sigma} C_f (T_{f,e} - T_{f,i}) \quad \text{............11}$$

where $\dot{\sigma} = \dot{m}/A_p$ is the mass flow rate of the transfer fluid divided by the plate area and C_f is the specific heat of the fluid. In mks units, $\dot{\sigma}$ is in kg/sec-m^2 and C_f is in J/kg-°C.

Consider a flat plate collector that is intercepting and absorbing solar energy at a constant rate under fixed ambient conditions. Suppose next that a transfer fluid enters the collector at a fixed temperature $T_{f,i}$. If the mass flow rate per unit area $\dot{\sigma}$ is varied, the output temperature, $T_{f,e}$, and the useful heat flux collected, J_C, will vary. For example, if the flow rate is very small, the fluid extracts very little heat; however, the temperature of the fluid leaving the collector will be high. As a result, the average plate temperature is also high so that thermal losses are large and the collector's efficiency is low. In fact, as $\dot{\sigma} \rightarrow 0$, the plate temperature approaches the stagnation limit; all the heat is lost to the environment and the collector efficiency approaches zero. If, on the other hand, $\dot{\sigma}$ becomes large, the fluid leaves the collector only at a slightly higher temperature than when it enters. The rapidly flowing fluid cools the plate so that thermal losses are small. Therefore although the outlet temperature is not very high, the extraction rate and the thermal efficiency are both increased.

The equations which described the operation of the collector are:

$$J_C = F_{abs} - \bar{U}_c(T_p - T_a) \quad \text{........... 12}$$

$$T_{f,e} = T_{f,i} + (T_p - T_{f,i})[1 - \exp(-H/\dot{\sigma}C_f)] \quad \text{.......... 13}$$

$$J_C = \dot{\sigma}C_f(T_{f,e} - T_{f,i}) \quad \text{........... 14}$$

Where T_p the plate temperature
$T_{f,i}$: inlet temperature of fluid
$T_{f,e}$: exite temperature of fluid
H :the coefficient for the transfer of heat from the plate to the fluid
After some simplification it can be shown that the thermal efficiency can be written :

$$\eta_{thermal} = \frac{J_C}{F_{abs}} = \left[1 + \frac{\bar{U}_C}{\dot{\sigma}C_f[1 - \exp(-H/\dot{\sigma}C_f)]}\right]^{-1}\left[1 - \frac{\bar{U}_c(T_{f,i} - T_a)}{F_{abs}}\right] \quad \text{......... 15}$$

A similar calculation

$$\frac{\Delta T_f}{F_{abs}} = \frac{(T_{f,e} - T_{f,i})}{F_{abs}} = \frac{1}{\dot{\sigma}C_f}\left[1 + \frac{\bar{U}_c}{\dot{\sigma}C_f[1 - \exp(-H/\dot{\sigma}C_f)]}\right]^{-1}\left[1 - \frac{\bar{U}_c(T_{f,i} - T_a)}{F_{abs}}\right] \quad \text{.... 16}$$

When the fluid flow rate is held fixed, the thermal efficiency in Equation is a linear function of the variable $(T_{f,i} - T_a)/F_{abs}$.

$$\frac{\Delta T_f}{F_{abs}} = \frac{T_{f,e} - T_{f,i}}{F_{abs}} \quad ......\ 17$$

EXAMPLE

A solar heating panel is characterized by the parameters $\bar{U}_c = 6\ W/m^2\text{-}°C$ and $H = 15\ W/m^2\text{-}°C$. The transfer fluid, water ($C_f = 4186\ J/kg\text{-}°C$), is flowing at a rate $\dot{\sigma} = 0.001\ kg/sec\text{-}m^2$ and enters at $T_{f,i} = 25°C$. Find the thermal efficiency of the panel and the exit temperature of the fluid when the ambient temperature is 10°C and the absorbed solar flux is 510 W/m².

Equations 6.16 and 6.17 take the form

$$\eta_{thermal} = 0.404\left[1 - \frac{6(T_{f,i} - T_a)}{F_{abs}}\right]$$

and

$$\frac{\Delta T_f}{F_{abs}} = 0.097\left[1 - \frac{6(T_{f,i} - T_a)}{F_{abs}}\right]$$

Since $F_{abs} = 510\ W/m^2$, $T_{f,i} = 25°C$, and $T_a = 10°C$, we find

$$\eta_{thermal} = 0.33 = 33\%$$

and

$$\frac{\Delta T_f}{F_{abs}} = 0.08$$

Therefore

$$T_{f,e} = (0.08)(510) + 25 = 66°C$$

EXAMPLE

Referring to the preceding example, find the efficiency and the exit temperature of the water when the flow rate is increased to $\dot{\sigma} = 0.01$ kg/sec-m^2.

For the new flow rate,

$$\eta_{thermal} = 0.678\left[1 - \frac{6(T_{f,i} - T_a)}{F_{abs}}\right]$$

and

$$\frac{\Delta T_f}{F_{abs}} = 0.016\left[1 - \frac{6(T_{f,i} - T_a)}{F_{abs}}\right]$$

Using $F_{abs} = 510$ W/m^2, $T_{f,i} = 25°C$, and $T_a = 10°C$, we find

$$\eta_{thermal} = 0.56 = 56\%$$

And

$$\frac{\Delta T_f}{F_{abs}} = 0.013$$

Therefore

$$T_{f,e} = (0.013)(510) + 25 = 32°C$$

For a flat plate heating panel to be more efficient:

1. Apply highly absorptive coatings on the plate and use highly transmissive glazings to increase optical efficiency.
2. Use selective absorber coatings (i.e., highly reflective in thermal infrared region) with good insulation on back and sides of absorber plate. If possible, partially evacuate the enclosure or at least make it airtight to reduce convective losses. Use more than one glazing where feasible.
3. Arrange the channels or ducts as uniformly as possible across the absorber plate with good thermal contact so that heat exchange to transfer fluid is efficient.

To obtain maximum efficiency from a given flat plate panel:

1. Allow the panel to track the sun so that it remains normal to the sun's rays for as long as possible during the day. If this is not feasible, fix the panel in a position so that the obliquity of the sun's rays is as small as possible throughout the day. This increases the intercepted flux as well as the optical efficiency.
2. Operate the panel at a temperature as close to the ambient temperature as possible. Under severe conditions use the panel as a preheater to supply a warm rather than a hot fluid. Use a secondary heater to complete the process. Also use well-insulated pipes or ducts to carry the fluid to and from the panel.

Problems

Q.1

A single-glazed flat plate has a plate-to-glazing transfer coefficient, $\bar{U}_{p-g} = 6\ W/m^2\text{-}°C$, and a glazing-to-air coefficient, $\bar{U}_{g-a} = 12\ W/m^2\text{-}°C$.

(a) Find the overall transfer coefficient $\bar{U}_c$ for the panel. Neglect back losses.

(b) Find the stagnation temperature and the glazing temperature when the absorbed solar flux is $F_{abs} = 400\ W/m^2$ and when $T_a = 0°C$.

(c) Plot $(T_{p,s} - T_a)$ and $(T_{g,s} - T_a)$ versus F_{abs}.

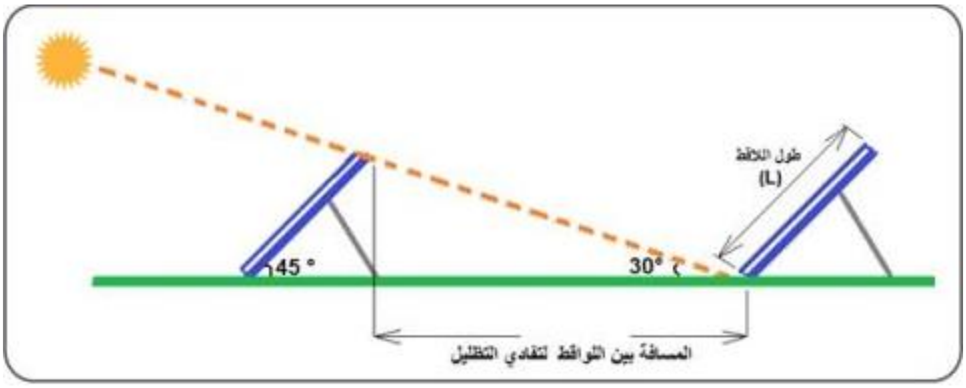
Q.2

The plate of the collector in Problem 6.1 is coated with a selective absorber and the region above the plate is partially evacuated so that the plate-to-glazing transfer coefficient is reduced to $\bar{U}_{p-g} = 4\ W/m^2\text{-}°C$. Repeat (a), (b), and (c), showing that the glazing temperature is unaffected.

Solar Heating Systems Array Orientation

At the winter solstice a vertical south-facing array is more effective than a horizontal one. The opposite is true at the summer solstice. As

Choosing the appropriate location is very important, and the solar collectors must be exposed to sunlight The sun most hours of the day, especially between nine in the morning and three in the morning In the afternoon, this means that our region is facing south, and it should be Away from tall neighboring buildings or tall trees for fear of shading and is usually installed
On the roofs of buildings To calculate the minimum distance D between two rows of solar collectors to avoid shading



ان يراعي عند وضع أكثر من صف من اللواقط الشـمسـية ضبط المسـافة بينها، لكي لا يقع ظل الصـفوف الأمامية على الصـفوف التي خلفها بحيث لا تزيد الزاوية بينهما على (٣٠ درجة)، كما هو مبين الشكل

Choose the angle of inclination of the solar collectors to benefit from sunlight for the longest possible period year and according to the desire of the consumer. In normal conditions, it is preferable for the inclination angle to be equal to The latitude of that region. If the consumer desires to benefit from the solar heater in During the winter period, the angle of inclination is equal to the latitude plus 10 to 15 degrees The desire was to benefit from the solar heater in the summer, so the angle of inclination was adjusted It is equal to the latitude of that region minus 10 to 15 .degrees

توفير الماء الساخن طيلة أيام السنة هي الوظيفة الرئيسية للسخانات الشمسية لذا يجب اختيار زاوية ميلان اللواقط الشمسية للاستفادة من أشعة الشمس لأطول فترة ممكنة من السنة وحسب رغبة المستهلك. للأحوال العادية يفضل أن تكون زاوية الميلان تساوي خط عرض تلك المنطقة، أما إذا كانت رغبة المستهلك الاستفادة من السخان الشمسي في فترة الشتاء فتكون زاوية الميلان تساوي خط عرض مضافاً إليه 10 إلى 15 درجة واذا كانت الرغبة للاستفادة من السخان الشمسي في فصل الصيف فتكون زاوية الميلان تساوي خط عرض تلك المنطقة مطروحاً منها 10 إلى 15 درجة

Array Size

The size of the array is determined by such factors as ambient conditions, heating needs, array efficiency, and available insolation. Suppose, for example, the daily heating needs of a home during the heating season are 100 kw-hr/day ($\sim 3.4 \times 10^5$ Btu/day) and that the available daily insolation on the array is 4 kw-hr/m^2-day. Also assume that each panel has an area of 1.5 m^2, an efficiency of 50 percent, and that one-third of the heating will come from auxiliary heaters. The solar heating requirement is then 66.7 kw-hr/day. Since the array is 50 percent efficient, the required array area is

$$A = \frac{P^{(\text{daily})}}{F^{(\text{daily})} \times \eta} = \frac{66.7}{4 \times 0.5} = 33.3 \text{ m}^2$$

Since each panel has an area of 1.5 m^2, the number of panels required is ~22.

$$\text{The number of Panels} = \frac{\text{the area of array}}{\text{the area of one panel}} = \frac{33.3}{1.5}$$

$$= 22 \text{ panels}$$

Series and Parallel Arrays

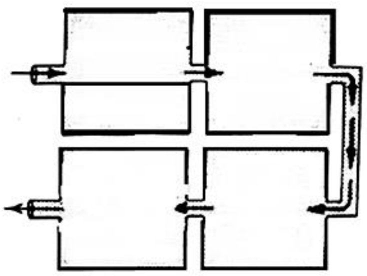
A solar array can consist of heating panels arranged in either Series, parallel, or a combination of the two, as shown in Figure. A large array will not produce a higher temperature than is possible with a single collector

خصائص ربط المنظومات على التوالي: انظر الشكل a
1: ربط مخرج كل لوح بمدخل اللوح الذي يليه كما في الشكل
2: يجب أن لا تحتوي المنظومة على عدد كبير من الألواح لان طولها يولد مقاومة لتدفق المائع الناقل
3: الألواح لا تعمل كلها بنفس الكفاءة التي قريبة من المدخل تكون درجة حرارة العمل فيها منخفضة فيعمل على زيادة كفاءتها

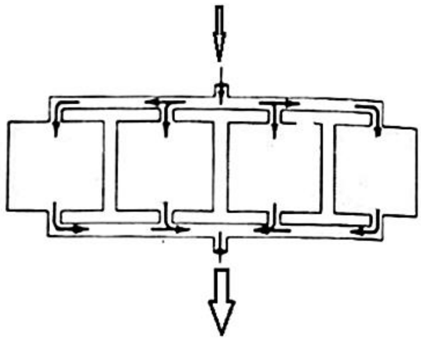
سرعة (ṁ) تدفق المائع للمنظومة = سرعة تدفق اللوح 1 + سرعة تدفق اللوح 2 +سرعة تدفق اللوح 3

كفاءة المنظومة = كفاءة اللوح 1+ كفاءة اللوح 2+ كفاءة اللوح 3 وهكذا

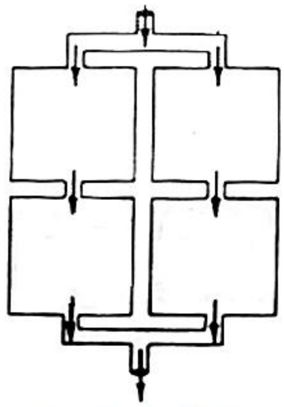
الربط على التوازي الشكل b
تربط مناطق دخول السائل لكل لوح مع خط مغذ مشترك اما مناطق خروج السائل لكل لوح يربط بمنفذ مشترك
سرعة التدفق للمنظومة = سرعة التدفق في اللوح 1 = سرعة التدفق في اللح 2 = س التدفق في 3
كفاءة المنظومة = كفاءة لوح 1 = كفاءة لوح 2 = كفاءة لوح 3
كفاءة المنظومة = N مضروبا بعدد الألواح



(a)
Series connection



b) Parallel array



c) the combination array

Pipe Losses

Exterior pipes that carry warm transfer fluids from the array will lose heat to the cooler surroundings. Because the ambient air acts as a heat reservoir at a temperature T_a, the heat transfer process can be approximated using the single-current, heat exchanger equation, If we apply exchanger equation to an exterior pipe carrying fluid from an array at a hot temperature T_H to a storage tank, we find that the temperature of the fluid reaching the tank is

$$T_{storage} = T_a + (T_H - T_a)\exp(-\bar{U}_L L/\dot{m}C_l) \quad (1)$$

where $\bar{U}_L$ is the overall coefficient per unit length of pipe for heat transfer from the fluid to the surrounding air and L is the length of the pipe. , the heat loss from the pipe is given by

$$\dot{Q}_{pipe\ loss} = \dot{m}C_l(T_H - T_a)[1 - \exp(-\bar{U}_L L/\dot{m}C_l)] \quad (2)$$

For well-insulated, short lengths of pipe, the product $H' = \bar{U}_L L$ will be small; in this case we would find $T_{storage} \simeq T_H$ and $\dot{Q}_{pipe\ loss} \simeq 0$. The effect of pipe losses on both small and large arrays is demonstrated by the next two examples.

EXAMPLE

A single solar heating panel uses water ($C_f = 4186$ J/kg-°C) as the transfer fluid. The water is flowing at $\dot{m} = 0.005$ kg/sec; it enters the panel at 20°C and leaves at 50°C. The fluid is carried to a storage tank by an exterior pipe 10 m long whose overall heat transfer coefficient per unit length is $\bar{U}_L = 0.2$ W/m-°C. The ambient temperature is $T_a = 15$°C. Find the temperature of the water entering the storage tank and the percent of the heat produced by the panel lost by the pipe.

The solar panel is collecting heat at a rate

$$\dot{Q}_c = \dot{m}C_f(T_H - T_C) = (0.005)(4186)(50\text{–}20) = 628\text{ W}$$

Using Equation (1) we find that the temperature at storage is

$$T_{storage} = 15 + (50 - 15)\exp[-(0.2)(10)/(0.005)(4186)] = 46.8°\text{C}$$

According to Equation (2), the pipe loss is

$$\dot{Q}_{pipe\ loss} = (0.005)(4186)(50 - 15)\{1 - \exp[-(0.2)(10)/(0.005)(4186)]\} = 67\text{ W}$$

The percent loss is

$$\%\,\text{loss} = \frac{67}{628} \simeq 11\%$$

Example 2.

Consider a parallel array of 10 panels, each of which is operating as the panel in the preceding example. Find the collection rate, the temperature entering storage, and the percent pipe loss.

The flow rate is increased by a factor of 10 to $\dot{m} = 0.05$ kg/sec. Assuming that the temperatures of the inlet and outlet remain at 20 and 50°C, respectively, the collection rate is increased by a factor of 10 to $\dot{Q}_c = 6280$ W. Using Equations 1 and 2 we find

$$T_{storage} = 15 + (50 - 15)\exp[-(0.2)(10)/(0.05)(4186)] = 49.7°\text{C}$$

and

$$\dot{Q}_{pipe\ loss} = (0.05)(4186)(50 - 15)\{1 - \exp[-(0.2)(10)/(0.05)(4186)]\} = 70\text{ W}$$

The percent loss is now

$$\%\,\text{loss} = \frac{70}{6280} \simeq 1.1\%$$