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CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 1

SOLAR ENERGY RADIATION AND SOLAR THERMAL COLLECTORS

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Absorptance of Flat Plate Collectors

Absorptance refers to the ability of a material to absorb incident solar radiation and convert it into heat. In the context of flat plate solar collectors, the material that absorbs sunlight is usually a selective surface or coating on the absorber plate. This surface is designed to maximize the absorption of solar radiation and minimize the loss of heat.

For a flat plate collector, the absorptance is typically high for solar radiation in the visible and infrared wavelengths. Materials such as copper, aluminum, or specially coated surfaces are often used for the absorber plate. The selective coating on the absorber surface is crucial because it maximizes the absorption of solar radiation while minimizing thermal losses due to reflection and radiation. The absorptance (α) is a ratio of the absorbed radiation to the incident radiation on the surface.

In practical terms, the absorptance of flat plate collectors is a key factor in determining their performance. A higher absorptance means more solar radiation is absorbed and converted to heat, leading to a more efficient collector. Typical values for absorptance are around 0.8 to 0.95 for good solar absorber materials.

Heat Transfer Correlations

Heat transfer in flat plate solar collectors is driven by the conversion of solar radiation into heat, which is then transferred to a fluid (usually water or air) circulating through pipes embedded in or in contact with the absorber plate. The key heat transfer mechanisms involved in these collectors are:

1. Conduction: Heat is transferred from the absorber plate to the fluid through the metal pipes or other conduits. The efficiency of this heat transfer depends on the thermal conductivity of the materials in contact with the fluid, such as the pipe material and the absorber plate.

2. Convection: The heat from the absorber plate is transferred to the fluid through convection. This depends on the temperature difference between the plate and the fluid, the properties of the fluid (such as its specific heat and viscosity), and the flow characteristics of the fluid (whether it is laminar or turbulent). Forced convection (with a pump) generally enhances heat transfer compared to natural convection.

3. Radiation: The absorber plate also loses some of its heat through radiation to the environment. The amount of radiative heat loss depends on the temperature of the plate and its emissivity, which is a measure of the material's ability to emit thermal radiation.

To model and calculate heat transfer in flat plate collectors, researchers use various heat transfer correlations that combine these three mechanisms. One of the most commonly used is the **heat balance equation** for the collector:

$$Q_{absorbed} = (I - I_b) * A * \alpha - U * A * (T_{collector} - T_{ambient})$$

Where:

- $Q_{absorbed}$ is the total heat absorbed by the collector.

- I is the incident solar radiation (W/m^2).

- I_b is the reflected radiation (W/m^2).

- A is the area of the collector (m^2).

- α is the absorptance of the absorber plate.

- U is the overall heat loss coefficient ($W/m^2 \cdot K$).

- $T_{collector}$ is the temperature of the collector.

- $T_{ambient}$ is the ambient temperature.

For better accuracy, the overall heat loss coefficient (U) is typically modeled using a combination of convective and radiative losses, which are temperature-dependent. This can be expressed using the following relations:

$$U = h_c + h_r$$

Where:

- h_c is the convective heat transfer coefficient.

- h_r is the radiative heat transfer coefficient.

Collector Efficiency

The efficiency of a solar collector is a measure of how effectively it converts solar energy into usable thermal energy. It is defined as the ratio of the useful heat energy collected by the system to the total solar energy incident on the collector.

Collector efficiency (η) can be calculated using the following equation:

$$H = (Q_{useful} / Q_{incoming}) * 100\%$$

Where:

- Q_{useful} is the useful heat energy collected (in watts).

- $Q_{incoming}$ is the total solar energy incident on the collector (in watts).

In practical terms, the useful heat energy collected by the flat plate collector depends on the balance between the heat absorbed by the collector and the heat lost due to various factors like radiation, convection, and conduction. Therefore, collector efficiency can be affected by factors such as:

1. Collector Temperature: As the temperature of the collector increases, the heat loss due to radiation and convection increases, which decreases the overall efficiency. In general, collector efficiency tends to decrease as the temperature difference between the collector and the ambient environment increases.

2. Incident Solar Radiation: Higher levels of solar radiation improve the efficiency of the collector. On sunny days with higher radiation, the collector is able to absorb more energy, thus increasing its performance.

3. Heat Loss: Minimizing heat losses from the collector to the environment is critical for improving efficiency. This is typically achieved by improving the insulation and minimizing the radiation losses. The better the selective coating on the absorber plate, the less heat is lost to radiation.

4. Fluid Flow Rate: The flow rate of the heat transfer fluid also impacts efficiency. At low flow rates, the heat transfer to the fluid may be inefficient, and the fluid may not carry away enough heat, causing the collector to overheat. On the other hand, excessively high flow rates can reduce the time the fluid spends in contact with the absorber plate, which reduces the overall heat transfer.

5. Environmental Factors: Cloud cover, ambient temperature, and wind speed can all influence the efficiency of a flat plate collector. For example, high wind speeds can enhance convective heat losses, thereby reducing efficiency.

Thermal Efficiency Curve

Collector efficiency is often plotted as a function of the temperature difference between the collector and ambient air. This is known as the **thermal efficiency curve**. It typically shows that at lower temperature differences (when the collector temperature is close to ambient), efficiency is high. However, as the temperature difference increases, efficiency decreases because of increased heat losses.

A simplified version of the collector efficiency can be expressed by the following linear relationship:

$$H = \eta_0 - (U * (T_{collector} - T_{ambient})) / I$$

Where:

- η_0 is the optical efficiency (the efficiency of converting incident solar radiation into absorbed radiation).

- U is the heat loss coefficient.

- $T_{collector}$ is the temperature of the collector.

- $T_{ambient}$ is the ambient temperature.

- I is the incident solar radiation.

This equation shows that efficiency decreases linearly with increasing temperature difference between the collector and the surrounding environment. The optical efficiency (η_0) typically accounts for the performance of the material in absorbing solar radiation and converting it to heat.

In summary, the efficiency of flat plate collectors depends on multiple factors, including the absorptance of the absorber plate, heat transfer mechanisms (conduction, convection, and radiation), and environmental factors. Proper design and optimization of these parameters are essential for maximizing the thermal efficiency of flat plate collectors in solar thermal systems.