Example of thesis on solar collectors

Technology, Innovation

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Introduction

With people becoming more conscious of the detrimental effects of fossil fuel, the demand for green sources of energy is on a rise. The Sun is the source of all the energy in this world. Even if a small percentage of solar irradiance is collected every day then all the problems related to the scarcity of sufficient energy will be solved. However, it is not very easy to collect and store solar energy in an effective way. Solar Collectors also known as Solar Thermal Collectors are designed to absorb solar energy from solar radiation which is then reduced to heat water to generate electricity using a turbine and generator. There are different types of collectors. Most of the commercial collectors are used in residential buildings for hot water supply and space heating. Some of the bigger commercial collectors are used to generate electricity and street lighting. This essay will discuss upon the basic concept of solar collectors, how it works, the different types of solar collectors and finally the factors that determine the efficiency of a solar collector.

How it Works

Solar collectors are used to transform solar energy into heat and then transfer that heat into other mediums like water or air. The heart of any solar system is its absorber. The absorber is mainly made up of narrow metal strips or metal tubes. Carrier fluid inside the solar collectors then carries the absorbed heat to the medium which it wants to heat (Stine & Geyer). Through the circulation of the carrier fluid the heating process continues to heat the medium like air and water and circulates back to the absorber panel. This process continues.

Types of Collectors

There are several types of solar collectors. The main four types of solar collectors include flat plate collectors (FPC), evacuated tubular collectors (ETC), air collectors and parabolic collectors. Flat plate collectors are by far the most used solar collector followed by evacuated tubular collectors. They are used mainly in residential heating and water heating purposes. Bowl collectors on the other hand are used for electricity generation.

Flat Plate Collector

Flat plate collectors are made of some basic parts including an absorber, a transparent cover glass and an insulated box. The absorber which has either a painted or coated surface to cause maximum absorption of radiant energy is basically a metal sheet of high thermal conductivity with either integrated or attached tubes or ducts. The cover glass allows sunlight to reflect on the absorber and prevents cool air from blowing into the space above the absorber. The insulated box besides giving a structure decreases loss of heats from the rear end of the collector (Stine & Geyer).

The absorber is meant to perform three crucial functions; 1) absorb maximum amount of radiant energy, 2) conduct the heat received from the radiant energy into the working fluid at the difference of minimum temperature and 3) allow the loss of only a minimum amount of energy back to the environment (Stine & Geyer). Surface coating or painting is used on the absorber to maximize heat absorption in a uniform manner from all directions. Transferring the absorbed radiant energy into the working fluid is done by passing the absorbed heat through ducts or tubes which carry heat-transfer fluid. Either plain water or water combined with antifreeze or even gas could be used as heat-transfer fluid. When the heat-transfer fluid is liquid then some problems may crop up during the transferring of absorbed radiant energy into the working fluid and therefore, absorber plates consisting of flat metal sheet with tubes or ducts attached or integrated are used as liquid collector. The flat metal sheet absorbs maximum amount of solar heat and then functions like a fin to transfer the absorbed heat into the working fluid (Stine & Geyer). When air is used as heat transfer fluid then the internal passage for air circulation should be designed in a way to provide sufficient amount of high airflow velocity through the rear end of the absorber to maximize heat transfer without creating a high pressure drop in the collector. If the rate of heat transfer is low then the absorber plate becomes very hot leading to an increased loss of heat.

Fig 1: Flat Plate Solar Collector (Stine & Geyer)

One or more transparent cover glasses or sheets are used to cover the absorber in order to reduce the amount of heat loss. If the cover glass is not there then convection created by local wind makes the absorber lose a lot of heat. Not only that, heat is lost also due to natural convective air currents which are created by the absorber being hotter than the ambient air (Stine & Geyer). The cover glass produces a space to trap the circulation of air just above the absorber, leading to a reduction in heat losses. Chances of convective heat loss, however, cannot be totally eliminated due to the formation of convective air currents between the cover glass and the absorber which results in constant transferring of heat from the absorber to cover glass. External convection is used then to cool down the cover glass resulting in a net amount of heat loss. The number of cover glasses used for flat-plate collectors ranges between none to two or more. There are flat-plate collectors without any cover glass but these collectors can function efficiently only when the working temperature is close to ambient temperature. As the number of cover glasses increases, so does the temperature for the collector to operate efficiently (Stine & Geyer). Usage of one or two cover glasses is common but three or more cover sheets are only used for severe climatic conditions. Usually glass is used as cover sheet but when two or more cover sheets are added, then plastic foil is used.

Flat plate collectors can absorb both direct and diffuse solar energy from all directions (Stine & Geyer). This type of solar collector does not require tracking the Sun and hence these collectors can be firmly placed on a mounting structure. Any other sort of equipment like motors, or the Sun tracking device or a moving structure is not needed at all. Due to the simplicity of design and the absence of an intricate tracking system, flat plate collectors cost less compared to other sort of collectors.

Evacuated Tube Collectors

Evacuated tube collectors are made of glass tubes. This type of collector generates low amount of heat loss when it functions in high temperature. This type of collector mainly has one cover glass with the space between the absorber and cover glass evacuated to eliminate heat loss due to convection. Heat transfer fluid as used in flat plate collectors can be used for evacuated tube collectors to generate heat. Another option that can be used for heat generation is a heat pipe with a small amount of heat transfer fluid flowing inside each evacuated pipe (Trier, 2012). Four steps follow in transferring the radiant energy into the working fluid:

Figure 2 & 3: Evacuated Tube Collectors (Senya, 2011)

- First of all, solar radiation transmutes the heat transfer fluid into vapor.
- The vapor rises to the surface and encounters a cold pipe with a liquid flowing through it.
- The vapor gets condensed and transfers the latent heat to the liquid in the top pipe (Trier, 2012).
- The condensed fluid runs back to the bottom of the evacuated tubes to have the process kick off again (Trier, 2012).

Evacuated tube collectors are used to heat greater volume of water than any other collectors. The collector is so effective in heating the water that it is also used in steam production and space heating as well. Evacuated tube collectors can work well under cloudy conditions and can even keep the heat at subzero temperatures. It is more efficient than the flat plate collector in terms of efficiency and heating capability (Senya, 2011). The main drawback of this type of collector is that it is much bulkier than the flat plate collector and often small evacuated tube collectors are not commercially available. That is the main reason why flat plate collectors are still the most used solar collectors by individuals for residential use.

Air Collector

Air heat collectors are the simplest solar collector. As the name suggests solar air heater collectors are only used for space heating purpose and it heats the air directly. Air collectors generally have a glazed front sheet followed by insulated sheet in the back and side panels to minimize heat loss. The absorber plate is often perforated. Modern perforated absorber plates can actually have efficiency as high as 93% absorption ratio (Kramer, 2013). Air typically enters through the front of the air heater collector and gets heated while passing through the perforated passage of the absorber plates. The heated air leaves the air heater collector from the back side of the collector. This heated air then can be used for heating applications directly. This type of air heated collector is not only one of the cheapest collectors with very high efficiency but also one of the most cost effective among all the solar collectors.

Parabolic Collectors

Figure 3: Schematic of a Parabolic Solar Collector (Kalogirou, 2004)

Parabolic Collectors commonly known as parabolic trough is a parabolic shaped collector. All other types of solar collectors are flat but parabolic collectors are curved. According to the property of the parabola, the sunlight which enters the mirror from an angle is reflected back to a single point. Absorber tube which is constructed along the focal line absorbs the reflected heat from the mirrors (Kalogirou, 2004). For example, food placed on the focal line will receive concentrated sunray reflected from the mirror and the heated sunlight would help the food get cooked. The parabolic surface which receives the sunlight also rotates as the sun moves along the sky to get maximum exposure and efficiency. Heat transfer fluids are used in the basic design as heat absorbers along the focal line. Parabolic solar collectors can achieve a temperature as high as 400 degree C. The efficiency in this process varies between 60-80%. The overall efficiency of electrical output from this type of solar collector is around 15% which is almost similar to photovoltaic cells. There are different types of parabolic collector designs like single mirror and double mirror design.

Parabolic collectors are used as a hybrid power in many commercial plants. During the night fossil fuel is used to generate energy in those plants whereas during the day parabolic solar troughs are used to get electrical output. Though this type of solar collectors is good for commercial purpose, it is not suitable for residential use (Kalogirou, 2004). Parabolic trough power stations can produce substantial amount of energy in places where sunny days are high in number. For example, Solana generating Station in Arizona has a capacity of 280MW.

Efficiency

Figure 5: Solar heat absorption process (Kalogirou, 2004).

The efficiency of a solar collector is dependent on the ability of the collector to absorb heat and keep the heat loss to a minimum. The basic energy efficiency is calculated using the equation below:

Where

(Kalogirou, 2004)

There are two types of losses in any solar collector - optical losses and thermal losses. Optical losses are constant irrespective of the surrounding temperature. It is mainly dependent on the construction and geometry of the solar collector. To reduce optical losses the current practice is to use one sided anti-reflective glasses which allow the sunlight to come in but reflect back when it tries to escape. Heat loss on the other hand is a function of ambient temperature. As the difference between ambient temperature and the collector temperature increases, the heat loss from the solar collector increases rapidly (Kalogirou, 2004). This is the reason why when the ambient temperature drops the performance of the solar collectors reduces drastically.

Another factor to influence the efficiency of the solar collectors is incidence angle. As the sun travels along the sky during the course of the day, the incidence angle of sunray changes constantly. For every solar collector design there is an angle for which the energy efficiency is maximum. In most of the cases if the angle of incidence is 90 degree, the efficiency of the solar collectors becomes maximum high. For flat plate collectors even if the angle of incidence is slightly less or more than the critical angle, then also the efficiency remains almost same. However, the cosine loss increases with the changing angle for parabolic trough, leading to a drastic reduction in its efficiency (Trier, 2012). That is why solar power stations with parabolic trough solar collectors are designed to change the angle to get maximum sunray as the Sun changes position in the sky.

Flow rate is another factor to influence the efficiency of a solar collector. When the number of collectors connected to the system flow pipe increases the system pipe length decreases, causing reduction in heat loss from the system pipes. This increases the efficiency. However, it is not that simple because with an increase in the number of collectors, the temperature of the water or fluid in the small system pipe increases very quickly and in order to maintain a stable equilibrium high flow rate is required. If that cannot be maintained then the outlet may see pressure loss and mixing of cold and hot fluids which will reduce the efficiency drastically. Pressure loss of the collectors and the pipe design are of equal importance as the absorbing part of the design (Fan and Furbo, 2008). The more number of collectors means more complicated design which creates design challenge to the solar designers to maintain equilibrium.

Among the flat plate collectors and evacuated tube collectors, flat plate collectors are more energy efficient in normal operating conditions. It the temperature difference between the surrounding and the collector is less than 30 degrees, then a flat plate collector can provide efficiency as high as 80% compared to 75% of the evacuated tube collectors (Trier, 2012). However, as the difference between ambient temperature and collector temperature increases the efficiency of the flat plate collector decreases fast. For a temperature difference of 60 degrees a standard flat plate collector gives an efficiency of 55% whereas evacuated tube collector continues to give an efficiency of around 70% (Trier, 2012). Flat plate collectors are suitable for places where during the course of the year the temperature variation is less. On the other hand, evacuated tube collectors are suitable for places where temperatures during winter go well below zero degrees.

Parabolic trough collectors are not as energy efficient as the flat plate collectors but it has the potential to provide very high efficiency. The current parabolic troughs used in various power plants only provide 40-50% efficiency under varying weather conditions. Research is going on in this type of solar collectors and some of the lab tested parabolic solar collectors show efficiency as high as 90% (Figueredo, 2011). Hopefully in the coming days more fruitful research will be done in this space and better parabolic troughs will be designed to provide solar energy to millions.

Conclusion

Solar collectors are one of the purest forms of green energy. The working principle of the solar collectors is simple. It absorbs the solar energy and then uses that energy to heat water or air which is then used for various purposes. Solar collectors are also used to generate electricity. There are different types of solar collectors with flat plate solar collectors, evacuated tube solar collectors and parabolic solar collectors being the most commonly used ones. We know that solar collectors are a source of green energy but due to lack of technological advancement solar collectors are still not able to supply power to masses in a cost effective manner like fossil fuel. In recent years, the cost of fossil fuel is on a rise which is forcing many of us to think about other alternative sources of energy. Solar collector designs are seeing newer advancements. From new flat solar collectors to parabolic troughs, the design of solar collectors has walked a long way. Flat collectors and evacuated tube collectors are seeing more usage in household heating and air heating applications with every passing year. In many states in USA where average sunny days per year is high in number, people are using solar collectors for heating water and generating electricity to meet small domestic needs. In places which are colder but see lot of sunny days people are using evacuated tube collectors to keep their home heated. In future hopefully with more advancement in solar technology we will be able to capture the solar energy more efficiently and use it to meet our day to day need for heating and electricity.

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