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COMPARISON OF THE EFFICIENCY OF THREE TYPES OF SOLAR COLLECTORS

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ABSTRACT

Solar energy is one of the most abundant resources energy available in the world. Solar collectors have evolved in the last decades, but still they haven't reached very high efficiencies.

The collector efficiency is dependent on the temperature of the plate which in turn is dependent on the nature of the fluid flow inside tube, solar isolation, ambient temperature and top loss coefficient, the emissivity of the plate and glass cover. This paper presents the test results of three different solar collectors and compares their efficiency.

KEYWORDS: heat transfer, solar collector, solar energy, system efficiency, thermal performance

1. Introduction

Solar energy is one of the most available, cleanest and cheapest energy of all sources on the surface in the world.

Because of that and of the global shortage of fossil energy source and environmental pollution, it became increasingly favorable.

Scientists ask themselves how we can get hold of solar energy such that it can be stored and transported from the sun and the uninhabited region of the earth's sunbelt to the world's industrialized and populated zones.

This question has motivated them to find methods to capture solar energy even if it happens to be a cloudy or rainy day, good enough reason for increasing its potential utilization.

Recently they have found a method [2] who converts solar energy into solar fuels. In what follows, we will analyze several types of solar collectors producing heat.

2. Models of collectors

2.1. Collectors without concentration of solar radiation

A flat-plate collector is shown in Fig. 1. When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of a high absorptive, a large portion of this energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use.

Glazing: one or more sheets of glass or other diathermanous (radiation-transmitting) material. Tubes, fins, or passages: helping to conduct or direct the heat transfer fluid from the inlet to the outlet.

Absorber plates: flat, corrugated, or grooved plates, to which the tubes, fins, or passages are attached. The plate may be integral with the tubes.

Headers or manifolds: to admit and discharge the fluid.

Insulation: to minimize the heat loss from the back and sides of the collector.

Container or casing: to surround the aforementioned components and keep them free from dust, moisture.

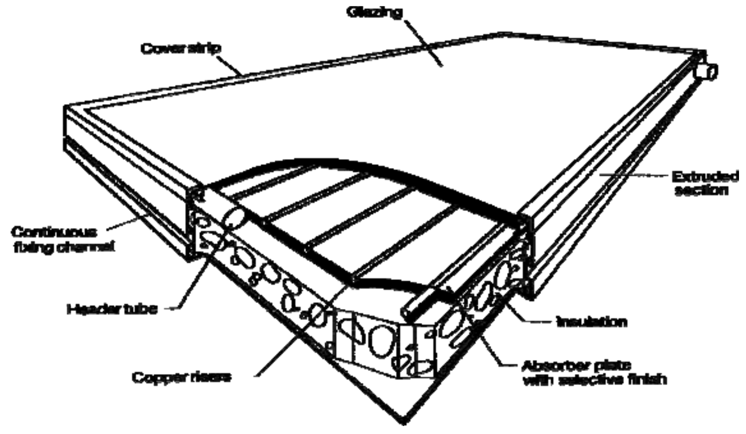

Fig. 1. *Flat-plate collector*

The evacuated tube collector (Fig.2) uses liquid–vapors phase change materials to transfer heat at high efficiency. These collector works by converting energy into tubes.

They have a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe is made of copper, contains a small amount of fluid (e.g. methanol). The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures.

These types of collectors can reach higher values of temperature than flat-plate collectors.

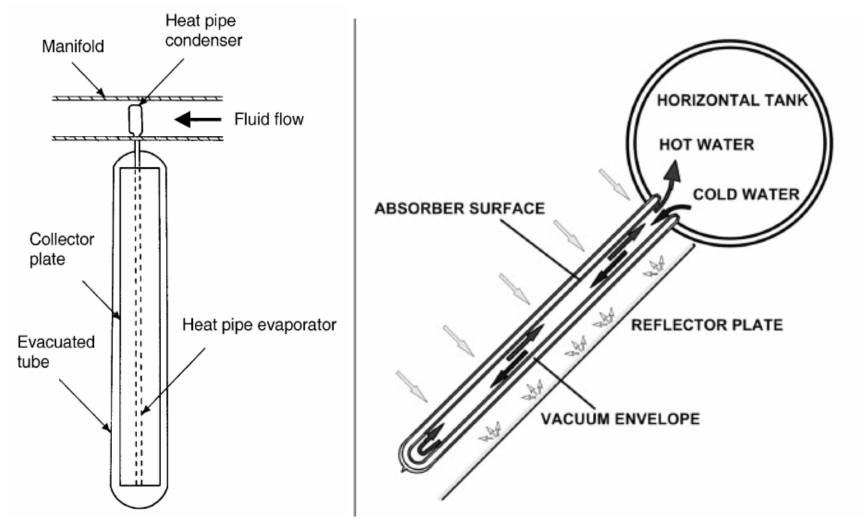

Fig. 2. *Evacuated tube collector and the process of natural circulation flow in a water-in-glass tube*

2.2. Collectors with concentration solar radiation

Dish/Engine systems use an array of parabolic dish-shaped mirrors (stretched membrane or flat glass facets) to focus solar energy onto a receiver located at the focal point of the dish (Fig. 3). The fluid in the receiver is heated to 750˚C (1,382˚F).

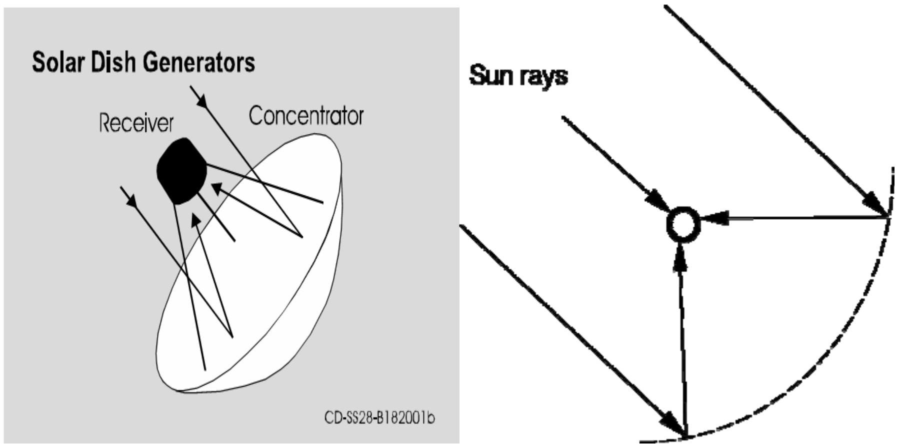

***Fig. 3.** Solar dish engine system*

Collector Parabolic Trough systems use parabolic trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid (Fig. 4). This fluid is heated to 390˚C (734˚F) and pumped through a series of heat exchangers to produce superheated steam.

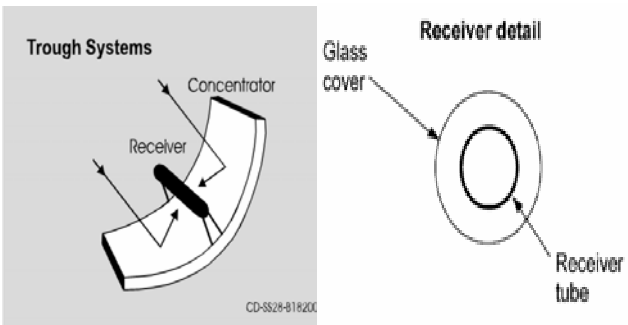

***Fig. 4.** Solar parabolic trough collector*

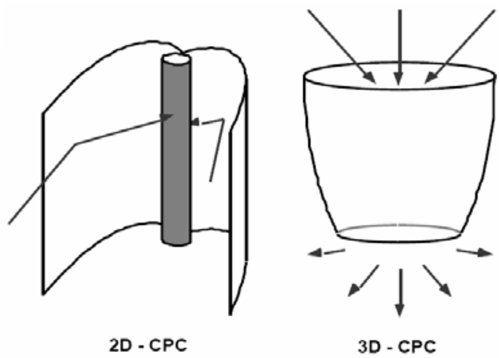

***Fig. 5.** Schematic of a 2-D, 3-D compound*

These types of collector have reflective inner walls that are used to augment the solar flux concentration of the primary concentrator.

Higher concentration ratio imply lower heat losses from smaller receiver, and consequently, higher attainable temperatures on the receiver.

The power flux concentration can be increased by a factor ρ $(\sin\Phi_{rim})^{-1}$ for 2-D CPC and ρ $(\sin\Phi_{rim})^{-2}$ for 3-D, where Φ_{rim} is the angle of the primary concentration system and ρ is the inner wall total hemispherical reflectance of the CPC.

3. Principles of solar energy concentration

This conventional method, of parabolic-shaped mirrors, presupposes collecting solar energy from a large area and delivering it onto a small one. A parabola focuses rays parallel to its axis into focal point. The angle focusing on extremities is approximated at θ=0.0093 radian. It considers that the focal length *f* is perfectly positioned and the rim angle Φ_{rim} is aligned to the sun, and the reflection of the rays at the focal plane forms a circular image centered at the focal point (Fig. 6).

The diameter is:

$$d = \frac{f \cdot \theta}{\cos \theta_{rim} \left(1 - \cos \theta_{rim}\right)} \quad (1)$$

When the dish is aligned toward the sun, the reflection of the sun rays at the focal plane forms a circular image centered at the focus of diameter *d*.

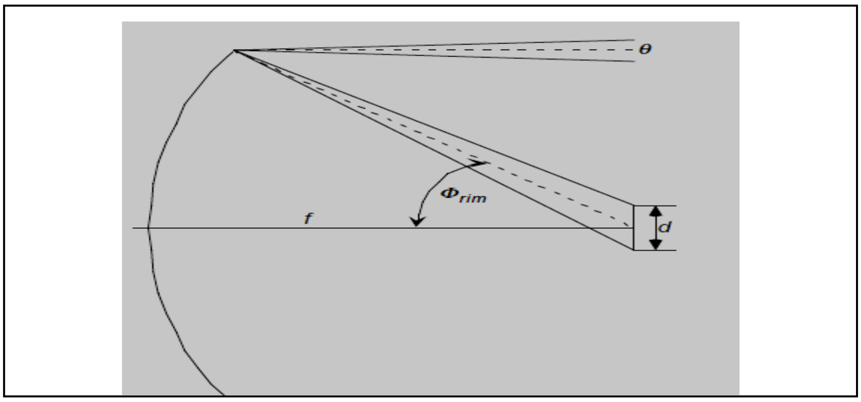

Fig. 6. *Concentration of sunlight by a parabolic dish of focal length f and rim angle* Φ_{rim}

On this circle, the radiation flux intensity is maximum and uniform in the paraxial solar image (the “hot spot“). It decreases for diameters larger than $f \cdot q$ as a result of forming elliptical images. The theoretical concentration ratio *C* at the hot spot is defined as the ratio of the radiation intensity on the hot spot to the normal beam insulation, where C - solar flux concentration ratio, θ - angle subtended by the sun at the earth’s surface.

$$C \approx \frac{4}{\theta^2} \sin^2 \phi_{rim} \quad (2)$$

For a rim angle of 45˚ the theoretical peak-concentration ratio exceeds 23,000 suns, where 1 sun refers to the normal beam isolation of 1kW/m^2. The thermodynamic limit for solar concentration is given by the factor $\sin^{-2} \phi \approx 46{,}000$ suns.

4. The efficiency of solar collectors

The table below presents the performances of different types of solar collectors described above [5].

Table 1. *Solar energy collector*

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (˚C)
Stationary	Flat plate collector (FPC) Evacuated tube collector (ETC)	Flat Flat	1 1	30-80 50-200
Single-axis tracking	Linear Fresnel reflector (LFR) Parabolic trough collector (PTC)	Tubular Tubular	10-40 15-45	60-250 60-300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500

The efficiency of a solar collector is shown below:

$$\eta = F_t \left[(D \cdot A) - \frac{K \left(T_i - T_a\right)}{E \cdot k} \right], \% \quad (3)$$

where: F_t - is heat transmission factor, D·A – transmission-absorption product for incidence angle, K - overall heat loss coefficient, T_i - fluid inlet temperature, T_a - ambient temperature, E - solar radiation on a horizontal surface, k – collector concentration ratio.

The absorption coefficient must be larger and the transmission coefficient must be smaller.

The heat transmission factor represents real useful heat which might be obtained in the collector if the absorbing medium would have the fluid inlet temperature.

This is:

$$F_t = \frac{m \cdot c_p \left(T_e - T_i\right)}{A_c \left[E_a - k(T_i - T_a)\right]} \quad (4)$$

where: m – mass flow working fluid;

c_p - specific heat; A_c - heat exchanger surface area; E_a - solar radiation absorbed.

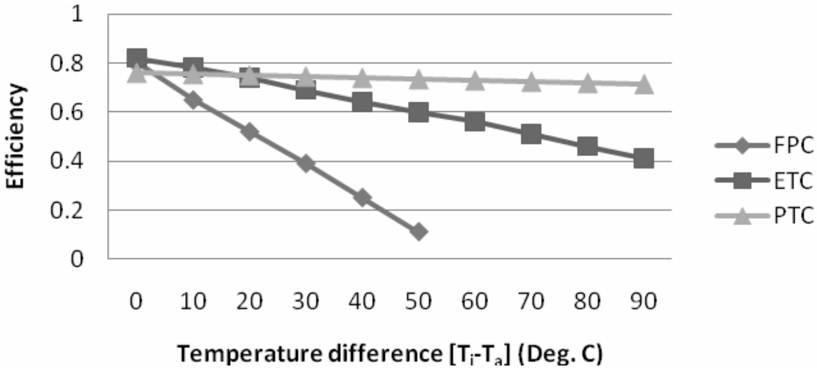

Fig. 7. *Comparison of the efficiency of three types of collectors at 500W/s irradiation levels*

The table presents the efficiency of flat-plate collector, evacuated tub collector and parabolic trough collector.

As seen in Figure 7, the better efficiency and the higher performance have been observed for vacuum tube collectors and parabolic trough collectors and retain high efficiency even at higher collector inlet temperatures.

5. Conclusion

The paper compares several of the most common types of collectors. The various types of collectors described include flat-plate, evacuated tub collector, dish engine and parabolic trough.

The thermal analysis method of collectors is presented to evaluate their performances.

The application areas described in the paper show that solar energy collectors can be used in a different places where are not fully developed, could provide financial benefits, and can be used whenever possible and in terms of environmental protection.

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