EXPERIMENTAL STUDY OF A CONCENTRATION HEATING SYSTEM WITH OPTICAL FIBER SUPPLY

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Abstract

The buildings thermal function is important to provide comfort to its tenants. This means to provide cooling during hot seasons and/or heating in cold season. Current study concerns modelling of a new design of thermal photo sensors that results in a more efficient heating for Tlemcen site, Algeria.

Keywords: Conception, Simulation, Solar Energy, Optical fiber, Heating of the sanitary water,

Introduction – The idea of carrying concentrated solar energy started in 1980 by a group of French researchers (Cariou et al., 1982, Nakamura et al., 1995). Studies achieved on transmission concentrated solar energy via optical fibers for various purposes are very recent Kandilli et al. (2007). They can be listed as follows:

- Khatri et al. (1993) discussed a solar energy collection system in which optical fibers are used to transport energy from a single-stage and a double stage (CPC);

- Liang et al. (1997) emphasized on the high flux solar energy transmission by a flexible optical fiber bundle and the research on the associated CPC would largely expand the existing field of solar energy concentrators applications;

- Gordon et al. (2002a, 2002b and 2001) showed that optical fibres used to transport sunlight exhibit considerable light leakage within their nominal numerical aperture and this leakage depends on (i) the incidence angle, (ii) the optical properties of the core and the cladding and (iii) the fiber length;

- Often the technology for optical fiber transmission offers a high quality production with a large diameter of the heart (Kato et al, 1976);

- Feuermann et al. (1998) in studying solar surgery used remote fiber-optic irradiation with highly concentrated sunlight in lieu of lasers.

- Jaramillo et al. (1999) developed a theoretical thermal study of optical fibers transmitting concentrated solar energy;

- Kribus et al. (2000) presented a study on the potential use of optical fibers for solar thermal power generation. The main performance characteristics (numerical aperture and attenuation) and typical costs of currently available fibers were discussed.

In this work, we use light drivers that have the advantage of low attenuation, and minimal losses in the conversion (Cariou et al., 1985). That is to say:

- To reduce heat losses of thermal photo sensor and increase the temperature inside the tank;
- To reduce heat losses of the sensor coolant fluid.

This study consists in adopting a new design of hot water production and storage system, in order to minimize losses and increase the efficiency.

The system is completely isolated from the external environment and connected by an optical fiber in its summit. It gave us promising results compared to the thermal classic photo sensor.

The heat energy available from a solar collector is equivalent to the incident energy. The heat losses are due to reflection, reemission of radiation, convection and conduction.

As shown in Fig.1, for a stream of 1000W/m^2 at the window, almost 14% of the radiation is lost by reflection in the front and rear glass and 21% in the absorber; in all cases the recovered power is about 60% (i.e. 40% of global radiation incident is lost).
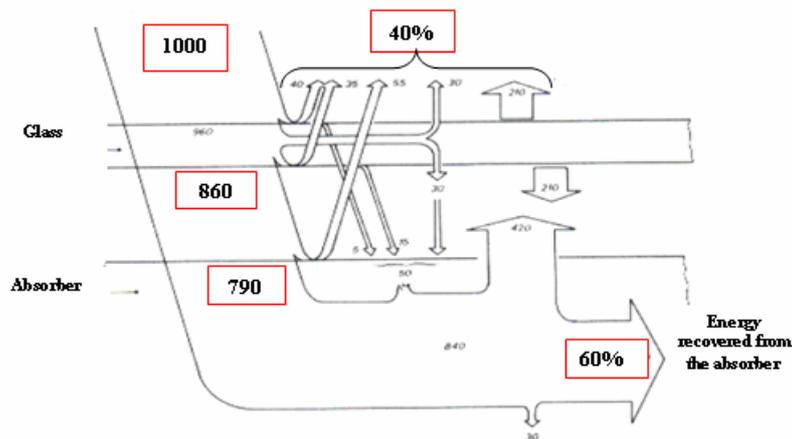
Fig.1. Distribution of incidental energy on a traditional sensor

The question is: how can we eliminate these losses? In fact we can no longer eliminate the losses, we can only reduce them. This is the aim of the presented study, through the design of a new photo sensor system, with reduced heat loss and high efficiency (Fig.2).
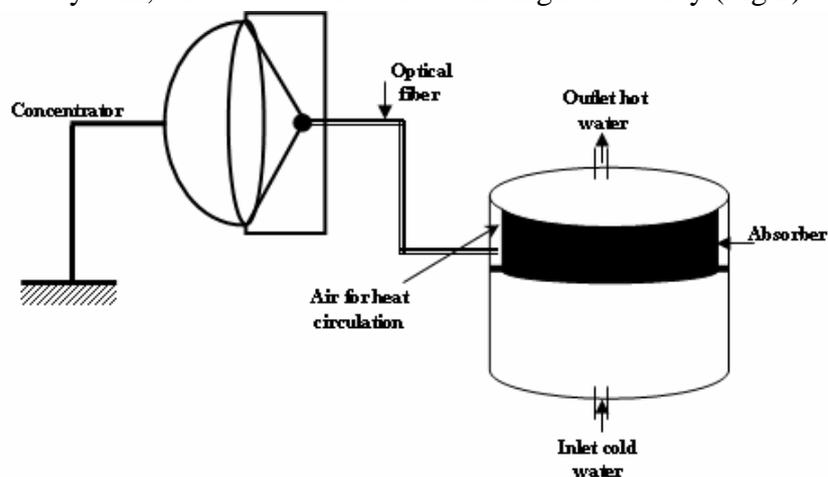
Fig.2: Hot water production and storage system

The system contains:

* The concentrator represented by a parabolic mirror that has the following geometrical characteristics: D=148 cm, the focal length f = 82 cm.

* An optical fiber SPCH 1000/1035/1400Z with:

- A length of l = 2 m,

- A heart composed of 1 mm of diameter of silica,

- Average attenuation $\tau = 6.2*10^{-3}$ dB/m on all solar spectrum,
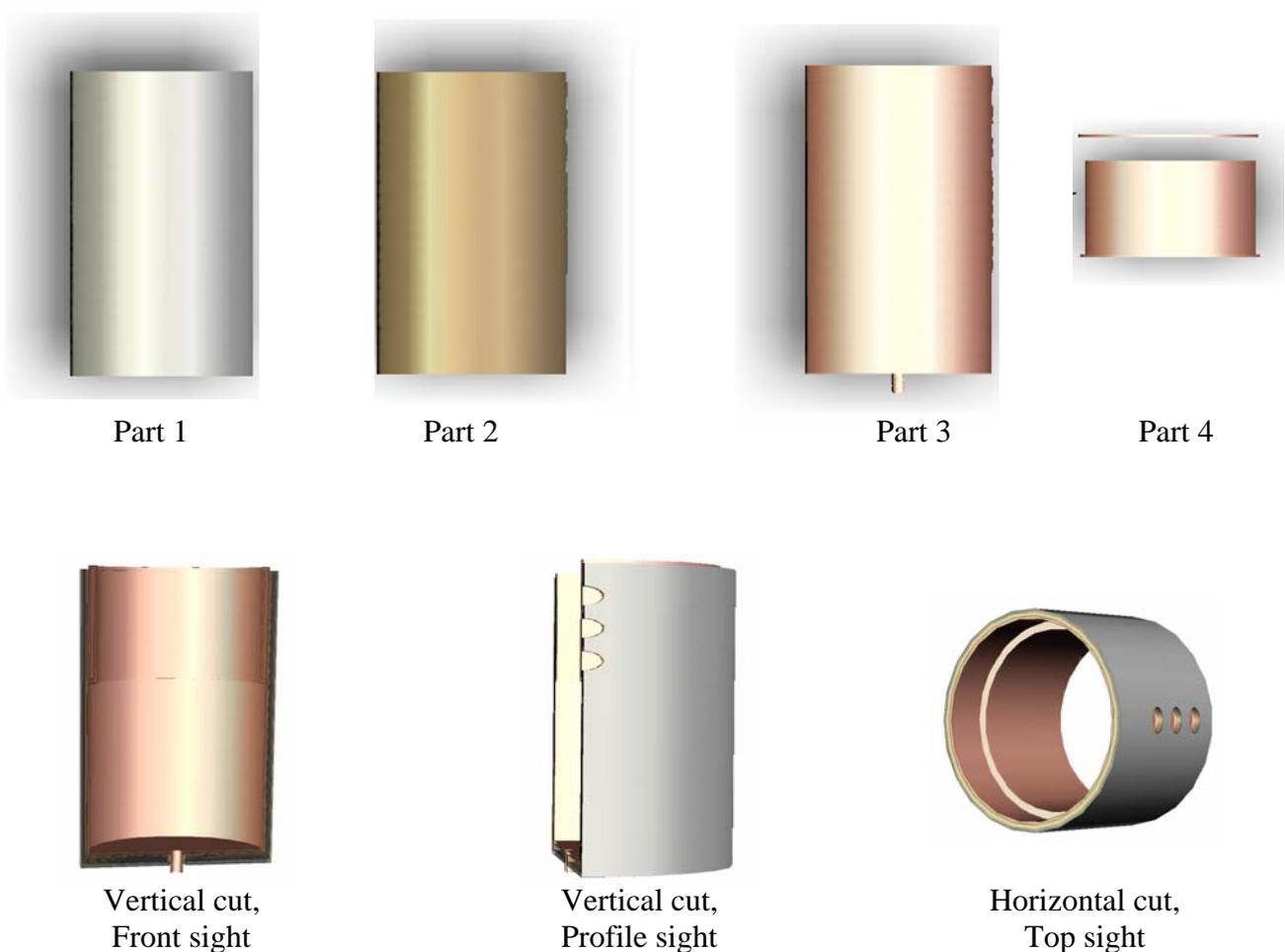
- Numerical aperture $\theta_f=20°$,

* A cylindrical storage tank with a height of 1.5m and a volume of 150litres, composed of four parts (Fig.3).

Part 1 : The external wall of the tank is made of galvanized steel with a height of 1.5m and 0.6m of diameter.

Part 2 : The thermal insulating foam with a height of 1.55m and 0.55m of diameter.

Part 3 : The tank internal wall made of galvanized steel with a height of 1.5m and 0.5 of diameter.
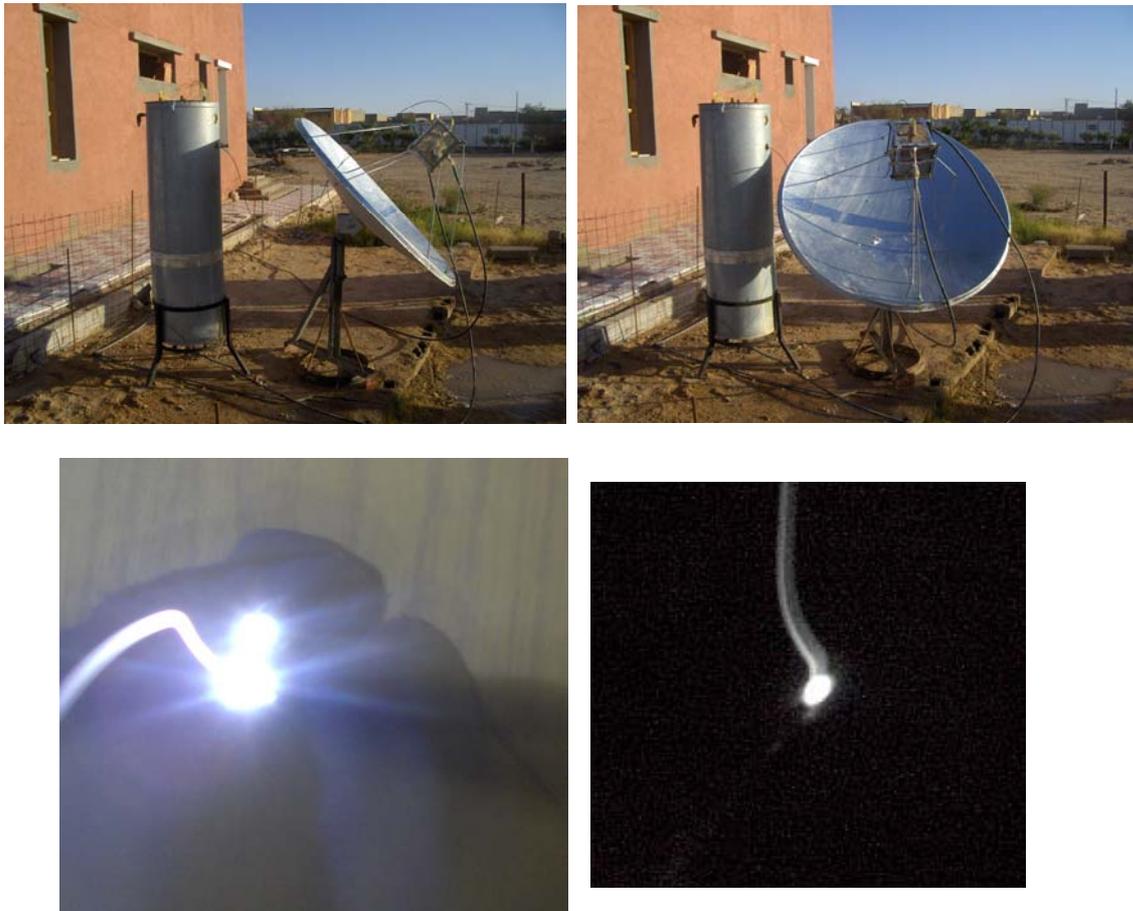
Part 4 : The absorber made of galvanized steel with a height of 0.5m and 0.46 m of diameter.

| Part 1 | Part 2 | Part 3 | Part 4 |

| Vertical cut, Front sight | Vertical cut, Profile sight | Horizontal cut, Top sight |

Fig.3 : Cylindrical tank

Discussions and results

After designing and assembling the two modules (concentrator + storage tank) (Fig.4), we undertook an experimental study.


Fig.4: Photos of the designed system and sunlight in the optical fiber outlet

In the concentration systems only the direct radiation is concentrated. Fig.5 shows the variation of the direct radiation concentrated at the optical fiber outlet. In the site of Adrar city the annual average is about 1.7 W/mm^2.
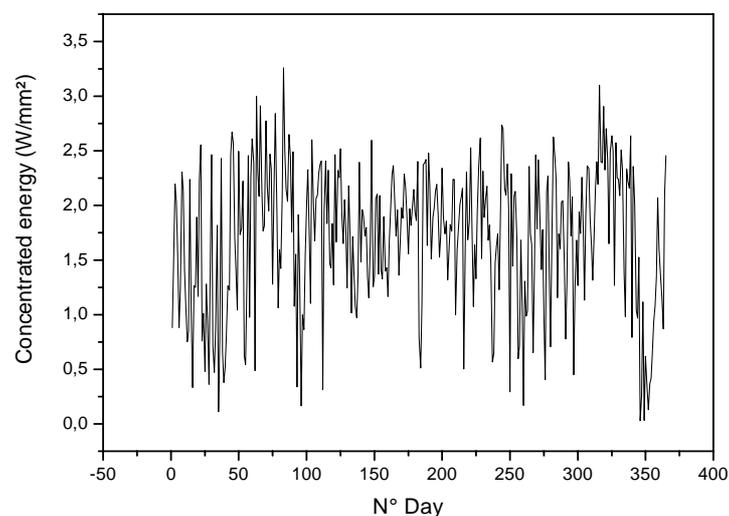

Fig.5: Direct concentrated radiation daily variation at the optical fiber outlet

After the determination of the energy quantity transported by the optical fiber to the storage tank, where it is absorbed then transmitted by the selective surface, the temperature can reach 170°C at the equinoxes and 150°C at the solstice (Fig.6).

**Summer solstice**   **Winter solstice**   **Equinoxes**
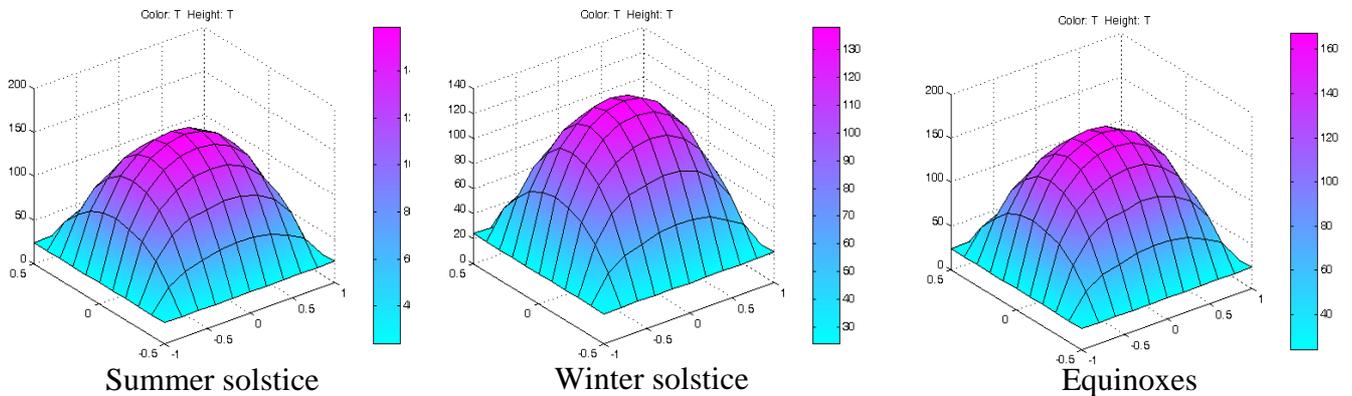
Fig.6: Temperatures reached on a selective surface at the solstices and the equinoxes

In the essay carried out we used a circuit system with a flow rate of 0.6 l/min. Fig.7 shows the inlet and outlet temperature variation on 22 January 2009. Under the light of these results, we noted the existence of a gap in the beginning of the manipulation of over 10 °C which became 50 °C at midday. We also noted that it took us four hours to fill the storage tank with a flow rate of 0.6 l/min to obtain an average daily temperature of 36.5 °C. The decreases observed in Fig.7 for the outlet temperature T_s are due to the monitoring system which was done manually.
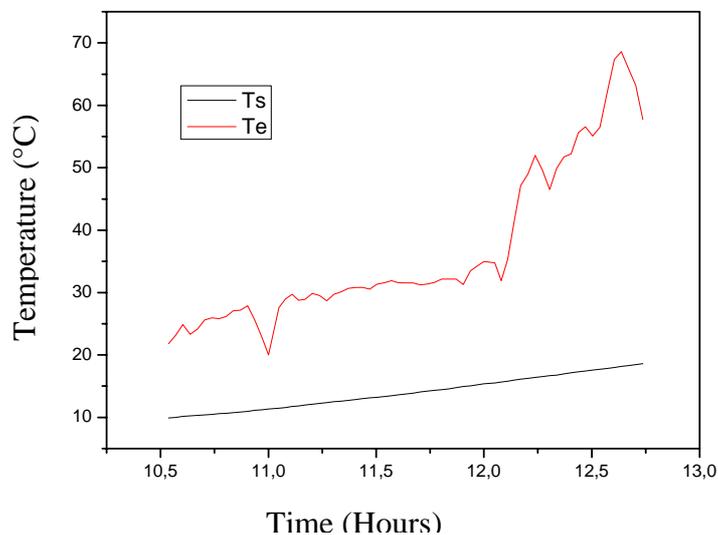
Fig.7: System inlet and outlet temperature variation

After that, we have increased measures relating to the production of heat water. In Fig.8 we presented the system instantaneous efficiency. We noted that the maximum yield can easily reach 75%.
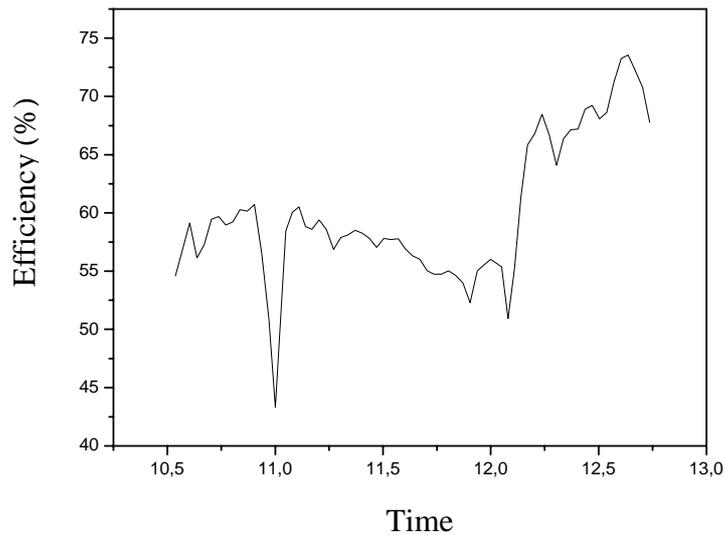
Fig.8 : Instantaneous efficiency variation

Economic approach and difficulties encountered

Among the main concerns encountered we can evoke:

- The penetration and accumulation of dust on the mirror and the tip of the fiber,
- To manufacture the concentrator, we couldn't find parabolic mirrors in the market. The only solution was to purchase a satellite dish and to cloth it with a foil tape. By accepting a lot of energy accumulation loss due to aluminum plies. The concentrator cost 70 euros.

- To align the optical fiber with the concentrator focus, we've added a cone at the focus with a length of 15 cm and a diameter of 7.5 cm, and the optical fiber at the other side, all at a price of 5 euros.

- The monitoring system was made manually.

- The unavailability of optical fiber in local market. The mitigation of optical fiber based quartz, integrated over the solar spectrum, is sufficiently low so that its flow easily reaches 10 kilo suns according to Polymicro, 2001 and Feuermann et al., 2001.

While more appropriate optical fiber should have a relatively large diameter and high numerical aperture (NA), we used two optical fibers of respectively 2 and 3 m with an NA of 0.4 at FiberGuide United States, the prices are 1450 euros.

- The storage tank was made of galvanized steel and stainless steel for all parts of the tank due to lack of copper. The tank cost 300 euros.

The economic assessment is needed for such a system. This requires to take into account the daily consumption of hot water per person. Commonly, the highest heat water needs varies from 40 to 50 liters per person per day with a temperature of 40 °C.

We take for instance in this study a family composed of 4 persons whose heat water consumption is about 180 liters/day. Using typically a 30 liters capacity water heater, which consumes an average of 1450 W, the aforementioned family will receive an energy invoice of 330 euros per year. The mortgage time of our system, will then spread over 4 years.

Conclusion

The concentrated solar energy can be transported with light drivers; this technique is very promising for thermal applications. It should allow the use of concentrated solar energy to yield very high power.

In this study, we analyzed the performance of a concentration heating system with optical fiber supply to produce and store heat water. The concentrated energy is transferred and then transported by an optical fiber to a selective surface inside the storage tank where heat is between the surface and the fluid.

The temperature distribution within the tank plate receiver, under the conditions of concentrated solar radiation, was determined experimentally. A theoretical model of conduction and radiation heat was established.

The use of higher flow rates can reduce the plate temperature, but also the fluid inlet and outlet temperature difference.

The main lessons we can draw from this study can be given as follows:
- Exploiting the idea of carrying concentrated solar energy through optical fibers.
- Optimizing the concentrator to maximize the system efficiency and to reduce costs.
- The outlet temperature easily reached 70 °C, with a system efficiency of 75%.

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