A CASE STUDY:

Conventional use of concentrated solar power and its advances in today's world

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Solar energy exploitation and related new technologies are assuming an increasing interest for industrialized countries where medium-to-long term production of low cost energy with reduced emissions is carried out. Indeed, several solar energy power plants have been designed and are currently under testing in many countries including India also.

Applied research in solar furnaces started at the beginning of the 1950s. Perhaps, the greatest motivation for the use of this peculiar source of thermal energy was the study of the effects of the "new" nuclear weapons on all types of materials and the search for possible candidates for protection. The time profile (Nuclear Thermal Transient) of a nuclear explosion can be easily reproduced in a solar furnace. Military solar furnaces were built in White Sands (New Mexico, U.S.A.) and in the French 'Laboratoire Central de l'Armament' in the Eastern Pyrenees. In the beginning, work was strictly on basic research with wide publications of refractory material phase diagrams ($A1_2O_3$, ZrO_2 etc.), studies on ignition and kinetic studies on refractory materials, crystal growth for use in semiconductors, solar cells and lasers. Another field of study has been the field of thermo-physical properties of materials at high temperatures, such as mechanical properties, spectral emissivity, thermal expansion, thermal conductivity, absorption and diffusion as well as electrical properties. In all these activities, a common difficulty, innate to the energy source, has appeared in the inability to find out the exact temperature on the irradiated surface. Sensors, vulnerable to the incident radiation density, cannot be placed on the exposed surface, since even if they could withstand the concentrated radiation, they would measure their own temperature instead of that of the sample. This has given rise to research into the entirely new field of non-contact temperature measurement (pyrometry) and into new measurement systems determining the flux densities in the focal plane. With the development of different concentrated solar energy applications, solar furnaces have slightly modified the direction of their activities. The follow-up of the solar chemistry of the 1970s, mainly in the hands of French researchers, and the appearance of the volumetric receiver concept in power generating CRS inspired the use of furnaces for the small-scale pre-testing before their full-size implementation. At the end of the 1980s and the beginning of the 1990s, several new furnaces were installed. Chronologically these are:

– 1989: Solar furnace at the Paul Scherrer Institute (PSI) (Switzerland)

–1989: Solar furnace at the National Renewable Energies Laboratory (NREL) (U.S.A.)

–1991: Solar furnace at the Plataforma Solar de Almería (PSA) (Spain)

–1994: Solar furnace at the German Aerospace Center (DLR) (Germany)

Lamp concentrators in the typical solar furnace arrangement but using a set of Xe-lamps instead of the sun as the radiation source were set up at the PSI in 2005 and are under construction in the DLR.

Three typical designs of solar furnaces are presented below.

– A scheme of the arrangement of the 1000 kW solar furnace in Odeillo (France) and with similar in Taskent (Uzbek) can be seen in Fig. 1. The furnace in Odeillo was inaugurated in 1970 and consists of a field of 63 heliostats on eight terraces each with a surface of 45 m^2 as a collector. The concentrator is integrated into the building and has a dimension of 40 m height and 54 m width. Because of its large half angle of the radiation cone coming from the concentrator concentration factors of close to 10,000 can be achieved (Fig. 2).

– Smaller on-axis furnaces with a similar design but using a single heliostat are located in Israel at the Weizmann Institute of Science (WIS), at the Sandia National Laboratories

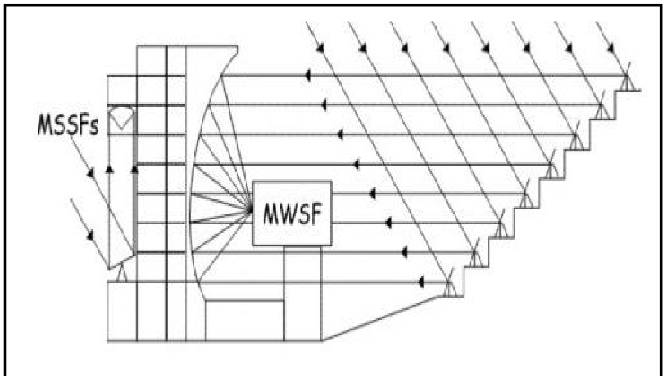

Fig. 1 : Scheme of the solar furnaces in Odeillo (France) (MWSF: Mega Watt Solar Furnace, MSSFs: Medium size solar furnaces)

Fig. 2 : The 1000 kW Solar furnace in Odeillo (France)

(SNL) in Albuquerque (U.S.A.) and at the PSI (Fig. 3) in Switzerland. They reach a power level between 16 kW and 40 kW and concentration ratios between 5000 and 10 000 (PSI) without secondary optics.

The 60 kW furnace at the PSA uses one 120 m² flat faceted heliostat (Fig. 4). This application achieves a concentration ratio of 4000.

Fig. 3 : Small on-axis solar furnace at the PSI

– Solar furnaces of 15 kW to 20 kW in off-axis configurations are available in Golden (Colorado, U.S.A.) and Cologne (Germany) (Fig. 5) with concentration factors of about 5000. Both facilities use the concentrated beam inside of a laboratory building.

Fig. 4 : The 60 kW solar furnace at the PSA (Source: PSA)

An Italian law assigned to ENEA the mission to develop an R and D programme of systems able to take advantage of solar energy as a heat source at high temperature. One of the most relevant objectives of this research programme is the study of CSP systems operating in the field of medium temperatures, *i.e.* about 550°C, directed towards the development of a new and low-cost technology to concentrate the direct radiation and efficiently convert solar energy into high temperature heat (Rubbia, 2001). The problems concerning the use of CSP technologies has been analyzed and reported by several authors (Sargent, 2003; Price *et al.*, 2002; Lüpfert *et al.*, 2001). After some years of activities, ENEA has built an experimental tool at the Research Centre of Casaccia in Rome (ENEA Working Group), which incorporates the main proposed innovative element. The parabolictrough

Fig. 5 : Solar furnace in Cologne (Source: DLR)

solar concentrators are one of the basic elements of a solar power concentration plant. The functional thermodynamic process of a solar plant has been described in (Herrmann *et al.*,2004). The main elements of the plant are: the solar field, the storage system, the steam generator and the auxiliary systems for starting and controlling the plant. A solar parabolic-trough collectors line is divided into two parts from a central pylon supporting the hydraulic drive system (Antonaia *et al.*, 2001). Each part is composed by an equal number of identical collector elements, connected mechanically in series. To test these innovative systems, a real scale demonstration plant has been foreseen by means of the "Archimede" ENEA/ENEL project at Priolo, in Sicily. The start of a demonstrative phase requires the passage to a more detailed design phase implying the respect of Italian and/or European recommendations. A proposal of classification of such structures and, consequently, of the design criteria to be followed have been presented (Giannuzzi *et al.*, 2007). This has been done with the aim of obtaining a compromise between reaching a sufficient safety level and an adequate budget. The problem of designing linear parabolic solar concentrators is given by the necessity of defining both suitable criteria for assigning an appropriate typology to the structure and a new, appropriate design guide referring to existing national recommendations as well as Eurocodes. However, the international competition introduced constraints to the concentrated solar power systems in terms of economic impact reduction and at the same time increasing their efficiency and reducing the cost of the components. The main codes of practice used in Italy and in the European community, have been considered and design criteria chosen to find a compromise between requirements of rules, which should be precisely followed, and costs.

Loads, actions and more generally the whole design procedure has been considered in agreement with the "Limit State Method", a new approach is critically and carefully proposed to use this method in designing and testing the structure such as the one here analyzed. The definition of suitable specific recommendations dedicated to solar concentrators is suggested. Starting from a preliminary examination of the parabolic trough collector structure, together with the knowledge of codes of practice used in Italy, it has been possible to classify the concentrator as a "special structure". The above classification has allowed the authors to extract all the desired recommendations useful for designing and checking solar concentrators, performing this according to adequate structural design guidelines. Then, complete structural guidelines for parabolic-trough solar concentrators have been built and designed at ENEA to produce an optimized design capable to ensure high performance and low costs but also an adequate safety level. These guidelines have been adopted by ENEA in order to perform a preliminary analysis of the structural behavior of a 100 m collectors line. This analysis has put in evidence that, compared to the 50 m collectors line designed using the allowable stresses method, the limit state design leads to a dimensional reduction for some elements, in spite of the load increment due to the doubled length. The details of this application are described with a discussion on seismic effects. It is additionally underlined that, being the selected codes of practice conceived for civil structures, available codes of practice are too stringent for a structure such as the one analyzed. Hence, suitable specific recommendations should be written for solar concentrators, allowing for optimization of the components and subsequent costs reduction.

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