Perspectives for Concentrating Solar Power in coastal areas of Mediterranean sea

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Summary

A renewed interest in Concentrating Solar Power (CSP) is rapidly growing worldwide. Indeed, new commercial applications for electricity production are starting right now, 20 years after the deployment of the first 354 MW_e of the so called "SEGS" plants in the Mojave desert, still operating since the early '80s. New plans comprise more than 1000 MW, mostly in Spain and USA. These developments are promoted by the pressure of compliance mechanisms to the Kyoto protocol commitments in connection with the increasing awareness that the potential in the "sun belt" area is very high, and triggered by new technical developments in CSP technologies. One distinctive advantage is the possibility to introduce thermal storage - for instance using molten salt storage systems - to significantly increase the dispatchability - and therefore the value - of the electric output of the solar plant without the need of fossil fuel integration.

Indeed a large amount of energy and water desalination needs in the so called EU-MENA region (Europe-MiddleEast-North Africa) – therefore comprising large areas around the mediterranean coasts - could be actually satisfied using CSP technologies. These plants, could operate in conjunction with wind power plants through HVDC links to form a highly renewable power pool; the plans for the so called "medring" electrical network are only the first phase of such development. The paper briefly describes the available technologies for electricity production focusing on the possible applications on the coastal mediterranean areas; examples of applications are also given for process heat production in harbours and tourist resorts areas.

Keywords: solar energy, CSP technology, solar thermal technology

Introduction

Solar thermal power is a relatively new technology which has already shown enormous promise. With few environmental impacts and a massive resource, it offers a comparable opportunity to the sunniest countries of the world as offshore wind farms are currently offering to European nations with the windiest shorelines [1]. This fact can be regarded as "the rationale" for being present with a "solar" paper within an "offshore wind power" seminar like OWEMES; we are grateful to the organizers for their kind invitation.

Solar thermal power uses direct sunlight, so it must be sited in regions with high direct solar radiation. Among the most promising areas of the world are the South-Western United States, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Middle East, Iran, and the desert plains of India, Pakistan, the former Soviet Union, China and Australia.

As is possible to see from a map of the solar radiation at earth level (fig. 1) most of the radiation is concentrated in the so called "sun belt" area, comprising the tropical and subtropical areas around the equator .

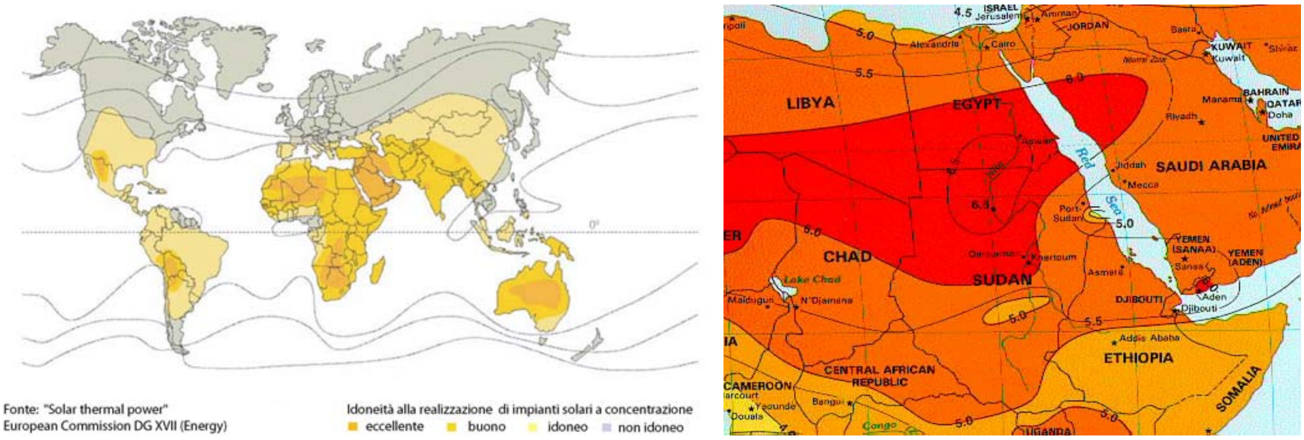

Fig. 1 – World map of direct solar radiation on earth, evidencing the "sun belt" (source E.C.- DGXVII) and a closer view of irradiation levels over North Africa and Middle East (source [21]).

The Mediterranean sea and especially areas on its southern shores offer particularly favourable conditions for the exploitation of such technology.

Basics of CSP technology

Before proceeding on, it is worthwhile to introduce some basic information about the CSP technology. CSP means Concentrating Solar Power; in this type of plants the **Direct component** of the solar radiation (normally measured in terms of Direct Normal Irradiation or **DNI,** in W/m^2 , referring to a flat surface perpendicular to the sun vector) is concentrated by a system of mirrors and then utilized to produce medium to high or very high temperatures.

The heat obtained in this way can then be used:

- to produce process heat for industrial processes or relatively high temperature for civil/residential purposes (temperature ranges roughly 100 – 250 °C)
- to produce electricity using thermodynamic conversion, with air, gas, or steam cycles, and using diathermic oils, water, gas or molten salt mixtures (according to the range of temperatures and final use) as Heat Transfer Fluid (HTF) (temperature ranges roughly 300 – 565 °C); this is the CSP as normally intended.
- produce hydrogen from water splitting using very high temperature driven thermochemical reactions (temperature ranges roughly 800 – 1500 °C).

The most mature and diffused (in terms of global installed productive capacity) use of CSP is for multi-MW sized plants; depending on the type of collecting element, CSP plants are normally classified into three typologies:

Plants with linear parabolic trough collectors, where linear parabolic mirrors – following the sun position rotating along a single-axis – reflect and concentrate sun radiation on a tubular "receiver" line, positioned on the geometric focus of the parabola. All the receivers are connected in series o form a pipe where a Heat Transfer Fluid circulates and is progressively heated by the solar radiation.

The HTF, generally a diathermic oil, enters a steam generator, where water is heated and boiled up to the necessary steam temperature and pressure for a steam turbine-alternator group where electricity production takes place.

This typology is actually the most commercially diffused worldwide, and retains the record of CSP energy production since in the middle of the eighties a series of plants – called SEGS, standing for Solar Electric Generating Systems– have been installed and are still operated in the Mojave desert (California, USA) with a total capacity of 354 MW_e divided into 9 units.

The cumulative energy produced by these plants is reported in the order of 13 TWh. R&D on these plants focus on the direct steam generation (DSG) using water as heat transfer fluid, thus integrating the Steam Generator (SG) into the solar field, and on utilization of molten salt, either as HTF and/or HSF (Heat Storage Fluid).

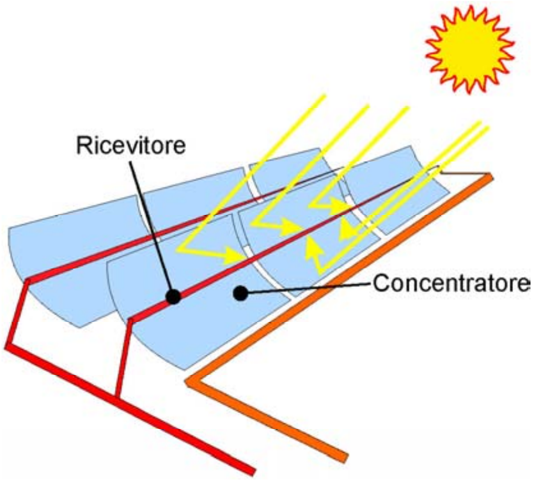

Fig. 2 –Schematic of a linear parabolic trough collectors system (source: www.solarpaces.org)

Fig. 3 - View of a part of SEGS plant at a Kramer Junction (source: [17])

Central receiver or "Solar tower" plants, where a number of independent mirrors (heliostats) able to rotate along two different axis follow the sun movement and reflect (and collectively concentrate) the solar radiation on a central "receiver" positioned atop of a vertical structure; in other cases at the top of the tower a secondary reflecting system is supported, thus permitting to concentrated the radiation on a "receiver" located at the base of the tower. From the receiver the heat is extracted and sent to the power generating unit, by means of an HTF. Using a "central receiver" higher concentration factors, and therefore higher temperatures with respect to linear systems, can be achieved.

The most famous plant of this type is the "Solar Two", rated at 10 MW_e, that operated as experimental plant from 1996 to 1999 at Daggett, California, USA.

The Solar Two has been the first in utilizing a mixture of molten salts (60% $NANO_3$ – 40% KNO_3) either as HTF and Heat Storage Fluid (HSF).

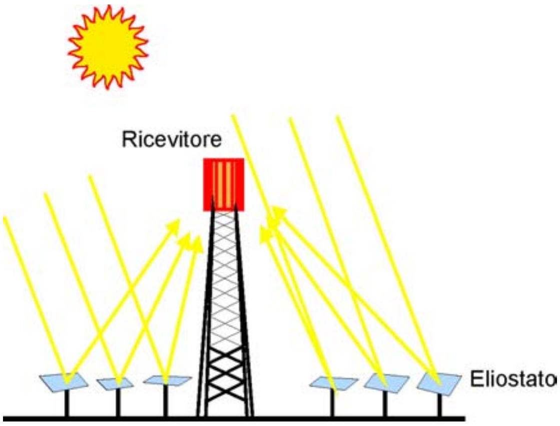

Fig. 4 - Scheme of a "central receiver" system source: www.solarpaces.org)

Fig. 5 – Aerial view of Solar Two

Parabolic dish systems, also called "Solar dishes" where a reflecting surface (or set of surfaces) is shaped to form a paraboloic mirror supported by a structure able to rotate along two distinct axes and therefore reflects and concentrates the direct solar radiation on a "receiver" positioned in the geometrical focus of the paraboloid. The high temperature heat is normally transferred to a fluid to be utilized by a thermal engine (e.g. a stirling engine) positioned on top of the receiver, that converts the thermal energy into mechanical energy and then to electrical energy by means of an electric machine.

As an alternative, an HTF can be transferred to a central storage system, or a direct production of hydrogen can be carried out using a chemical reactor instead of the thermal engine.

The concentrating factor, and consequently the achievable temperature of the receiver, can be very high. The parabolic dish two-axis movement permits to maximise the solar collection since allows to face the mirror towards the sun direction from sunrise to sunset.

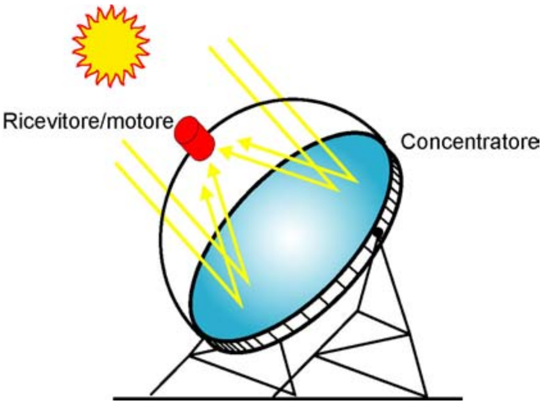

Fig. 6 – Scheme of a parabolic dish system (source: www.solarpaces.org)

Fig. 7 – picture of a solar dish (Eurodish-CESI) (source: www.ilsolea360gradi.it)

World potential and market perspectives for CSP technology

As stated before, the main part of the potential of solar source is located in the "sun belt" area; in particular, North Africa and Middle East hold a significantly large amount of areas with high solar irradiation, limited or no economic value for other applications and no environmental drawbacks to the deployment of large solar arrays. As an order of magnitude, in these areas a single square meter of land can produce a yearly thermal output equivalent to the thermal content of a barrel of crude oil [3].

The recent study MED-CSP, commissioned by the german Ministry of Environment to the DLR institute [4], points out that the available potential in the southern mediterranean area is largely greater than actual electric energy consumption of the so called (EU-ME-NA) area, comprising southern Europe, Middle East and North Africa. The CSP technology is particularly fit for a massive exploitation of such potential.

The CSP technology could then be regarded as "in competition" with the solar photovoltaic (pv), well known among the public opinion and actually experiencing a significant market expansion in Europe; this is true only in part. In that respect, two aspects are to be considered: the pv technology exploits either the direct and the diffuse components of solar irradiation, therefore is utilizable also in areas, like northern Europe, with lower direct solar irradiation; in addition it permits a range of applications, from personal equipment to household architectural integration or distributed energy in civil or industrial sector, hardly or not at all exploitable by CSP technology. On the other hand, for multi-MW plants and in areas with high direct solar irradiation, CSP technology can produce electricity at lower prices [4], and this advantage will remain for enough time unless significant technological breakthroughs on pv side will appear.

Therefore, with reference to the euro-mediterranean area, a sort of "market integration" among the two technologies could arise: the photovoltaic technology in areas, like Europe, with lower direct irradiation levels and, generally speaking, for a number of distributed grid-connected or isolated power applications; the CSP technology for bulk-power production in areas with high levels of direct solar irradiation.

Since the electric transmission costs with HVDC lines can be evaluated at 0,7-1,5 $/kWh, for distances in the order of 1.000 km (comprising 100 km of undersea cables) [6] it is not unrealistic to take into consideration the installation in these regions a number of solar plants intended to substantially contribute to satisfy the growing electrical needs of both sides of Mediterranean, of Middle-east and of northern Europe itself, in a frame of socio-economic integration and of distinctive policy for renewable energy production.

It is worth to notice that, apart from the energetic objectives, the completion of the so called "mediterranean electric ring" (medring) is actually planned, intended to electrically inter-connect all the countries facing the mediterranean shores to the European grid. Several projects are planned or were recently launched [5], among them the completion of east-west connections in the southern side and several trans-mediterranean lines.

Recent "long term" studies asking for a large "solar perspective" [7] envisage the introduction of high capacity HVDC lines in the North-South direction; in such perspective the total transfer capacity would reach 60 GW in 2050, capable to assure 450 TWh/y of solar electric energy from South to North.

Clearly, the feasibility of these scenarios is dependent not only on the economic situation but also on the international policy that will develop in the first half of the century.

In an even more "futuristic" perspective, the massive production of hydrogen from high temperature concentrating solar plants could permit to significantly increase the solar energy production in the "sun belt"; it is worth to notice that hydrogen quotes of up to 10% or more could be introduced in actual natural gas pipelines without major changes in the infrastructures and in consumer equipments.

Status of CSP technology

A possible trend on CSP installations - indeed matching the target of the CSP-GMI support initiative, involving a turnover of $ 10 billion, that advocates the installation of 5.000 MW worldwide at 2015 - ([8], [17]) is shown in the graphs of fig. 1, taken from [9].

The actual programmed or planned CSP "portfolio" can be evaluated in the order of 1700 MW, of which 300 can be considered sufficiently firm; the perspective can evolve rapidly, depending on the international evolution of energy prices and on commitments of governments. Levelized Energy Cost (LEC) targets are in the range of 3,5 to 6 $/kWh within 2025, depending on analysts ([9], [15], [16]).

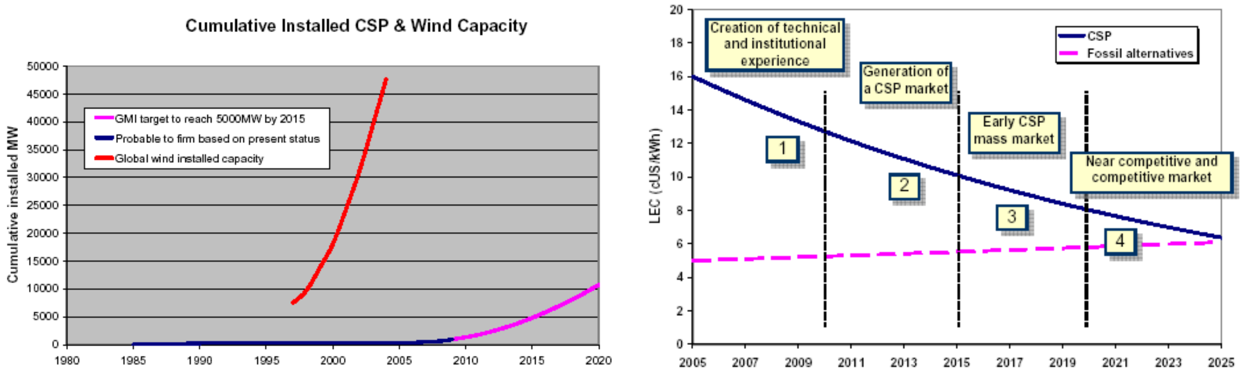

Fig. 8 – Possible commercial development of Wind and CSP power plants, and cost reduction forecasts within 2020-2025 (source: [9]).

It will depend on the political and economical situation if and how these forecasts will come true, or will be even surpassed. It seems anyway quite clear that the commercial situation of CSP technology is at a level corresponding to the Wind power technology in the mid of eighties. At that time few people could bet on it, but 20 years later, actually in 2005, the total installed Wind power capacity is over 50.000 MW worldwide, is still increasing, and the main wind turbine's producers are going to be part of the major multinational companies dealing with Power Generation , like Siemens, ABB, GE.

The advantage of Wind technology has been that it has been at first developed principally in countries (northern Europe and USA) where either the technology and the source were located; the technology subsequently spread out worldwide.

Solar CSP, leaving apart US and, partially, Spain, is in a different situation; in some way the technology will probably have to be "exported" quite soon, right in the first development stage.

CSP Developments in the Mediterranean

As stated in the previous section the mediterranean area, being at the centre of the so called EU-ME-NA region could rapidly became the leading area in worldwide CSP development.

In the immediate, some areas of southern Europe, Spain in particular but also Italy, are interesting for the exploitation of CSP technology, in order to increase the renewable share in electric production.

Spain in particular is in a favourable situation, either from the point of view of the solar irradiation and from the point of view of the experience gained, since 1981, at the Plataforma Solar de Almeria, in a significant synergy with German companies and research institutes like the DLR. In fact Spain recently established, with the Royal Decree n. 436 of 2004, a clear and sound support system for solar developments, based upon a fixed feed-in "premium" for solar plants equal to 0,18 €/kWh (0,21 for the first 200 MW) with a 25 years guarantee. Recently a number of projects have been therefore launched, involving utilities like Iberdrola, totalling roughly 900 MW of plants planned, some of them ready to build; among the others [11], [12], [13]:

- The 10 MWe solar-only power tower plant project Planta Solar (PS10) employing saturated steam receiver technology, by the Albengoa group. The PS10 project has received a €5 million grant from the European Union's Fifth Framework Programme. Construction started in summer 2004 and will be completed in 2006. Project development of the following two 20 MW power tower plants PS20 of the same type has started. Albengoa has also started to develop various 50 MW parabolic trough plants.
- The 15 MWe solar-only power tower plant Solar Tres project, promoted by the Spanish company SENER, employing US molten-salt technologies for receiver and energy storage. Solar Tres will have a 16-hour molten-salt storage system to deliver this power around the clock. The Solar Tres project has received a €5 million grant from the EU's Fifth Framework Programme.
- The 15 MWe solar trough power plant EuroSEGS at Montes de Cierzo near Pamplona, promoted by the Spanish EHN group in co-operation with SolarGenix.
- Two 50 MWe solar trough power plants, AndaSol-1 and 2, are being promoted jointly by ACS Cobra and the Solar Millennium group in the region of Andalucia, with a 510,120 m² SKAL ET solar collector field and six hours' molten salt based thermal storage. The AndaSol-1 project has received a €5 million grant from the EU's Fifth Framework Programme and financial support from the German Ministry for Environment. Construction is planned to start on January 2006 and will to be completed in December 2007. ACS Cobra and Solar Millennium have started development of various 50 MW follow-up plants in Southern Spain.
- National electric utility companies, such as Iberdrola and Hidrocantabrico-Genesa, have started promotion of over a dozen 50 MW parabolic trough plants all over Southern Spain. Iberdrola alone is claiming plans for 450 MW of CSP plants [12].

Other southern mediterranean countries have development plans, among them [18]:

- Algeria, with a planned target of 500 MW within the year 2010, and concrete initiatives for a 150 MW hybrid solar/gas power plant of 150 MW at Hassi R'mel and a 140 MW ISCCS (Integrated Solar Combined Cycle System) with 30 MW solar output planned by NEAL, a joint venture between Sonatrach and Solelgaz.
- Egypt, with a projected ISCCS plant with similar to characteristics (Total capacity: 150 MW, solar share: 30 MW).
- Israel, encompassing 500 MW of CSP plants by 2010 and another 1000 MW by 2015. The selected site for the first 100 MW has enough room for 5000 MW of CSP plants.
- Marocco, planning a 250 MW ISCCS project, with 30-50 MW solar capacity.
- Italy is developing its own technology, and is planning to integrate a 28 MW_e solar field into an existing ENEL gas fired combined cycle Power Station in Sicily (Archimede Project); further information is given below.

The ENEA effort and the Archimede project

Starting from the beginning of year 2000 ENEA has undertaken a research, development and demonstration activity in the field of CSP technologies; the activities benefit of a public funding, established with the art. 11 of the Law n. 388/2000, with an initial endowment equal to 103 M€ - subsequently reduced to 48 M€ due to funding restrictions – and are managed in that frame of the so called "Grande Progetto Solare Termodinamico" (SOLTERM, meaning Solar Thermodynamic Large Project). The program spans from basic R&D to demonstration for electricity production by CSP plants, including R&D on direct hydrogen production by means of thermochemical solar driven processes.

The technology that ENEA is developing for solar electricity production combines some characteristics of linear parabolic troughs and of high temperature "solar towers", aiming at technological innovations that permit to overcome the critical points of both [3], namely:

- the utilization of linear parabolic trough collectors, since they are a well known and established technology;
- the development of high performance receivers able to operate at higher temperatures;
- the utilization of molten salt mixtures (KNO_3 – $NaNO_3$), yet experimented in the US "solar Two", as HTF;
- the introduction of a molten salt based thermal storage, again similarly to the "Solar Two".

The resulting basic scheme is illustrated in the following pictures:

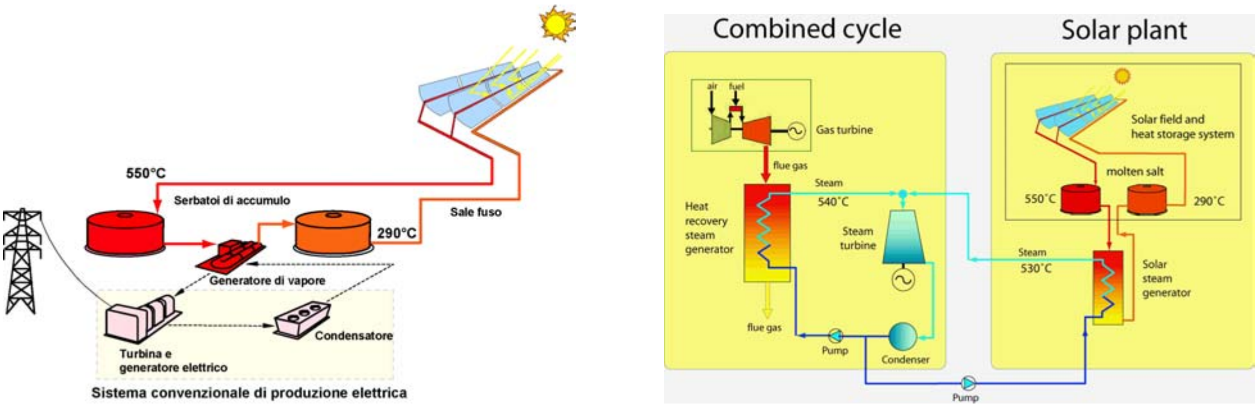

Fig. 9 – Schematic of ENEA technology for a full solar or an ISCCS molten salt based solar field

Two tanks ("Hot" and "Cold") are present, containing the molten salt mixture and operating at nominal temperatures of 550 °C and 290 °C, respectively. Two independent circuits depart from the tanks, both with their own circulation pumps.
In the **solar field (SF)** circuit, as the solar irradiation is sufficient the salt exiting from the cold tank and entering the troughs is heated at 550 °C and is fed to the hot tank. In the **steam generator (SG)** circuit the salt exiting from the hot tank is fed to the cold tank through the SG (composed by heat exchanger and evaporators) where the production of high temperature saturated steam takes place.

Within the storage capacity limits the two cycles – "solar energy capture" and "steam production" – are completely decoupled, thus permitting a highly controllable (with high dispatchability potential) electric power generation.
The use of molten salts leads to cost effective storage systems, able to significantly increase the dispatchability of solar electricity, and therefore of its market value. 6 to 10 hours of storage at rated output are typically achievable, with specific investment cost roughly as low as 36 €/kWh$_e$; in perspective costs of 25 €/kWh$_e$ (30 $/kWh$_e$) seem to be achievable [3]. Molten salts allow also to increase the solar field temperature output therefore producing high quality saturated steam at temperatures of 530 °C or even more, thus permitting to feed high efficiency steam turbine power cycles (up to 42-44% with respect to 37,6% typical of a steam cycle operating at 370 °C). This advantage must be obviously traded-off with respect the higher power losses in the solar field and with the need of developing a more performing technology, in particular for the receivers, but even in case of substantial parity in terms of overall efficiency and investment costs, the advantage of a higher temperature would remain since this temperature levels allows the adoption of commercial equipments for the Power Block and to directly feed the steam to conventional CC steam sections.

Among the main achievements of the program, corresponding to a 17,5 M€ expenditure up to now, the following results can be claimed: the development of parabolic trough solar collector for large solar fields application that achieved a peak global efficiency in excess of 65 % at temperatures of 360 °C; the patenting of a high performance cermet coating able to operate at temperatures up to 550 °C; the prototyping of the deposition process of the coating on receiver pipes, thus allowing fabrication of full scale 4 m long receiver units; the completion and operation, since 2003, of a test circuit (PCS) able to field test in real conditions collector prototypes up to 100 m long in molten salt service, at temperatures up to 600 °C.

Fig. 10 – PCS test field at ENEA - Casaccia (Rome)

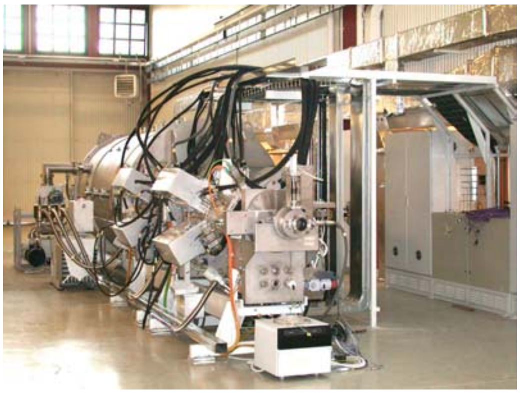

Fig. 11 – coating deposition machine prototype at ENEA – Portici (Naples)

The first commercial application of ENEA technology is planned in the so called "Archimede project" a joint initiative with ENEL utility, that yet operates a combined cycle gas fired 760 MW Power Station at Priolo Gargallo (Sicily). The project involves the addition of a solar field able to integrate the fossil production. If the molten salt technology will be finally chosen for such project, the integration scheme will be similar to that illustrated in fig. 9 and will lead to a total of 318 solar collectors, each 100m long, organized into 4 sub-fields with a total of 53 loops (6 collectors per loop). The solar field total area will be 37.6 ha, with a total collector active area of 179,000 m^2. The solar field will yield up to 28 MW$_e$ of additional electrical capacity and the forecasted additional energy production is equal to 54,2 GWh$_e$/year, corresponding to a primary energy saving of 11.835 TEP (tons equivalent petroleum) and to CO$_2$ avoided emissions in excess of 36.000 tons/year [19].

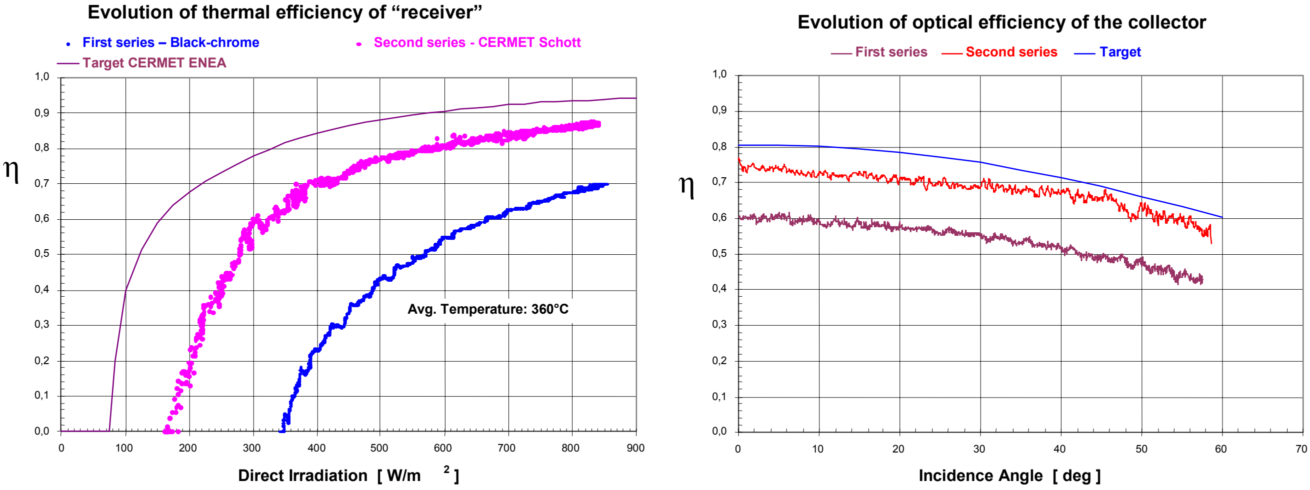

Fig. 12 – Evolution of measured ENEA collector parameters towards the target [19]

In a typical North-Africa desert site, where the Direct component can reach up to 2.900 kWh/m^2 year - with respect to 1.750-2.200 typical in the best sites in northern Mediterranean – the extrapolation to a fully developed molten-salt technology would allow the generation, for each square km of available land, of 275 GWh/y of electricity at levelled costs in the range of 4,5 c€/kWh, corresponding to a primary energy saving of 60 ktep/y and avoided emissions of 185 kton/year. It is worth to note that such saving alone is going to be valuable at 3,7 – 7,4 M€/year on the international emissions market, since the CO$_2$ cost is now in the order of 20 €/ton and this price will presumably double very soon.

Offshore and Coastal applications

The mediterranean area is, by definition, surrounding the Mediterranean sea; therefore it is clear that a number of CSP installation in this area would be actually sited along the coasts; the Archimede project is indeed an example of it, being the ENEL Power Station very close to the sea shore. This is a typical situation in the case of fossil fuelled Power stations, needing large amounts of water for cooling the condensers, and therefore normally sited along the main rivers or coasts.

The same situation will apply to most CSP plants, since they also need significant cooling; one interesting aspect to explore at this respect will be the joint production of electricity and fresh water by means of Multiple Effect Distillation (MED) Systems to be coupled to CSP plants for joint power production and seawater desalination.

In addition, a number of coastal installations, like docks or cast off harbour areas could be available; in these areas it seems anyway more appropriate to conceive direct applications of solar heat for industrial processes, as will be described further on.

The effect of the sea proximity on CSP plants have not yet deeply evaluated; it is clear that some effects could be significant in terms of material requirements (e.g. corrosion on steel structures) and possible increase on mirror cleaning requirements, due to salt deposition.

Also the higher wind energy content usually present in coastal areas should be taken into account, since the wind has a disturbing effect on reflecting surfaces. For instance, the normal operation of ENEA parabolic troughs requires a wind-speed less than 7 m/s; at wind speeds up to 14 m/s the plant will operate, but with a progressive reduction in optical efficiency, due to the effect of gusts on the reflecting structures. At wind-speed over 14 m/s the plant must be cut-out from service (i.e. the collectors must be rotated in order to protect the structure from excessive wind loads).

Since this seminar is devoted to off-shore, we will briefly present some comments on the possible application of real "off-shore" CSP plants. At present it seems not a good idea to think, apart from particular cases, to real off-shore applications of CSP, since the cost of supporting structures would be presumably prohibitive. Indeed CSP technology is characterized by a higher horizontal surface occupation than Wind Power (that only "virtually" occupies land and indeed mostly occupies "landscapes"). An off-shore supporting structure should also be rigid enough to assure precise tracking of the sun by the usually large mirror structures; for example a typical parabolic trough collector, with a parabolic focus at roughly 2 m from the mirror surface, is a single structure 100 m long by 6 m wide, whose angular position must be controlled with a precision in the order of 0,8 mrad. Even higher precisions are needed in the case of "solar towers" since the mirror surfaces focus the solar rays towards a receiver located at hundreds of meters far away.

Solar Heat for industrial applications and tourist resorts

Solar energy is mostly associated to the production of (electric) power or of low temperature heat for domestic purposes (sanitary water, swimming-pool warming ...). In this way a number of processes - where heat at temperatures ranging from 100 to 200 °C is needed – are not taken into account:

- process heat for industrial sector like food processing, chemical processing, pharmaceutical sector
- space heating and conditioning of large buildings (hotels, tourist resorts, commercial areas)
- sea-water desalination

In the field of low to medium temperatures three types of systems are normally adopted (for decreasing temperature levels):

- Parabolic Trough Collectors (PTC), similar to the parabolic troughs utilized for CSP plants; important differences can be found: smaller dimension and simplified technology (e.g. “not evacuated” receivers)
- Compound Parabolic Concentrators (CPC) where the concentrating mirrors do not track the sun’s position; the concentrating ratio is quite low (1,5 – 2) yielding temperatures in the order of 120 °C.
- Flat Plate Collectors (FPC); the usual flat plate home collectors, normally rated at 70 °C or less.

Recent studies show that PTC systems can produce heat at costs in the range of 3 to 1 c€/kWh_{th}, depending on site and meteorological conditions. With respect to traditional FPC and classical CPC, the annual energy yield of small PTC systems (with collector width in the range of 2 m) can be significantly higher than CPC’s and FPC’s, and the advantage increases with operating temperature. Also the energy cost, as shown in figure 13, taken from [20], is competitive and dependent on output temperature.

The lower “energy gain” at higher temperatures is due to the increasing heat losses from the receiver’s (absorber) surface. A significant thermodynamic difference exists between flat plane collectors and concentrating collectors: in the first the solar radiation is converted into heat by the absorber, that mostly extends over the whole collector’s surface; in the latter only the “direct” (e.g. not scattered by the atmosphere or by surface objects) component of the radiation is reflected and concentrated towards the “receiver” that extends over a smaller area. Therefore the total thermal losses, depending only on the receiver’s surface, are lower.

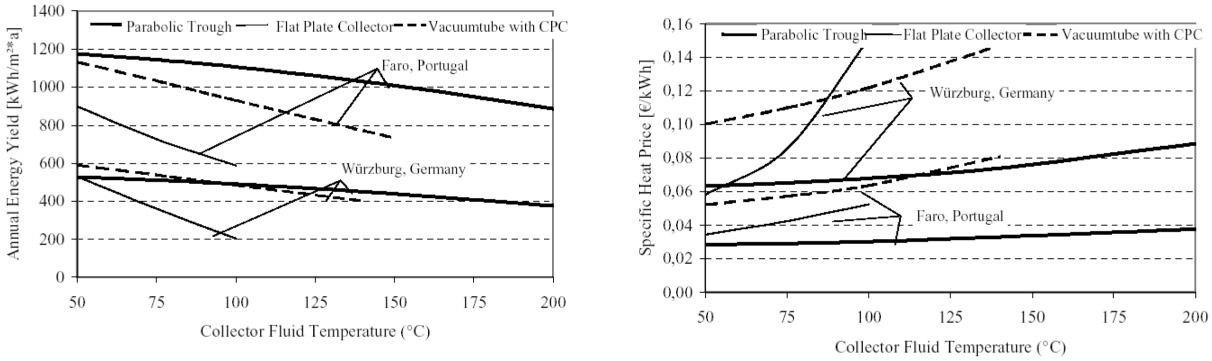

fig. 13 Energy Yield and specific heat price for low-medium temperature collector technologies (source: [20])

On the other side flat pane collectors utilize also the “diffused” component of solar radiation; such advantage must be traded-off taking into account that PTC’s can significantly capture more energy simply tracking the sun’s position.

The development of concentrating technologies for the Eu-ME-NA area can lead to a number of different situations, industrial and residential; 3 “real cases” of PTC’s taken from the literature will be here briefly presented:

- El Nasr (Egypt) pharmaceutical factory
- Hotel in a coastal area in Turkey
- Desalination applications

Pharmaceutical factory at El Nasr [22]

This project was established by the egyptian Renewable Energy Authority (NREA) and funded by the african Development Fund (ADF) with 2,2 $ millions. It is devoted to a pharmaceutical factory at El Nasr, near Cairo; the average daily direct solar radiation in this area is 5,5 kWh/m_2 day.

The solar plant is made by 144 PTC’s, 6 meters long by 2,3 meters wide, with a total reflecting surface of 1.900 m^2. The reflectors, made with high reflectivity aluminium, have been locally built and installed, while the receivers are steel pipes coated by a selective coating (black-nickel) and encapsulated into a 2” glass pipe in order to reduce heat losses.

Fig. 14 shows some pictures of the plant, taken from [22].

Fig. 14 – some pictures of El Nasr PTC plant (source: [22])

The plant produces approximately 0,3 t/h of saturated steam at 175 °C/8 bar, corresponding to 1,3 MW_{th} for the steam network of the factory, thus reducing the fossil fuel consumption. The solar field is organized into 4 identical loops, each with 6 collector's groups of 6 collectors (totalling 144 collectors), as shown in fig. 15.

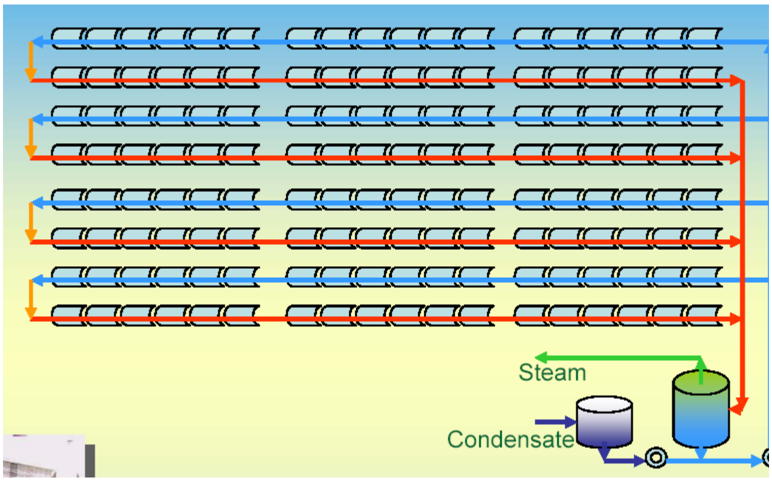

Fig. 15 - Schematics of El Nasr CPT solar field (source: [22])

The condensate is collected from the industrial process into a condensate tank, while the "flash" tank produces steam by dropping the pressure from 23 to 10 bar.

The plant is monitored by a computerized data acquisition system and a meteo station logging data as global and direct normal irradiation, ambient temperature, wind speed etc.

Hotel on the southern coast of Turkey

CPT's can find useful applications in hotels, since they can be utilized to produce hot sanitary water, swimming pool warming and air conditioning (solar refrigeration) thus reducing the fuel consumption and CO_2 emissions.

One example is at the "Iberotel Sarigerme Park" in the southern coast of Turkey [23]. The thermal load of the hotel is mostly due to steam demand for the laundry and to the conditioning, and for a smaller part to swimming-pool heating and sanitary water warming, as shown in the graph of fig. 16.

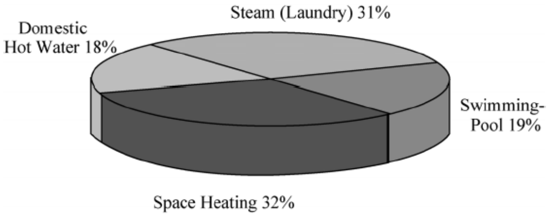

fig. 16 – heat consumption of the hotel (source: [23])

Here a PTC prototype with a total area equal to 180 m^2 successfully operating, according to [23], since April 2004. Each PTC module has a net surface of 9 m^2 (5 x 1,8 m); the concentrator is made with high reflectivity aluminium sheets. Each loop comprises 4 modules and the 5 lops are driven by a belt/pulley unit to track sun's position. The receiver pipe has a diameter of 38 mm, and is coated with a selective coating and encapsulated within an atmospheric pressure glass pipe. No data acquisition system is provided for experimental data logging.

Fig. 17 PTC's array of the hotel (source: [24])

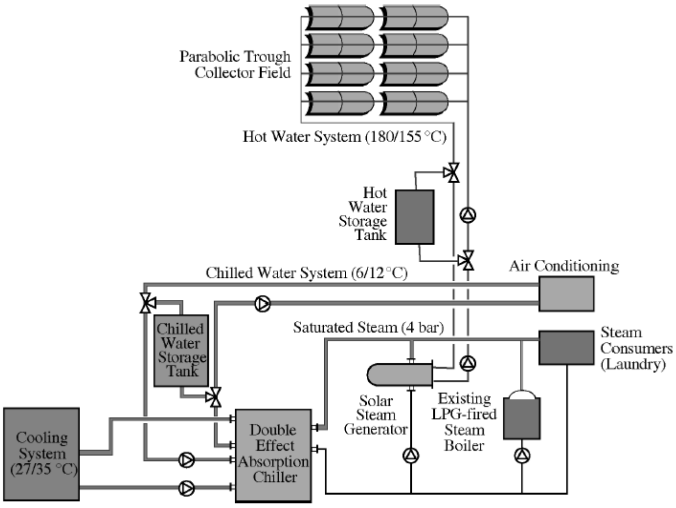

Fig. 18 Heat distribution scheme from PTC (source: [23])

The plant has been built by the german company Solitem Gmbh, developing the components in Germany and Switzerland and assembling them in Turkey, creating a synergy between different companies and research institutions (DLR – renewable sources division, ALANOD, producer of the aluminium reflecting sheets, Shott for the glass envelope, EGIS for the control equipment, Switzerland Energie Solaire for the absorber's coating).

The output from the PTC's feeds the steam laundry, the kitchen, and the refrigeration system using a double effect absorption chiller.

Inlet and outlet PTC temperatures are 155 ° and 180 °C respectively, allowing the production of steam at 4,3 bar, as required by the double effect refrigerating unit; the double-effect is more efficient than single-effect yielding a roughly 1,5 COP at partial load.

A second prototype is on construction at Gran Kaptan Hotel, Alanya, Turkey, while new projects are planned in Morocco (hotel), Jordan (clinic) and other are being negotiated in Spain, Cyprus and Tunisia. One problem in case of tourist resorts is that often energy consumption is too seasonal to justify capital investment on solar equipment instead of fuel consumption on demand.

Anyway the most promising markets are:

- Countries with high direct irradiation levels (Mediterranean area, Arab countries, Americas, Australia).
- Countries that implement subsidies schemes for solar applications
- Places where the fuel is hardly available or too expensive (e.g. small islands).

Sea-water desalination

Only 3% of the available earth water is fresh, the other 97% being salty sea-water [26]. Due to increasing population and industrial needs it is increasingly important the exploitation of the enormous water reservoir of seas and oceans. In order to become utilisable fresh water, the salt content must be reduced from 35 g/l to 0,25 g/l by desalination plants, with different techniques:

1. phase-changing processes driven by a thermal source
2. membrane process (where electric energy is used to feed reverse osmosis or electro-dialysis

The desalination process is highly energy intensive and is actually performed using fossil fuel combustion.

Solar energy can be used instead, either with reverse-osmosis systems fed by photovoltaic plants or with phase-changing systems fed by thermal collectors.

In this last case two categories can be introduced:

a) direct systems: the distilled water is produced directly in the collectors
b) indirect systems: the solar energy capture system is separated from the distillation system

Among indirect phase-changing processes one of the cheapest is the MEB process (Multiple Effect Boiling) , that can be coupled to a PTC system. This process requires low pressure steam at temperatures between 70 and 100 °C, obtainable by means of a flash system [27]; the pressurized water is heated in the PTC's; a flash-valve located at the PTC's outlet generates a pressure drop that produces steam from the water flow, subsequently stored in a flash vessel.

The steam is then sent to the MEB, with a series of boilers where the pressure is kept at low and decreasing levels and the salty water is boiled by means of the steam flow. Several boilers are provided in series , with decreasing pressure and temperature; the water in the first boiler is boiled by the steam produced by the flash vessel, that condensate into fresh water. The steam produced by the first boiler is sent to a heat exchanger contained in the second stage boiler where, due to the lower pressure, the salty water evaporation pressure is lower; and so on.

The final result of the process is distilled water at one side and brine at the other. Around 60% of the world's desalination plants is located in the ME-NA area, Saudi Arabia being the main user [25]. Not surprisingly, in Saudi Arabia is located a PTC driven desalination plant able to produce 6000 m^3/day of fresh water.

Conclusions

The utilization of solar heat has a huge potential impact on mediterranean energy scenarios. Increasing the range of temperatures, applications can span from water desalination to process heat for civil and industrial applications, where low or moderate concentrating factor parabolic troughs can be adopted, to electricity production by new generations of CSP plants and, in the next future, hydrogen production by hi-tech high temperature thermochemical water splitting driven by high ratio concentrating solar systems.

Even if a lot of technological development is needed in order to fully substantiate solar competitiveness with respect to fossil fuels, the field is ready for promoting the commercial introduction of concentrating solar technologies throughout the mediterranean area.

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