PARABOLIC TROUGH COLLECTORS

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Contents

Summary

The Section "Parabolic Trough Collectors" presents the solar thermal energy technology using parabolic trough collectors for the concentration of solar radiation. The intention is to provide a detailed description of trough technologies developed and used mainly for power generation and process heat utilization. The reader is introduced to the relevant parabolic trough collector technologies for applying solar thermal energy to thermal water desalination processes in single- or dual-purpose (co-generation) plants, mainly the large LS 3 trough collector presently used in the SEGS power plants in the USA and the small low-cost IST trough collector operating in process heat facilities in

the USA.

By presenting instructive pictures, diagrams and schematics, the parabolic trough technologies and other specific system/components of solar plants are described. The presentation comprises sections with:

- A brief history of the trough development,
- The state of the art of trough application,
- The current trough technologies,
- The prospects and potential and
- Cost and economic aspects.

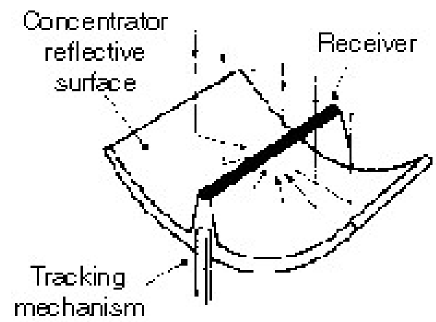
An extended bibliography is added in order to give a list of publications for further information of the interested reader. Finally, a glossary and a list of abbreviations complete the paper.

The section of parabolic trough collectors was prepared by an expert member of the German Aerospace Center (DLR), Solar Energy Technology Division in Köln (Germany) under contract of EOLSS Publishers. He has gained special knowledge in the field of solar thermal concentrating energy technologies by R&D activities for years. He used various publications listed in the bibliography for informative contributions. Two other expert members of the mentioned division volunteered kindly to review the drafted paper

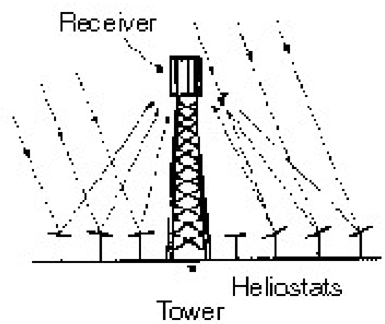
1. Introduction

Solar desalination processes using electric or thermal energy may be driven by energy supplied from power plants, cogeneration plants or directly by process heat-only generating systems. In regions of the sunbelt, part of the energy or even the total energy required by the desalination process may be efficiently and (as expected for the future) economically supplied by solar thermal concentrating systems. These systems may preferably be of the parabolic trough collector type, optionally of the heliostat collector type (for central receiver plants or of the parabolic dish type). Figure 1 illustrates the three leading solar thermal technologies. Single axis tracking systems (parabolic trough collector systems) are presently by far the mostly used and proven ones, while the others are point-focusing systems tracking the sun in two axes.

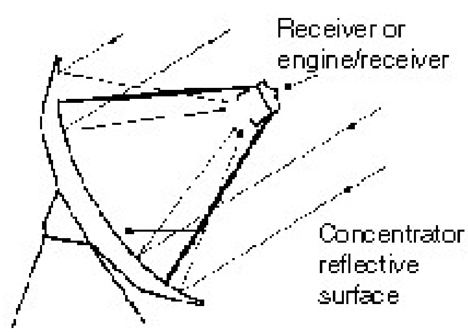
The solar collectors applicable to desalination processes are already commercially available. Different technologies have been proven during many operation years by experimental and commercial solar thermal power plants and by some first-of-its-kind small process heat plants, with only a few applications of solar seawater desalination. Further R&D work is going on in several countries in order to improve the technologies with regard to cost reduction and, hence, to become competitive to conventional systems. During the market introduction phase of solar systems expected in the next 10 to 20 years, the still existing economical gap against fossil fired systems may be bridged by subsidies from concerned governments, legislation, finance, insurance companies, industry, building/owner's consortia and operators.



(a) Parabolic trough



(b) Central receiver



(c) Parabolic dish

Figure 1. The three main concepts of concentrating solar thermal electricity generation: (a) Parabolic trough: line focusing, trough curvature in one direction, one-axis tracking, concentration factor 30 to 80, 30 to above 100 MW_e; (b) Central receiver: point-area focusing, elements of different paraboloids with various focal lengths, two-axes tracking, concentration factor 200 to 1000, 30 to 200 MW_e; (c) Parabolic dish: point focusing, parabolic shape, two-axes tracking, concentration factor 1000 to 4000, 7.5 to 50 kW_e. (Source: EUREC Agency)

Today, most mature and commercially proven among the above mentioned three solar thermal technologies using concentrating systems are parabolic collectors in a line-focusing trough configuration. Parabolic trough collectors (short name: trough collectors or troughs) have a geometric concentration factor in the range of 30-80 depending on the chosen application and technology. The troughs track the sun in one axis (in north-south or east-west orientation). The solar heat absorbing component (short name: receiver or absorber) is positioned along the trough in the line of the focus formed by the reflected rays. Water or thermo-oil is usually moved in conventionally designed circuits in order to transfer the absorbed solar energy to the user. Gas circuits have been proposed for higher temperatures. Air circuits for the low- to medium-temperature range and direct steam generation using troughs are under development.

Solar heat can be efficiently produced by troughs in the range of about 120°C up to 400°C and is used to generate electricity (in the case of electric power plant application) or electricity and heat (in the case of cogeneration application) or directly heat (in the case of process heat application). The plants may be commercially operated in the solar/fossil hybrid mode (short name: hybrid plants) being favorable during the market introduction phase and for continuous processes or, as expected for the future, in the solar-only mode using a thermal energy storage as the main source of supplementary energy. A thermal energy storage system may be used, when solar energy is not available or not sufficient to continue the operation of the industrial process. By such means, solar technologies can be applied to industrial processes in a very flexible way.

Trough systems are modulary arranged, and many of them can be grouped together in parallel rows to form small or large field arrays (where the short name "farm" system came from), which are optimally adapted to the power parameters required from the process in question in order to produce heat or electricity.

2. Brief History of Trough Development

The first solar thermal facility using line-focusing parabolic collectors to supply power for a 35 kW heat engine was erected and successfully operated in Egypt as early as 1913. However, the region's fledgling oil economy stopped further solar development efforts. Parabolic trough R&D activities started again in the mid-1970s, almost simultaneously with the central receiver (solar tower) plant development and the parabolic dish development, in response to the world oil crisis by the initiative of the International Energy Agency (IEA). In rapid succession, various R&D programs in the USA, Europe, Israel and Japan were launched. These programs were financed by governments and/or industry in each country. Early trough demonstrations occurred in the USA for application to process heat in industry in the low- to medium-temperature range.

Organized large-scale solar collector development began in the USA in the mid-1970s under the Energy Research and Development Administration (ERDA), and continued with the establishment of the Department of Energy (DOE) in 1978. Concentrating solar collectors, which have the capability to supply energy in the low- to medium-temperature (i.e. about 100°C to 400°C), were applied to both solar electricity generation as well as to industrial process heat production.

In the same period, the most significant trough project in Europe was the erection of the 500 kW_e experimental solar electric trough plant (called the *S*mall *S*olar *P*ower *S*ystems Project/*D*istributed *C*ollector *S*ystem: SSPS/DCS) on the test site of the IEA at Tabernas (the later Plataforma Solar de Almería) in the Province of Almería/south of Spain in 1981, and its successful test operation as well as test evaluation until the year 1985.

Engineering was conducted internationally through different collector configurations, specific components, control systems and test installations at several places around the world, mainly in the USA and in Europe. Operational experience of trough systems was gained by installation and test field operation of a number of industrial process heat plants and several prototype electric power generating facilities for irrigation or water pumping. Over 25 trough systems were operated having mirror reflector surfaces ranging from a few hundred square meters to about 5000 m^2. Up to now, most of these installations have been shut down or were dismantled after they had finished their scheduled operation time or due to other reasons. The most intensive R&D work for parabolic trough collector systems including field tests took place during the years 1977-1982. A large amount of experimental results were internationally accumulated. Key trough manufacturers in this period were the companies ACUREX, SunTec and Solar Kinetics in the USA, and MAN in Germany.

In 1979 the company LUZ International Ltd. (LUZ) was formed in Israel and in the USA, with the stated goal to develop and to build cost-effective trough systems for solar thermal industrial process heat applications. LUZ conducted a careful survey of the experience gained mainly by the DOE/Sandia and IEA-SSPS/DCS test plants and began to construct prototype systems for testing and application. In 1982 LUZ erected an industrial process heat system for the Tapu potato processing factory near Tel Aviv, Israel. LUZ initiated marketing activities in the USA in the early 1980s in order to promote solar process heat systems. Many industrial companies were interested in the use of solar energy as a source for hot water, steam and hot air due to the energy crisis. But LUZ found that the selling of such facilities had some major barriers which made selling expensive and difficult, in spite of the fact that solar process heat applications were assessed to be a large and yet untapped market.

In late 1984, LUZ began operating the first commercial solar thermal power plant, the 13.8 MW_e SEGS I (*S*olar *E*lectric *G*enerating *S*ystem) in Daggett, CA. (USA) due to favorable tax provisions and power purchase agreement with the Southern California Edison Co. utility (SCE). This was followed by construction of a series of improved, larger SEGS plants in California until 1990. Finally, one 13.8 MW_e, six 30 MW_e, and two 80 MW_e SEGS plants were in operation which supplied peaking power into the SCE grid. The SEGS plants were designed, constructed, and operated by LUZ for third-party equity owners. Specific ownership structure varied from project to project, reflecting the tax provisions and the financial conditions at the time of construction. Equity owners were providing roughly half the capital with the remainder coming from various debt sources. Unfortunately, financial problems of LUZ stopped further development in 1991. The existing plants continue to be financially and technically successful under the management of local operating companies in Kramer Junction and in Harper Lake. No additional plants were built because of financial uncertainties.

The fast progress of the trough collector technology for solar electric application from viewpoints of unit power size and cost reductions in the time period from the end of the 1970s to the 1980s can be demonstrated by the following three examples:

- The 150 kW_e facility at Coolidge, Arizona, USA (1979) was the first solar thermal full-system experiment to demonstrate automated operation in an irrigation application.
- The 500 kW_e IEA-SSPS/DCS experimental plant in Almería, Spain (1981) was designed, built, and operated as a collaborative R&D project under the auspices of the IEA.
- The SEGS I-IX plants in California (1984-1990) with units up to 80 MW_e, were built commercially by a group of American, Israeli, and German companies and marketed by LUZ.

Although LUZ failed to survive the financial breakdown in 1991, the existing plants in Kramer Junction (the five 30 MW_e plants SEGS III-VII) and in Harper Lake (the two 80 MW_e plants SEGS VIII and IX) are continuously operated. Their operation results in a large commercial operation experience accumulated up to now. The plants have fed more than 7 TWh_e into the SCE grid over a proven solar electricity record of more than 10 years of continuous operation which is equivalent to about half of the total solar electricity generated worldwide up to now. The solar field availability constantly exceeded 98 per cent, and the operation and maintenance costs have been successfully cut by 30 per cent.

In the meantime, other industries and entities have been active to pursue building new parabolic trough plants in the southwest of the USA, in the south of Europe and in the Mediterranean region as well as in other parts of the world. Project development and feasibility assessments for large installations in Crete (Greece), Egypt, India, Morocco, Spain and other countries in the sunbelt indicate cost reduction potentials and near-to-commercial applications. Furthermore, the trough system integration into combined cycles (gas/steam turbine based power stations) indicate a significant cut in specific investment costs and increase of capacity factor resulting in attractive near-to-competitive power generation costs, attracting multiple follow-up projects.

From a new development of a direct steam generation (DSG) trough technology, which is currently carried out mainly by Germany and Spain, further impulses are expected for the commercial application of solar electric power generation. This technology may also serve for future cogeneration plants and solar process steam applications including solar desalination purposes.

In parallel to the efforts undertaken for the commercialization of solar electric power generation, some remarkable activities could be observed particularly in the USA in order to attempt to receive solar process heat applications by improved low-cost trough collector technologies (example: small trough collectors of the Industrial Solar Technology Co. (IST) in Denver). Some first-of-its-kind projects were carried out in the

USA, examples of which are discussed in Section 3. In addition, in Europe some R&D work is going on in order to investigate low-cost trough collector designs. These trough designs may give new impulses to solar cogeneration plants and process heat applications including solar desalination purposes.

There are still major market barriers for the utilization of solar process heat (as is the case for solar electric generation today), in spite of the fact that several R&D efforts and commercialization activities are going on, and of the fact that solar process heat applications are assessed to represent a large and yet untapped market. Particularly seawater desalination using partly or in total solar energy is assessed to represent a large market potential in sunny countries. The depletion of natural drinking water resources in arid regions, where solar energy is abundant, leads to an encouraging assessment of such applications.

3. State of the Art of Trough Applications

Figure 2. The five 30 MW_e parabolic trough power plants SEGS III to VII at Kramer Junction in California (USA). (Source: Pilksolar)

Up to now, parabolic troughs have been mainly applied to:

- Nine grid connected solar thermal plants for commercial bulk electric power generation in the range of up to 80 MW_e-units (LS 1, LS 2 and LS 3 trough designs for the SEGS plants in California (USA), Figure 2.
- Some first solar thermal experimental and prototype facilites for electric power generation (MAN troughs and ACUREX troughs for the 500 kW_e IEA-SSPS/DCS plant at Almería in the south of Spain, Figure 3) and for industrial process heat generation up to 700 kW_{th} (MAN-troughs for facilities in Portugal, Italy and India) as well as process heat generation for small seawater desalination facilities (MAN

troughs for facilities in Mexico and in the United Arab Emirates).

- Some solar thermal prototype plants for small industrial and public process heat generation in the low- to medium-temperature range and with units of up to the low MW_{th}-range (SKI troughs and IST troughs in the USA).
- A 190 kW_{th} experimental seawater desalination plant ($3\ m^3\ h^{-1}$) at the Plataforma Solar de Almería in the south of Spain (ACUREX troughs).

Experience by the experimental, prototype and commercial trough collector systems has been accumulated over more than fifteen years and is continuously growing mainly by the nine commercially operated SEGS plants in California.

Figure 3. The 500 kW_e IEA-SSPS/DCS experimental power plant of the Consortium ACUREX/MAN in Almería (Spain). (Source: PSA)

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