EUROTROUGH COLLECTOR QUALIFICATION COMPLETE - PERFORMANCE TEST RESULTS FROM PSA

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Abstract – The EUROTROUGH solar concentrating parabolic trough collector has been developed by a consortium from industry and research during the last years. The EU-funded R&D work has been finished successfully and project results are available for project developers. The collector is line-focussing, with glass reflector and metal support structure in industrial design. The weight of the improved framework metal structure has been reduced to 18.5 kg/m^2 including drive. The length of the collector has been extended by 50% to 150 m. The thermal tests were performed with the improved UVAC absorber tube. The significant increase in absorber tube properties showed up in the test results. The paper presents characteristics of the EUROTROUGH collector types, specific results obtained from the PSA-prototype in the project, and results of the thermal tests and optical analysis.

1. INTRODUCTION

Parabolic Trough power plants are the most proven and most cost-efficient solar technology for electricity generation. The technology has demonstrated commercial operation since more than 15 years in the power plants in California with 354 MW of electric power installed. For parabolic troughs the optical and thermal conversion efficiency of the direct radiation into heat is better than for most other solar technologies (Geyer, Lerchenmüller et al., 2002).

Solar energy is doubtless one of long term energy sources of the world. Energy scenarios for the next decades show the strong need for large-scale solar power. The current status of solar power allows first solar applications in niche markets for photovoltaics and solar thermal systems in small to medium system sizes. Concentrating solar thermal power technology with large-scale power production from solar radiation is one of the promising perspectives. The EU directive for renewable energy systems 2001/77/EC passed by the European Commission, and national legislation will help towards market introduction with political means in view of the CO_2-mitigation goals for the year 2010. Under the actual global developments towards sustainable technology, clean energy and CO_2-emission reduction, a number of challenging solar thermal power projects are coming up.

The technological development of the solar thermal power generation has its key players in Europe, basically in Spain and Germany, in Israel and in California. The systematic analysis of the existing technology and stepwise improvement in parallel to the market introduction strategies were tasks of the partners in the European R&D project EUROTROUGH-II. The focus of R&D was in the theoretical and experimental analysis of the performance of a 150m parabolic trough collector (ET150) under various insolation and wind load conditions and its comparison with the LS-3 and the ET100 version. The overall objective of the programme was to lower the generation costs of solar thermal electricity. The successful outcome of the EUROTROUGH collector qualification results in EU-leadership in low-cost and high-efficient parabolic trough technology and has provided the project partners with the prototype at PSA to demonstrate their capability in this field when bidding in upcoming requests for proposals of Worldbank/GEF projects in the framework of the solar initiative.

2. TECHNICAL PROPERTIES

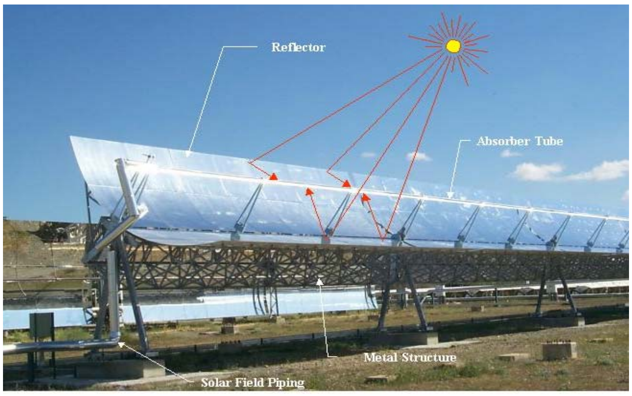

Figure 1: Working Principle of the EuroTrough collector

Figure 1 shows the working principle of the EUROTROUGH collector at the Plataforma Solar. By tracking the sun from sunrise to sunset, the parabolic EuroTrough collectors concentrate the sun's radiation with their parabolic mirror facets on the absorber tubes along their focal line. Through these absorber tube circulates a heat transfer fluid (HTF), usually thermal oil, which is heated to a temperature of nearly 400°C.

EuroTrough Model	ET100	ET150
Focal Length	1.71 m	1.71 m
Absorber Radius	35 mm	35 mm
Aperture Width	5.76 m	5.76 m
Aperture Area	552 m²	828 m²
Collector Length	99.5 m	148.5 m
Number of Modules per Drive	8	12
Number of Glass Facets	224	336
Number of Absorber Tubes	24	36
Mirror reflectivity	94%	94%
Weight of steel structure and pylons, per m^2 aperture area	19.0 kg	18.5 kg

Table 1: Main characteristic parameters of EuroTrough 100 m and 150 m

The EuroTrough collector models are made up of identical 12 m long collector modules. Each module comprises 28 parabolic mirror panels – 7 along the horizontal axis between pylons and 4 in a vertical cross-section. Each mirror is supported on the structure at four points on its backside.

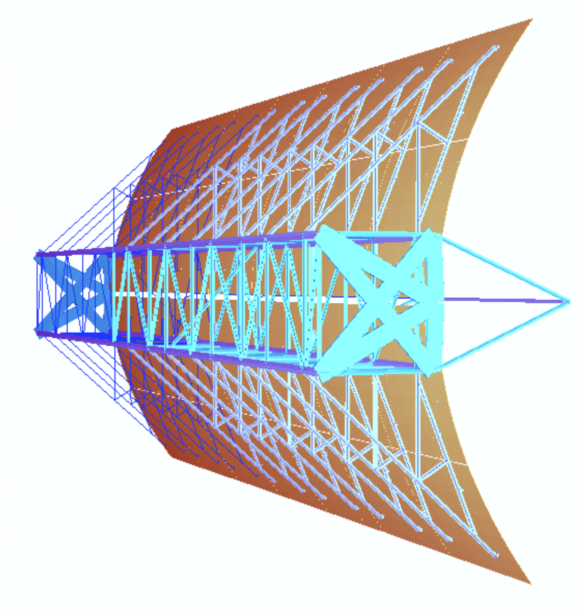

Figure 2: Computer model of a EuroTrough collector module with Torque-Box Design

Based on design studies a so-called torque-box design has been selected for the EuroTrough, with less weight and less deformations of the collector structure due to dead weight and wind loading than the reference designs (LS-2 torque tube or the LS-3 V-truss design, both operating in the Californian plants). This reduces torsion and bending of the structure during operation and results in increased optical performance and wind resistance. The weight of the steel structure has been reduced about 14% as compared to the available design of the LS-3 collector.

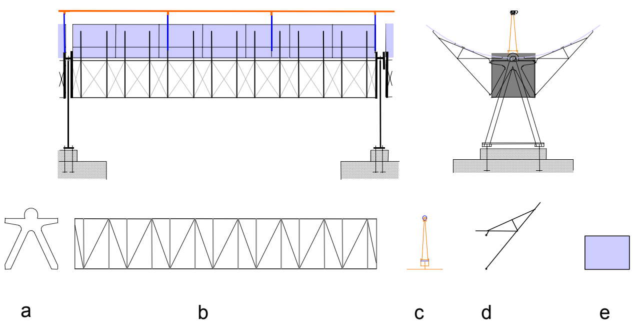

Figure 3: EuroTrough collector element consisting of: (a) 2 endplates; (b) 4 simple steel frames screwed to a torque box; (c) 3 absorber tube supports; (d) 28 cantilever arms and (e) 28 mirror facets.

The central element of the box design is a 12-m long steel space-frame structure having a squared cross section that holds the support arms for the parabolic mirror facets. The torque box is built out of only 4 different steel

Figure 4: Extended prototype collector (ET150) in operation at Plataforma Solar de Almería

parts. This leads to easy manufacturing, and decreases required efforts and thus cost for assembling on site. Transportation volume has been optimized for maximum packing. The structural deformation of the new design is considerably less than in the previous design (LS-3), which results in a better performance of the collector. The spillage during operation can be reduced 2-10 percentage points with improved stiffness and precision.

The design utilizes mirror supports that make use of the glass facets as static structural elements, but at the same time reduce the forces on the glass sheets by 40%. This results in less glass breakage with the highest wind speeds. Absorber tube supports were designed such to reduce the breakage risk and to ease mirror cleaning in comparison to the LS-3 collector.

The high geometrical accuracy of the concentrator is achieved by a combination of prefabrication with jig mounting on site. The majority of the structural parts are produced with steel construction tolerances. The accuracy for the mirror supports is introduced with the glass brackets on each of the cantilever arms. This concept allows minimum assembly manpower and low cost in series fabrication of solar fields.

The ET100 and ET150 are tracked with the sun during operation along their long axis with a hydraulic drive. The drive system consists of two hydraulic cylinders mounted on the central drive pylon. From a control box mounted on the drive pylon connecting cables lead to the hydraulic unit, the rotational encoder, limit switches and temperature sensors.

The tracking system developed for the ET100 and ET150 on the Plataforma Solar by Ciemat is based on 'virtual' tracking. For the prototype the usual sun-tracking controller unit with sensors that detect the position of the sun has been replaced by a system based on calculation of the sun position using a mathematical algorithm. The unit is implemented in EuroTrough with a 13-bit optical angular encoder (resolution of 0.8 mrad) mechanically coupled to the rotation axis of the collector. Comparing both sun and collector axes positions by an electronic device, an order is sent to the drive system, inducing tracking. The latest version of the solar coordinates calculation algorithm was checked against the Multiyear Interactive Computer Almanac (MICA), a software product of the United States Naval Observatory. Errors in longitude and/or latitude of the site below 10 km do not provoke a significant positioning error, if the parabolic trough collectors are correctly aligned.

Following cost reduction potentials have been exploited:

1. Cost reduction by simplification of the design: less different profiles, parts, better transportation; assembly concept; cost reduction by weight reduction of the structure; frame work structure, closed profiles, corrosion protection; finite element method for structural design calculations; wind analyses for proper definition of the load cases
2. Cost reduction by improvement of the optical performance of the collector: rigid support structure with frame work torque box; improved manufacturing and assembly accuracy, quality control
3. Cost reduction achieved in additional steps: possible tilt of the collector (up to 3% slope) and extension of collector length per drive unit to 150 m (ET150).

Overall cost reduction for the solar field of ET100 and ET150 collectors over previous trough collectors has been achieved and confirmed. Additional reduction of solar electricity cost is achieved by the higher annual performance due to improved optical and thermal parameters.

3. PERFORMANCE

The performance and qualification tests included:

- Thermal performance tests under numerous operating conditions, varying tracking offset, temperature and irradiation.
- Mechanical tests applying a torque load to the collector structures to measure the torsion of the frame work structure
- Stress measurement at the mirror fixing pads
- Optical analysis (photogrammetry) and raytracing, to analyse the achieved precision of the collector assembly
- Flux measurement in the focal region of the collector

Thermal tests have been performed on the 75m long prototype at PSA, which is set-up in east-west orientation. This orientation has been chosen to have normal irradiation at noon on any day of the year.

The results represented in the following graphs are valid for this configuration, and a volume flow of 4.5 l/s or 1.3 m/s (Syltherm 800) in the absorber tube.

The global efficiency of the collector is defined by the ratio of the increase of the enthalpy of the heat transfer fluid and the incident solar energy on the collector modules' area.

The resulting efficiency value is primarily depending on the absorber temperature and on the solar irradiation.

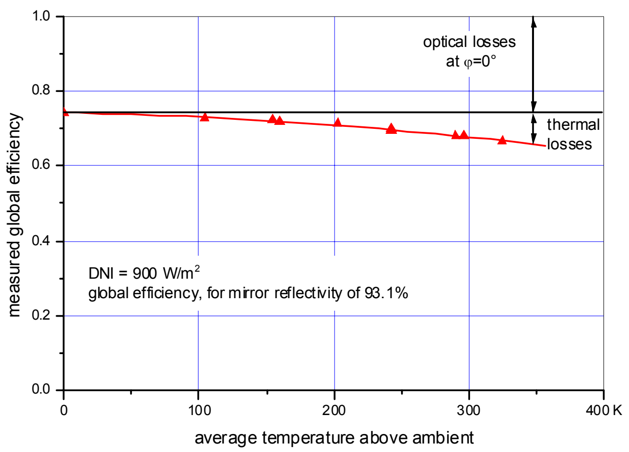

Figure 5: Global efficiency of the ET150 prototype at PSA for clean mirrors, reference area 6 x 11.98 x 5.76 m^2, and DNI = 900 W/m^2 solar irradiation

Figure 5 represents the results for 900 W/m^2 of direct normal irradiation perpendicular to the trough collector axis. The graph also shows the two most important loss mechanisms in such a collector: optical losses due to the imperfect reflection, geometric configuration, absorption parameters etc; and thermal losses at the receiver tube.

Both types of losses have been measured and evaluated independently. At testing conditions close to ΔT=0, the optical efficiency of the collector has been determined. Additionally the thermal performance of the collector was extracted from test runs at different irradiation levels and with a shadowed absorber tube (Figure 6). Specific heat losses represented here are local values, as extracted from an iteration evaluation process over the receiver length. The graph also reveals the improvement of the thermal receiver properties of the UVAC® over the previous HCE (dashed line). The ET150 collector with UVAC showed a performance of 5% points higher than LS-2 reported by Sandia, due to the improved optical properties on one hand, and due to the new receiver on the other hand. Furthermore the ET150 collector behavior for incident angles of more than 30° is more efficient than the LS-2 collector. This is due to the larger collector, higher geometric precision of the parabola, and less shading due to improved absorber support design.

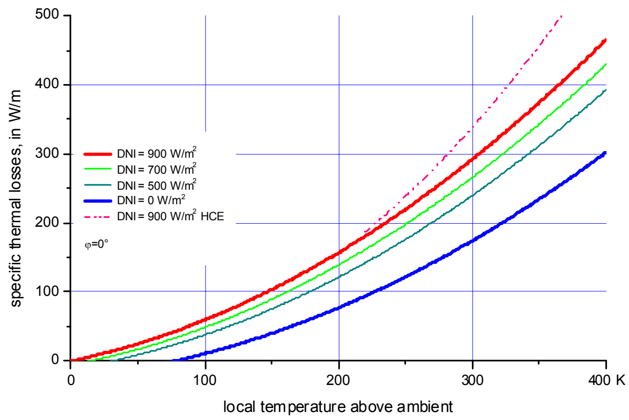

Figure 6: Specific local thermal losses for the focused and defocused absorber tube (UVAC) on the prototype

The new model of absorber tube, the UVAC (Universal vacuum collector, SOLEL), has the same external size and shape as the previous model (HCE), but higher performance and better durability. The following product improvements were achieved:

1. Coefficients of absorptivity α and emissivity ε are improved to give additional thermal annual output of up to 20% (depending on site conditions).
2. The original selective coating was designed to be stable at high temperature and in vacuum but the stability at exposed environment (air & humidity) was relatively limited. The applied UVAC selective coating is designed to work at vacuum and exposed outdoor conditions, with no oxidation or oxide deposit on the glass tubes. Operating temperature at exposed environment (air) is 400°C.
3. A new solar radiation shield set was designed in such a way, that it shields the glass to metal connection

zone and the bellow connections, maintaining the fixed relative position in spite of the axial displacement of the tube during heat up. The design specification demands of the shield set are to protect the glass-to-metal connection even at extremely low radiation angles of the sun, of both direct and reflected sunrays, while it interferes as little as possible with the effective collecting area of the UVAC, so as not to deteriorate the overall efficiency of the solar system.

Possible heat transfer fluids are ranging from the proven synthetic oils to silicon oil, water/steam and molten salts.

An important goal of the structural design with the torque box element was to improve the possibilities to align the collector and maintain it well aligned under dead load and under wind load. Specific alignment tooling helps to put the collector modules in place during the assembly process. The alignment and rigidity of the steel structure supporting wind loads up to 42 m/s is also important for maintaining optical efficiency during operation in windy conditions. Maximum torsion for 7 m/s wind speed has been proven to be below 3 milliradian.

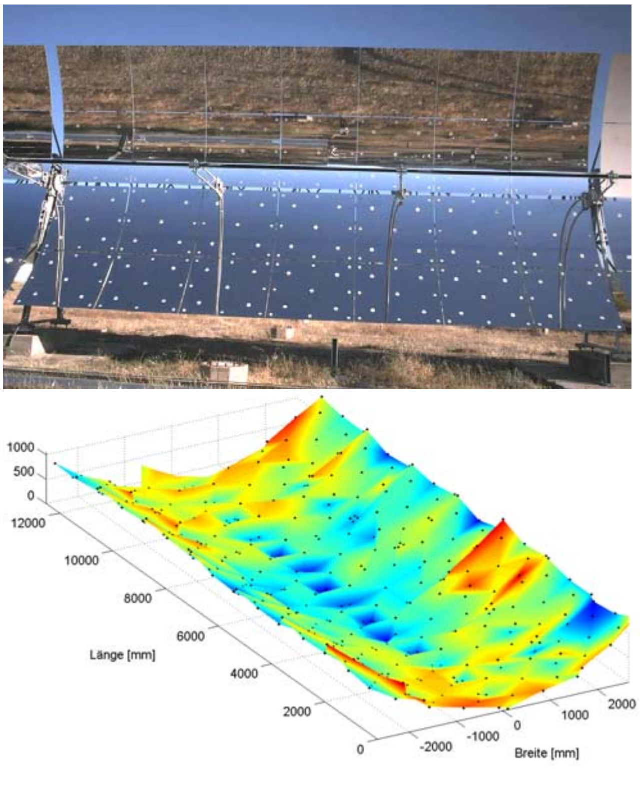

Figure 7: Targeted collector for photogrammetric 3D-analysis, above, and graphic output of the measurement for visualization, below

A test with photogrammetric surface analysis has been performed. Its results served for detailed 3-dimensional geometric analysis of the reflector and support structure properties and improvements towards higher collector efficiency. This technique also prepares options for quality control during series fabrication of such collectors.

4. SOLAR FIELD DESIGN

The ET100 and ET150 EuroTrough collector models can be serially connected with flexible ball joints to loops. Each loop can consist of six to eight ET100 collectors or four to six ET150 collectors, depending on the site conditions and solar field size.

Figure 8 shows a layout example of a solar field with the 100 m long ET100 collectors. The two collector loops located at the outside borders of the solar field are reinforced, so-called “strong” ET100 models to withstand the higher wind loads; the inner ET100 loops are of regular type.

Cold HTF flows from the power block area into a cold heat transfer fluid (HTF) header that distributes it to the parallel loops of collectors in the solar field. Two adjacent rows of collectors are connected by a crossover pipe near the edge of the solar field and form a loop. HTF is heated in the loop and enters the hot header, which returns hot HTF from all loops to the Power Block area.

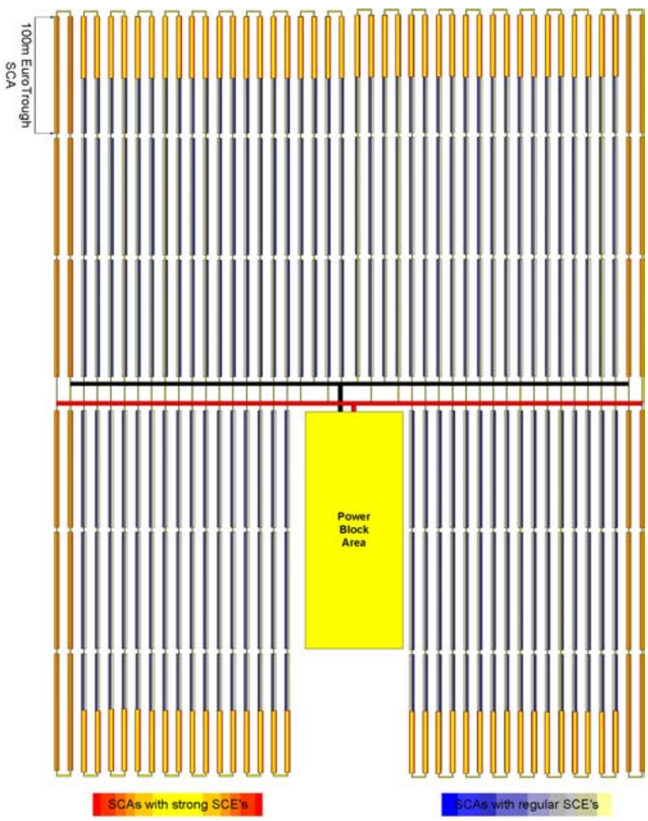

Figure 8: Principle layout of solar field with strong and regular ET100 collectors

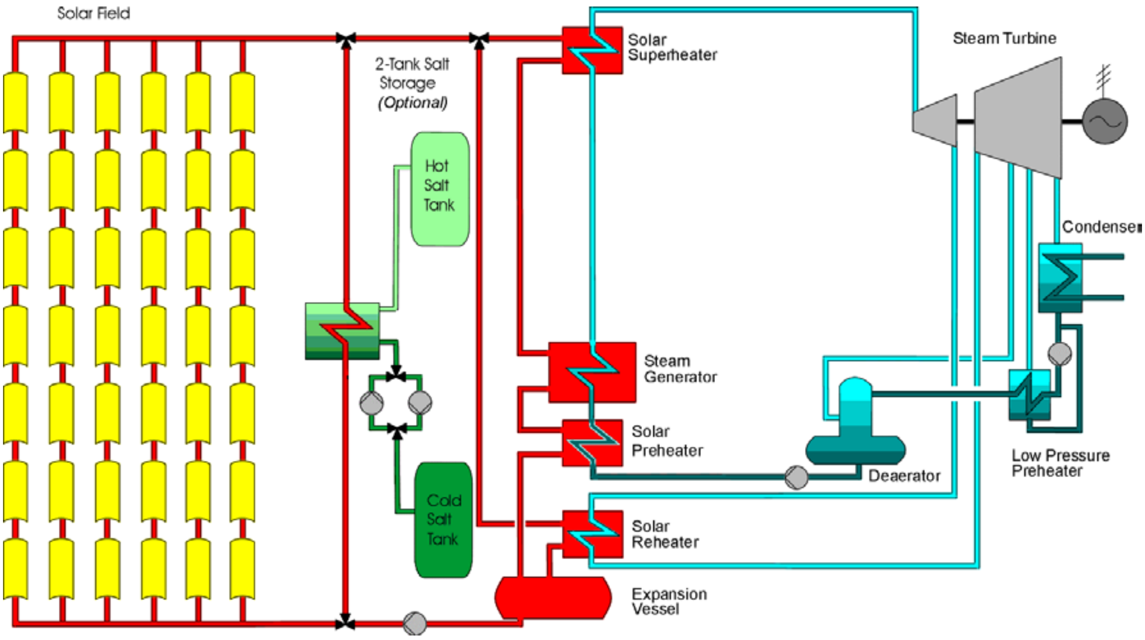

Figure 9: Rankine cycle power plant layout for solar thermal electricity generation in the AndaSol Projects with Parabolic Trough Solar Field and Thermal Storage (Flagsol)

The EUROTROUGH technology and engineering is fully backed by the industrial supply partners of the EuroTrough consortium, i.e. the companies Abengoa/Inabensa (Spain), Flagsol GmbH (Germany) and Schlaich Bergermann & Partner (Germany). Solel (Israel) contribute the high efficient UVAC absorber tubes for the ET100 and ET150 modules. Ciemat (Spain) and DLR (Germany/Spain) support the development mainly with their experience on collector development, testing and qualification at PSA.

6. CONCLUSIONS AND OUTLOOK

The development of the EUROTROUGH collector, performed in two stages, supported by additional activities of several of the project partners has been finished. With the effort of European industry and research partners and the financial contribution of the European Commission, the aim of a solar parabolic trough collector design has been reached.

The prototype of the EUROTROUGH collector has been prepared, started-up, operated and evaluated in detail at the Spanish Plataforma Solar de Almería (PSA). The further results of this project were the design and engineering documentation and workshop drawings for EUROTROUGH collector manufacturing and assembly. The qualification at PSA included thermal tests, mechanical analysis, optical assessment and design improvements as results of the prototype experience.

The designers and scientific partners have shown special activities in the field of optical and mechanical analysis and qualification of the collector design. The eager search for highly efficient, robust and mature technology has brought up additional results concerning finite-element-analysis (FEM), ray-tracing, flux density measurement, and photogrammetric structure analysis, mechanical analysis of the collector support structure under dead load, wind load, and the effects on optical performance.

The results of case studies and cost analysis will help with the next steps during technology implementation in international energy markets.

Solar Millennium AG and their industry partners have further advanced and qualified the EuroTrough in the SKAL-ET project: On April 24th this year, a 4360m² full collector loop was successfully implemented in the SEGS V plant at Kramer Junction. Based on this commercial operation experience in California, the Solar Millennium group will implement the SKAL-ET collectors in two 510’120m² solar fields of the two 50 MW AndaSol plants with thermal storage in Southern Spain, where the special feed-in tariff for solar thermal electricity has just been published in August 2002.

The European Commission financially supported the development and qualification of the EUROTROUGH collector within the 4th and 5th Framework Programme under contracts JOR3-CT98-0231 and ERK6-CT-1999-00018, and the AndaSol project within the 5th Framework Programme under NNE5-2001-00560. The Spanish and German Governments supported the EUROTROUGH development to Ciemat and DLR respectively. The German Federal Ministry of Environment financially supported the further advancement and full-scale loop test of the SKAL-ET collectors.

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