

SOLAR THERMAL POWER GENERATION

Parabolic Trough Technology: Status and Issues of Development

Dr. Ashvini Kumar
Ministry of New and Renewable Energy
New Delhi – 110 003

IIT Bombay
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Parabolic Trough Technology: An Introduction

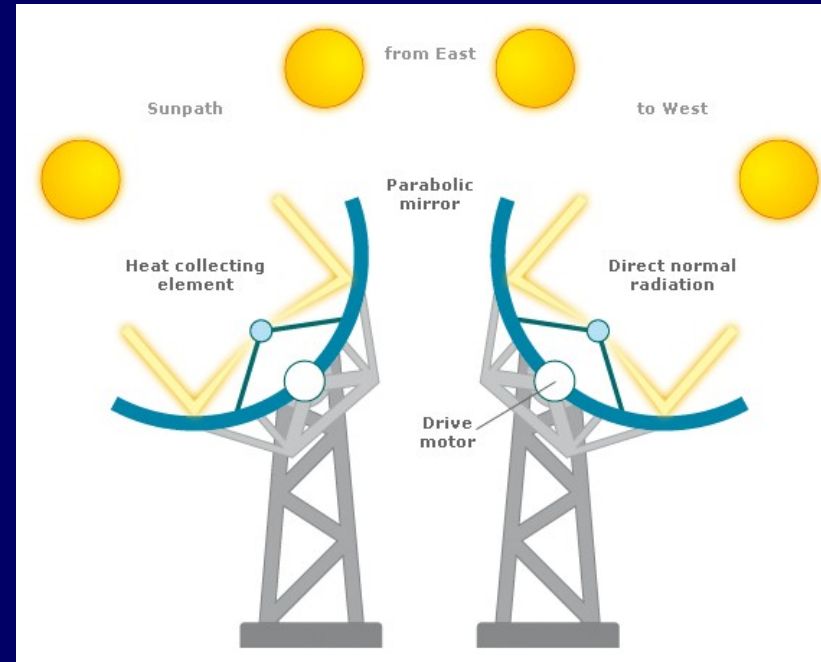
- ❑ **Most established of Concentrating Solar Power technologies in the world.**
- ❑ **The parabolic troughs are used to track the sun and concentrate sunlight on to the thermally efficient receiver tubes placed in the trough focal line.**
- ❑ **Heat transfer fluid, normally a high temperature oil, runs through these tubes and gets heated up generally to 200 – 400 °C.**
- ❑ **Hot fluid is then passed through a series of heat exchangers to produce steam, which is used to drive a conventional turbine to generate electricity.**
- ❑ **Rankine cycle configuration is used for power generation**

Parabolic Trough Technology: Characteristics

- ❑ Large thermal storage could be built to increase number of operating hours in a day
- ❑ Could be hybridized with power generation from fossil fuels
- ❑ Other alternatives for heat transfer fluid, such as **water** to produce DIRECT STEAM, and **molten salts** to produce higher temperatures are being tried out to increase the potential of the technology further.
- ❑ The parabolic trough technology is commercially available.

Technology

- Basic modular component is the **solar collector assembly (SCA)**
- Each SCA is an independently tracking unit
- Its main components are
 - **Parabolic Trough solar Collectors**
(parabolic reflectors, metal support structure and receiver tubes)
 - **Tracking system**
(Drive, sensors and controls)



Status

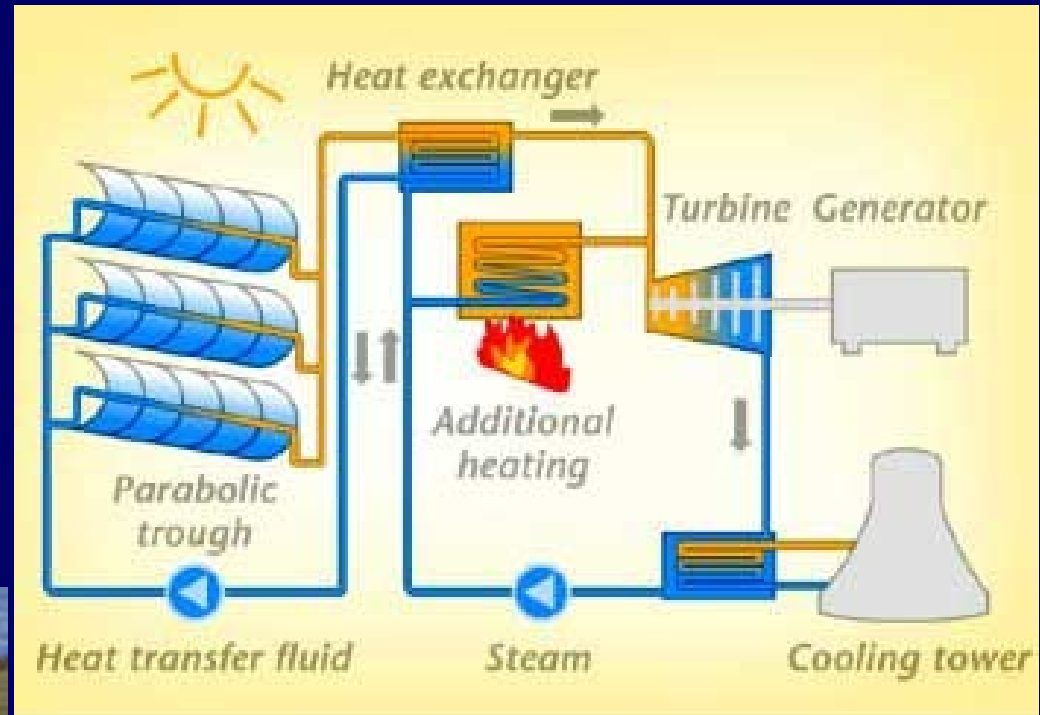
- The technology was initially developed for industrial process heat applications during 1970s and 1980s.
- In 1983, Southern California Edison signed an agreement with Luz International Limited to purchase power from Solar Electric generating Systems (SEGS).
- This resulted in the installation of **nine** commercial level plants during 1983-91 in the California Mojave Desert, with total aggregate capacity of 354 MWe.
- These plants have produced 11,000 GWh and more than \$1.7 billion revenue over the last 22 years. The plants are still working.
- 1 MW capacity plant based on organic Rankine cycle with Pantene as the HTF, heated to 300 °C, at Saugaro, Arizona came up in 2006.
- In July 2007, another plant **Nevada Solar One** of 64 MWe capacity has been commissioned in USA.

Power block of the SEGS parabolic trough power plant at Kramer Junction, US



Naveda Solar Power Plant

Commercial solar power plant after about 15 years



Capacity: 64 MW

Cost: \$ 250 M (Rs.1000 crores)

\$ 3.9 M/MW (Rs. 15.6 crores/MW)

kWh = 13 cent

Schott vacuum steel and glass receiver

Liquid heating

O & M Experience

- Based on the experience gained on SEGS plants, the following is reported
 - The plants averaged about 80% of the rated capacity from solar, and rest is met by natural gas.
 - Start up and shut down on a daily or even more frequently.
 - Normal day-to-day operation: Start up time (from initial tracking to synchronization of turbine generator) has been 45-90 minutes
 - 8-day annual maintenance outage is planned each year during November to February when solar output is lowest.
 - Lower limit of DNI in the plane of solar collector is about 300 W/m² for net positive power.

O & M Experience

- **The following major problems were faced**
 - **HTF pump seal failures resulting from daily thermal and operational cycling,**
 - **Non-optimized power plant equipment,**
 - **Inadequate training of the maintenance staff for unique requirements of large solar field (viz. washing methods to maintain the reflectance of mirrors)**
- **O & M costs at SEGS III – VII plants are reported to be about US\$ 25/MWh.**
- **Target O&M costs = US\$ 10/MWh.**

Characteristics of SEGS Plants

SEGS	1st yr operation	Net Output (MWe)	Solar field T _{out} (°C)	Solar field area (m ²)	Annual Output (MWh)
I	1985	13.8	307	82,960	30,100
II	1986	30	316	1,90,338	80,500
III	1987	30	349	2,30,300	92,780
IV	1987	30	349	2,30,300	92,780
V	1988	30	349	2,50,500	91,820
VI	1989	30	390	1,88,000	90,850
VII	1989	30	390	1,94,280	92,646
VIII	1990	80	390	4,64,340	2,52,750
IX	1991	80	390	4,83,960	2,56,125

Developmental Issues:

Receivers

- Typically, it is 70 mm OD SS tube with cermet solar selective coating surrounded by 115 mm OD anti-reflective (both sides) evacuated glass tube
- Glass-to-metal seal to achieve vacuum and metal bellows to allow differing thermal expansion are used
- Vacuum = 10^{-4} torr (~ 0.013 Pa)
- Getters, the metallic compounds, are installed in the vacuum space to absorb hydrogen and other gases which may permeate
- The following main reasons of failure are reported:
 - **Glass-to-metal seal failures due to insufficient protection**
 - **Hydrogen release related failures**
 - **Bowing**

Developmental Issues:

Receivers (contd.)

The following selective coatings are already available

Developer	Coating	α	ϵ (300 C)	ϵ (400 C)	Remarks
Luz	Electroplated black chrome	0.918	0.156	0.197	Used in SEGS I - V
Luz	Graded-cermet	0.938	0.118	0.146	Later plants
Solel	Graded cermet	0.954	-	0.134	UVAC absorbers
CIEMAT	Solgel double layer	0.940	-	0.120	Stable in air > 400 C

Target: Development of selective surfaces with $\epsilon < 0.10$ and temperature stability at > 600 C.

Developmental Issues:

Reflectors

- Presently, 4 mm thick glass mirror panels manufactured by Flabeg are used. Float glass with low iron content is used to produce parabolic shape.
- Present mirrors are back surface silver coated mirrors. Solar weighted specular reflectivity is 93.5%. Each panel is approximately 2 m² in area.
- Performance has been good and high reflectivity levels could be maintained, but suffer from breakages.

Target: Development of reflectors with reduced weight, cost and fragility, while maintaining high solar transmittance values (Target = 0.96).

Developmental Issues:

Reflectors: Alternatives

- **Thin glass (< 1mm)**
 - Relatively light weight, but more fragile; handling costs increase
 - Better protective backing needs to be developed
- **Front Surface Mirrors**
 - A silver reflective layer on a polymeric substrate with a protective hard coat at the top
 - Results of accelerated testing are encouraging (Luz).
- **Super Thin Glass**
 - NREL is working to use an ion beam assisted deposition process to deposit very hard (cleanable) and dense (protective) alumina top coat on polymeric or steel substrate.
- **All polymeric reflectors**
 - It employs alternating co-extruded polymers layers of differing refractive indices to create a reflector
 - UV-stability is the issue.

Developmental Issues:

Support Structure

- Supports the reflectors and receivers, maintaining them in optical alignment
- Withstand external forces, such as, wind
- Allows the collectors to rotate via a drive system
- Available designs are **Luz System**, **Euro-trough** and **Solargenix**.
- LS-2 used a torque-tube structure having three torque-tube collector modules on each side of the drive
- Very accurate, but used a lot of steel, and required precise manufacturing.



Developmental Issues:

Support Structure

- LS-3 used a bridge truss structure, in place of torque-tube to reduce the cost
- It has three 4-meter long receivers
- It suffered from insufficient torsional stiffness and the cost reduction was also not as was expected.
- Euro-trough collector utilized a torque-box to integrate the stiffness of a torque-tube and the lower steel content of a truss design.
- Stiffer design allows to increase length of each collector from 100 m to 150 m, thereby decreasing the total number of flex hoses, drives and the cost.



Developmental Issues:

Support Structure

- Support structure for Solargenix collector uses a space frame consisting of interconnected aluminium struts, arranged in a three dimensional truss-like pattern
- Each strut is made from 2-inch square extruded aluminium pipes
- It weighs less than steel structure, requires no welding, assembles easily and requires no field alignment.



Target: Development of optimized designs to reduce the cost and auxiliary power requirements.

Characteristics of collectors

Collector	Ap-width (m)	f (m)	Length/collector (m)	A-mirr/drive (m ²)	Receiver dia (m)	C (sun)	Wt (kg/m ²)	η_{peak} (%)
LS-1	2.55	0.94	50.2	128	0.04	61:1	NA	71
LS-2	5.00	1.49	49.0	235	0.07	71:1	29	73
LS-3	5.76	1.71	99.0	545	0.07	82:1	33	78
Euro-trough	5.76	1.71	100-150	545-817	0.07	82:1	26	78
Solargenix	5.00	1.49	100.0	470	0.07	71:1	24	78

- The weight includes the weight of the structure, mirrors, receiver and receiver supports.
- Does not include weight of pylons, drive system and flexible interconnections.

Developmental Issues:

Other Components

▪ Drive

- Each SCA uses a drive to position the collectors to track the sun. It is used in the centre of the collectors.**
- Standard motor and gear box arrangement (LS-2) or a hydraulic drive system (LS-3, Euro-trough, Solargenix) have been used.**

▪ Controls

- There is a separate controller for each SCA.**
- In addition, there is supervisory controller, which sends instructions to the local controller for operation.**

▪ Collector interconnect

- Original flex-hose design proved inadequate.**
- Flex hoses are being replaced with ball joint assembly.**

Developmental Issues:

Heat Transfer Fluid

- Type of HTF used determine the operational temperature range of the solar field and thus the maximum power cycle efficiency that can be obtained.
- Choice of HTF also affects the type of thermal storage technologies that can be used.

Developmental Issues:

Heat Transfer Fluid

Fluid	Application T- range (C)	Properties
Synthetic oil (Therminol VP-1)	13 to 395	Relatively high application temp, Flammable
Mineral oil (Caloria)	-10 to 300	Relatively inexpensive, flammable
Water/ steam	0 to 500	High receiver pressure and thick wall tubing required
Silicon oil	-40 to 400	Odourless, non-toxic, expensive, flammable
Nitrate salt (HITEC XL)	220 to 500	High freezing temperature, high thermal stability, corrosive

Linear Fresnel Reflector Technology

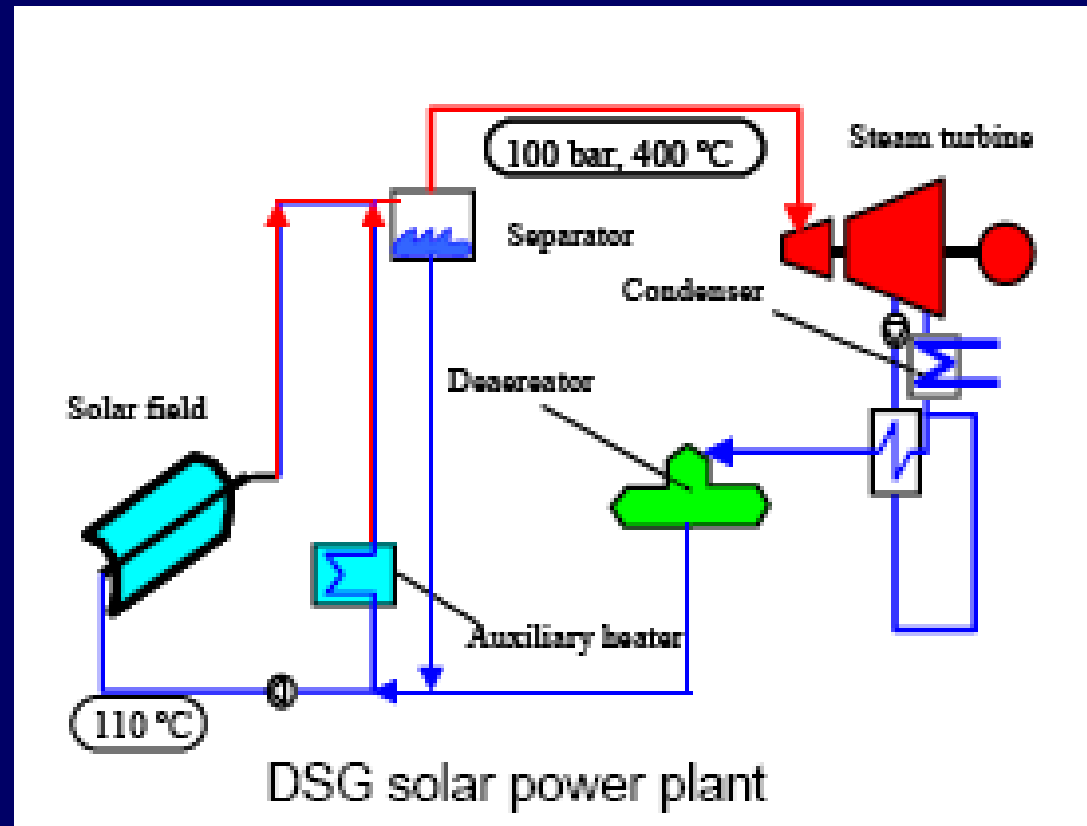
Preheats water
for the coal
fired power
plant.
(285 °C: 70bar
steam)



Liddel power station, NSW, Australia

Direct Steam Generation

- Has the potential to reduce the overall cost
- Does not face limitations of the thermal oil systems
- No realistic storage option exists presently.
- Initial studies indicate about 10% reduction in the solar portion of levelized cost of energy
- Faces serious challenges for safety and maintenance as large solar field is pressurized



Developmental Issues: Other Componets

- **Turbine**
- **Heat exchangers**
- **Storage systems**
- **Cooling towers (Wet vs dry)**

Developmental Issues: Resource Assessment

Place	Global	Beam-horz	DNI
Delhi	1971	1236	2139
Jodhpur	2051	1395	2389
Kolkata	1785	919	1540
Bangalore	2068	1258	1983

All values in **kWh/m²/year**

Thank you !