Solar Heat for Industrial Processes

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ECREEE Regional Forum on the ECOWAS Solar Energy Initiative

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www.aiguasol.coop
Cooperative Company funded in 1999 by two PhD from the Polytechnic University of Catalonia (UPC). Nowadays 20 people - PhD Engineers, engineers, physicists, etc. – exclusively dedicated to energetic engineering tasks, in four different areas:

- **SOLAR THERMAL SYSTEMS.** Analysis, simulation, optimization, design and planning. *Many large scale systems: 175-700 kWth and near three thousand dwellings supplied by solar thermal energy.*
- **BUILDING DESIGN CONSULTANCY.** Assessment, simulation, design of constructive solutions, energetic performance certification, etc.
- **ENERGETIC SYSTEMS CONSULTANCY.** Solar Cooling, geothermal, micro-CHP, Industrial Processes, DH&C, high temperature solar plants, etc.
- **SOFTWARE DEVELOPMENT.** Solar thermal systems, buildings thermal behavior and ventilation dynamic simulation (TRNSYS, TRANSOL, TRNFLOW, etc.)
AIGUASOL collaborates with the Spanish Government as energy consultants in:

- Energy Planning
- Assessment on developing legislation regarding energy efficiency, and renewable energies integration
- Technology feasibility studies
- Evaluation of Renewable Energy resources and its potential to satisfy country’s energy demand
- Reference tools development
Main concepts
Potential
Technologies
Existing Systems
And more...
Main concepts
Potential
Technologies
Existing Systems
And more...
Why and in which industries solar thermal and industrial consumption?
- **ELECTRIFICATION IS IMPORTANT, BUT…..**
- **IT IS ALSO IMPORTANT TO STAND OUT THAT MOST OF THE CONSUMPTION IN ALL COUNTRIES, EVEN INDUSTRIALISED COUNTRIES, IS THERMAL CONSUMPTION, MAINLY IN INDUSTRIAL PROCESSES**
  - **AND SPECIALLY IN THE AGROFOOD SECTOR, WHICH IS REALLY IMPORTANT IN ECOWAS COUNTRIES!!!!**
- **AT THE MOMENT, A GREAT QUANTITY OF AGRICULTURAL PRODUCTS ARE EITHER DIRECTLY EXPORTED OR TREATED REALLY FAR AWAY FROM ITS ORIGIN (PLACES WITH ENERGY SUPPLY)**
- **SOLAR THERMAL ENERGY IS A REALLY ECONOMICALLY FEASIBLE WAY TO PRODUCE ON-SITE ENERGY, EVEN FAR FROM ELECTRIFICATION, AT MUCH LOWER COSTS**
- **SO, ESTABLISHING A GOOD FRAMEWORK FOR SOLAR THERMAL FOR HEATING (AND COOLING!) FOR AGROFOOD PROCESSES CAN HELP DEVELOP THE CONDITIONS FOR THE ESTABLISHMENT OF AGROFOOD INDUSTRIES IN RURAL AREAS**
<table>
<thead>
<tr>
<th>Thermal Process</th>
<th>Temp</th>
<th>Food Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling, chilling</td>
<td>4 to 8°C</td>
<td>X X X X X X X</td>
</tr>
<tr>
<td>Freezing</td>
<td>-15 to -40°C</td>
<td>X X X</td>
</tr>
<tr>
<td>Blanching</td>
<td>80 °C</td>
<td>X</td>
</tr>
<tr>
<td>Cooking, boiling, frying</td>
<td>90 to 150°C or 100 to 300°C</td>
<td>X X X</td>
</tr>
<tr>
<td>Degumming</td>
<td>100 °C</td>
<td>X</td>
</tr>
<tr>
<td>Roasting</td>
<td>370 to 540°C (coffee) 130 to 150°C (cacao)</td>
<td>X X</td>
</tr>
<tr>
<td>Pasteurisation</td>
<td>72°C</td>
<td>X X</td>
</tr>
<tr>
<td>Bleaching</td>
<td>150 °C</td>
<td>X</td>
</tr>
<tr>
<td>Deodorization</td>
<td>180 – 270 °C</td>
<td>X</td>
</tr>
<tr>
<td>CIP</td>
<td>&gt; 50°C</td>
<td>X X X X</td>
</tr>
<tr>
<td>Baking</td>
<td>300 to 400 °C</td>
<td>X</td>
</tr>
<tr>
<td>Distillation, Evaporation</td>
<td>&gt; 100 °C</td>
<td>X X</td>
</tr>
<tr>
<td>Proofing</td>
<td>40°C</td>
<td></td>
</tr>
<tr>
<td>Defrosting</td>
<td>20 to 40 °C</td>
<td>X</td>
</tr>
<tr>
<td>Freeze storage</td>
<td>-18 to -40°C</td>
<td>X X X</td>
</tr>
<tr>
<td>Cooled storage</td>
<td>4 to 8 °C</td>
<td>X X X X</td>
</tr>
<tr>
<td>Air condition</td>
<td>10 to 20 °C</td>
<td>X</td>
</tr>
</tbody>
</table>

(SOURCE: OPTIPOLYGEN)
System configurations with and without solar heat storage.
Coupling of the solar system and the conventional heat supply

- Steam generation
- Direct coupling to the process
- Pre-heating of feed up water
- Central steam supply
- Return water
- Feed-up water
Direct coupling to an industrial process

Recuperació de calor

Generació auxiliar

Preescalfament solar

Escalfament del bany

ECOWAS Solar Energy Initiative. Dakar, October 2010

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SOLAR SYSTEMS CAN COVER DIFFERENT TEMPERATURES!
- Main concepts
- Potential
- Technologies
- Existing Systems
- And more...
### INDUSTRIAL SECTORS:
- Food industry (breweries, malting, milk)
- Paper
- Textile
- Chemical and pharmaceutical
- Tanning
- Cork industry

### PROCESSES AT LOW AND MEDIUM TEMPERATURE
- Hot air for drying
- Sterilising, pasteurising
- Distillation and evaporation. Detoxification
- Desalinisation
- Washing and cleaning
- Polimerisation
- Cold production (absorption cooling)
The industrial sectors showing the higher potential for solar process heat are food, wine and beverage (including breweries), textile, transport equipment (i.e. car washing), paper and part of the chemical sector (up to 250°C).

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Austria</th>
<th>Iberian Peninsula</th>
<th>Italy</th>
<th>Netherlands</th>
<th>Greece</th>
<th>Germany</th>
<th>Belgium</th>
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<tbody>
<tr>
<td>Food processing</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Wine and beverages</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Beer brewing and malt</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Textile</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Tanning</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Tobacco</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Chemical</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Transport equipment</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Other</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Overview of the industrial sectors taken into account within different potential studies (IEA Task33)
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>297</td>
<td>220</td>
<td>74.1</td>
<td>5.4</td>
<td>2.4</td>
<td>4.3</td>
<td>3</td>
</tr>
<tr>
<td>Spain</td>
<td>1175</td>
<td>841</td>
<td>71.5</td>
<td>17</td>
<td>2.0</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Portugal</td>
<td>243</td>
<td>184</td>
<td>75.6</td>
<td>4</td>
<td>2.2</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Italy</td>
<td>1652</td>
<td>1136</td>
<td>68.8</td>
<td>32</td>
<td>2.8</td>
<td>15.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Netherlands</td>
<td>573</td>
<td>425</td>
<td>74.2</td>
<td>1.5 - 1.95</td>
<td>0.3 - 0.5</td>
<td>0.8 - 1</td>
<td>0.7</td>
</tr>
<tr>
<td>Germany</td>
<td>2416</td>
<td>1575</td>
<td>65.2</td>
<td>50</td>
<td>3.2</td>
<td>35</td>
<td>24.5</td>
</tr>
<tr>
<td>EU 15</td>
<td>11372</td>
<td>7880</td>
<td>69.3</td>
<td>199</td>
<td>2.5</td>
<td>110 - 138</td>
<td>77 - 97</td>
</tr>
<tr>
<td>EU 25</td>
<td>12964</td>
<td>9145</td>
<td>70.5</td>
<td>230</td>
<td>2.5</td>
<td>128 -160</td>
<td>90 - 112</td>
</tr>
</tbody>
</table>

*Industrial energy demand and solar process heat potential for individual Countries and for EU (IEA Task33)*
Solar process heat potential [PJ/year].

<table>
<thead>
<tr>
<th>Industrial Sectors</th>
<th>TWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, beverage and tobacco</td>
<td>1.4</td>
</tr>
<tr>
<td>Textile, Leather and shoes</td>
<td>0.4</td>
</tr>
<tr>
<td>Paper</td>
<td>1.6</td>
</tr>
<tr>
<td>Transport equipment</td>
<td>0.6</td>
</tr>
<tr>
<td>Chemistry*</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* Estimated: no case studies available

Potential for solar process heat in Spain by industrial sector. Data in TWh/year
- Low (<60°C) and medium (<160°C) temperature heat demand in Spain
Preheating of hot water for baths (washing, bleaching, dying)
Temperature: < 90 ºC
Continuous demand: 8000 hrs / yr

Other processes:
- Bath heating (substitution of vapour)
- Drying processes (hot air from 140 to 220 ºC)
Vapour for heating of paper

Temperature: 135 °C
Continuous demand: 7 days/week.

1000 m² parabolic trough collectors
Energy saving: 500 kWh/m²
Preheating of air for drying

Air temperature: 150 ºC
6 days/week

2000 m² flat plate collectors + 500 m³ storage (sundays)

750 kWh/m², pay-back 7 years

Solar fraction: 11 %
Solar process heat: evaluation criteria

Evaluation criteria

- Continuity of the heat demand
- Working temperature (heating-preheating)
- Climatic conditions
- System size

POSHP Case Studies: energy cost vs. working temperature

Solar heat costs for the systems studied
Colors: solar radiation in kWh/m2: > 1750 (red), 1600 – 1750 (yellow), 1400-1600 (green)
Symbols: continuous demand (circles), continuous 5 days / week (rombs), seasonal(triangles).

< 6 cent/kWh without funding
- Mains concepts
- Potential
- Technologies
- Existing Systems
Collectors Technology (1): Static

- Air collectors
- Flat Plate Collectors (FPC)  
  High selective surfaces (TiNOX, Sunselect etc.)
- Evacuated Tube Collectors (ETC)  
  Including CPC reflector
- Evacuated Flat Plat Collector (EFPC)
- Concentrating Parabolic Collectors (CPC)
- FPC with anticonvective barriers  
  Teflon Film  
  Transparent Insulation (TIM)
Collectors Technology (2): Trackers

- Parabolic Trough Collectors (PTC):
  - IST (EE.UU.)
  - LS-3 (SOLEL, Israel)
  - Sopogy (EE.UU.)
  - PEurotrough (Synthesis Solar, Alemania)
  - Direct Steam Generation (DISS)
  - ...

- Fresnel Collectors
  - PSE-Miroxx
  - CCSTAR
  - AIRA
  - ...

Collectors Technology (3): Cost Comparison

€/m²e

- Flat plate collectors
- Evacuated collectors
- Concentrating collectors
- Low-concentration collectors

UFPC, FPC, SFPC, CPC, EFPC

60 ºC, 100 ºC
Solar gains (useful heat)
Comparison of collectors

**Barcelona**

- FPC
- EFPC
- ETC
- CPC
- PTC

**Huelva**

- FPC
- EFPC
- ETC
- CPC
- PTC
Resulting energy cost (useful heat)
Comparison of collectors

Heat cost in €/kWh

**Barcelona**
- FPC
- ETC
- CPC
- EPFC
- PTC

**Huelva**
- FPC
- ETC
- CPC
- EPFC
- PTC
- Mains concepts
- Potential
- Technologies
- Existing Systems
- And more...
- 92 solar systems have been identified in 20 different countries with a total equivalent power of 41.6 MWth

- 50% of plants are previous to year 2000

Figure 2. Solar industrial process heat plants reported within Task 33/IV - SHIP: distribution by Country. Number of projects: (a) total and (b) plants in operation. State: March 2006.
Figure 4. Solar industrial process heat plants reported within Task 33/IV - SHIP: distribution by industrial sector. Number of projects: (a) total and (b) plants in operation. State: March 2006.
Figure 6. Solar industrial process heat plants reported within Task 33/IV - SHIP: distribution by solar collector type. Plants in operation. State: March 2006

Figure 7. Solar industrial process heat capacity installed as reported within Task 33/IV – SHIP. Share by solar collector type: number of projects in percentage (left side) compared to the capacity installed (right side). Plants in operation. State: March 2006
- Technologies and temperature level distribution

Figure 11. Solar plants reported to Task SHIP: distribution by working temperature (outlet temperature from solar system to load). Plants in operation and shutdown. State: March 2006.

Figure 12. Solar plants reported to Task SHIP: correlation between the type of collectors and the working temperature (outlet temperature from solar system to load). Plants in operation and shutdown. State: March 2006.
Lessons learnt from plants in operation

- Up to now, the information available on the operational behaviour of the reported plants are very scarce.
- For very few projects the following failures and operating problems have been reported:
  - Automatic control failures
  - Low flow rate and inadequate level of antifreeze in the primary circuit
  - De-aeration problems in the solar circuit,
  - Hydraulic circuit (e.g. long distance between the solar plant and the storage, scarce insulation of the pipes)
  - Heat losses in storage tanks and in heat exchangers
  - Inadequate level of maintenance (dirty glasses, deposition of material from exhaust gasses on collectors’ glasses)
  - Control of the tracking systems.
Company name: Parking Service S.A.
Location: Castellbisbal

**Information on the process**

Industrial sub – sector: Car and lorry washing
Industrial process: Car washing, degreasing
Working temperature [°C]: 20–80

**General information on the solar system**

Year of construction: 2004
Designer and/or installer: AIGUASOL
Installed thermal capacity [kW]: 357 (510 m²)
Collector type: Flat plate collector (Sonnenkraft)
Storage tank [m³]: 40
Storage tank volume/Solar collector area (V/A) [l/(m²)]: 78.4

**System concept:** SPOHX water ??

**Performance of the solar system**

Annual useful solar heat [MWh/a]: 429
Annual specific useful solar heat [kWh/kW*a]: 1201.68 (840 kWh/m²*a)
Solar fraction [%]: 22
Technical problems or failures: n.a.

**Economics**

Total investment cost [€]: 268,546
Total cost per kW installed [€/kW]: 752 (527 €/ m²)
Co – financing [€ or %]: 48% (IDEA/ICAЕ)

**Data source:** AIGUASOL
MAFRICA SLAUGHTERHOUSE (Spain)

Heating of water to 70°C

Collectors: 600 m² Fresnel (increasing to 3000 m²)

Collectors: 70-90°C

Investment: 90k€

Year: 2010

Source: aiguasol
Fratelli Rizzi (Verona)

Industrial sector: wine (hot water and space heating)

Temperature: 35-60 °C

Potència instal·lada : 42kW (60m²)

Collectors : Evacuated tube CPC

Solar production: 517kWh/m².any

Solar fraction: 20% (heating)

Solar fraction : 70% (hot water)

Source: Kloben
<table>
<thead>
<tr>
<th><strong>Plant:</strong></th>
<th>AQUINOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location:</strong></td>
<td>Huelva (Spain)</td>
</tr>
<tr>
<td><strong>Solar field:</strong></td>
<td>1316 m² (flat plate)</td>
</tr>
<tr>
<td><strong>Process:</strong></td>
<td>Fish farm (water heating)</td>
</tr>
<tr>
<td><strong>Working temp.:</strong></td>
<td>30 – 40 °C</td>
</tr>
<tr>
<td><strong>Source:</strong></td>
<td>SODEAN</td>
</tr>
</tbody>
</table>
Plant: TE-PE S.A.
Location: Seville (Spain)
Solar field: 260 m² (flat plate)
Process: Water heating (olive production)
Working temp.: 50 – 60 °C

Source: SODEAN
Plant: Tyras
Location: Trikala (Greece)
Solar field: 1040 m² (flat plate)
Process: dairy
Working temp.: 80 ºC

Source: CRES / Solenergy Hellas SA
Plant: El NASR
Location: Egypt
Solar field: 1900 m² (parabolic trough)
Process: Saturated steam (173 ºC/8bar) for processes in the pharmaceutical industry
Working temp.: 173 ºC

Source: Fichtner Solar GmbH
Plant: SODESA
Location: Pozo Izquierdo, Gran Canaria (Spain)
Solar field: 48 m² (flat plate)
Process: Sea water desalination
Working temp.: 20 – 95 ºC
Source: Fraunhofer ISE
Plant: SARANTIS
Location: Oinofita Viotias (Greece)
Solar field: 2700 m² (flat plate)
Process: Solar cooling in cosmetics industry
Working temp.: 90 °C

Source: CRES / SOLESA
Plant: **BRISA**
Location: **Carcavelos (Portugal)**
Solar field: **663 m² (CPC)**
Process: **Space heating and cooling**
Working temp.: **80 ºC – 90 ºC**

Source: **AO SOL Ltda.**
NEFERIS WINERY (Tunisie)

Cooling of 23 tanks

Cooling power: 13 kWf

Collectors: 88 m² Fresnel

Temperature: -5, 5°C

Collectors: 120-180°C

Investment: 120k€

Year: 2008

Source: POLIMI
APPLICATION

- Hot water (60°C) for container washing
- Industrial sector: transport equipment
- Heat demand: 1990 MWh/year
- 70 – 80 m³ / day, 5,5 days/week
Solar storage in serial connection with storage for auxiliary heating
Selective flat plate collectors
- Solar collector field: 357 kW ( 510 m² )
- Inclination: 25 ° (/horiz.)
- Orientation: -24 ° (/south)
- Solar storage: 40 m³ (78.4 l/m²)
- Collector flow rate: 17 l/m²h
- Auxiliary heating: steam boiler

Investment cost: 268,545,92 €
Project co-financed by IDAE, ICAEN
Design details

- Non pressurized storage (without expansion vessel -> cost reduction)
- Low flow system: less installation cost <-> very small loss of efficiency
- Low inclination of collectors: 25° (compromise between optimum output per unit area and optimum use of available roof space)
- Anti-legionella protection: serial connection with auxiliary storage above 70 °C, chemical treatment
- Dynamic simulation with the Aiguasol software TRANSOL (based on TRNSYS)
- $\Delta T = 16 – 17 \, \text{K}$
- **Useful solar heat**: 429 MWh/yr
- **Solar fraction**: 21.6%
- **Useful heat per collector area**: 840 kWh/m² yr
Main concepts
Potential
Technologies
Existing Systems
And more...
FOUR BIG PILLARS OF SOLAR THERMAL SYSTEMS FOR PROCESSES

METEOROLOGY
WE HAVE VERY GOOD CONDITIONS FOR THE INSTALLATION OF THESE SYSTEMS!

TECHNOLOGY (LOCAL TECHNOLOGY)
One of the biggest advantages of solar thermal technology is the use of local technology (neither very machine-intense nor very energy-intense manufacture processes)

-> development of low cost solar collectors for medium temperature

CUSTOMER’S PROFILES AND NEEDS
Only certain demand profiles can cope with solar thermal technology, but they are significantly important in our countries (yesterday in the presentations some of you showed how significant is your primary sector)

POLICIES
WE NEED TO ESTABLISH POLICIES IN VARIOUS LINES TO ALLOW THE DEVELOPMENT OF A GOOD MARKET
Demonstration plants

Limited possibility to develop projects by national funding only

- A concerted programme for large-scale solar systems?

Virtuous circle: large systems -> stimulation of demand -> reduction of system cost and improvement of quality (industrial-scale production, qualification of installers, ...).

RTD

The REAL potential for solar process heat is at medium and high temperature: heating after waste heat recovery, solar cooling, solar thermal electricity

- demonstration plants for medium temperature systems
- development of low cost solar collectors for medium temperature
Where to go – low or medium temperature ... ?

Energy costs for medium temperature systems (> 60 °C) are higher

But ... The best way to cover the low-temperature heat demand is (nearly) always: heat recovery (waste water, exhaust air,...) by heat exchangers or heat pumps

-> The REAL potential for solar thermal applications is for T > 60 °C ?
¿ Are solar systems always the best way to save energy ?

-> INTEGRAL SOLUTIONS required considering solar thermal, waste heat recovery, cogeneration and possible improvements in the processes
THANKS FOR YOUR ATTENTION

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